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Effects of variability of weather and temperature extremes on cardiovascular diseases

Vliv proměnlivosti počasí a teplotních extrémů na onemocnění oběhové soustavy

Ph.D. THESIS

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Declaration

I hereby declare that I completed this Ph.D. thesis independently, and only with the cited sources, literature and other professional sources. I did not submit or present any part of this thesis for any other degree or diploma.

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Abstract

Elevated mortality represents one of the main impacts of temperature extremes on human society. Increases in cardiovascular mortality during heat waves have been reported in many European countries; much less is known about which particular cardiovascular disorders are most affected during heat waves, and whether similar patterns are found for morbidity (hospital admissions). Relatively less understood is also cold-related mortality and morbidity in winter, when the relationships between weather and human health are more complex, less direct, and confounded by other factors such as epidemics of influenza/acute respiratory infections.

This thesis comprises a collection of four papers, three of which address the impacts of extreme temperatures on cardiovascular disease (CVD) in the population of the Czech Republic with a focus on ischaemic heart disease (IHD) and cerebrovascular disease (CD). The three papers are complemented by a study analysing trends in cardiovascular mortality and hospitalisations in the Czech Republic. The first paper focuses on comparing the effects of hot and cold spells on mortality from CVD in the population of the Czech Republic during 1986–2006 and examines differences between population groups. The second paper analyses effects of hot and cold spells on IHD mortality in the Czech population between 1994 and 2009 with an emphasis on differences in effects on acute myocardial infarction (AMI) and chronic IHD. The third study compares impacts of hot spells on CVD mortality and morbidity (hospital admissions) in the Czech population between 1994 and 2009 with an emphasis on possible differences between CD and IHD. The last paper examines trends in hospital admissions and in-hospital case-fatality of selected cardiovascular diagnoses, compares them with national CVD mortality during 1994–2009, and estimates the potential contribution of improved in-hospital case-fatality rates to declining mortality from AMI and stroke.

Abstrakt

Zvýšená úmrtnost představuje jeden z hlavních důsledků extrémních teplot vzduchu na lidskou populaci. Nárůsty kardiovaskulární úmrtnosti v období horkých vln byly zaznamenány v mnoha evropských zemích, méně je však známé, která kardiovaskulární onemocnění jsou v období horkých vln ovlivněna nejvíce a zda se vliv horkých vln projevuje i v případě nemocnosti (hospitalizací). Méně zřejmý je také dopad chladných období na úmrtnost a nemocnost v zimních měsících, kdy jsou vztahy mezi počasím a lidským zdravím komplexnější, méně přímé a zkreslené dalšími faktory, jako jsou epidemie chřipky a akutních respiračních onemocnění.

Předkládaná dizertační práce je souborem čtyř studií, z nichž tři se zabývají analýzou vlivu horkých a studených vln na úmrtnost a nemocnost na kardiovaskulární onemocnění (CVD) v České republice, se zaměřením na ischemickou chorobu srdeční (IHD) a cerebrovaskulární onemocnění (CD). Práce je doplněna studií trendů v úmrtnosti a nemocnosti (hospitalizacích) na CVD v ČR. První článek srovnává vliv horkých a studených vln na kardiovaskulární úmrtnost v ČR v období 1986–2006 a vyhodnocuje rozdíly mezi jednotlivými skupinami populace. Druhý článek se zabývá podrobně vlivem horkých a studených vln na IHD, se zaměřením na akutní infarkt myokardu (AMI) a chronickou IHD. Srovnání vlivu horkých a studených vln na kardiovaskulární úmrtnost a nemocnost (hospitalizace) v české populaci, se zaměřením na rozdíly mezi IHD a CD, je předmětem třetí studie. Poslední článek popisuje trendy v hospitalizacích a hospitalizační úmrtnosti vybraných kardiovaskulárních diagnóz, porovnává je s celkovou kardiovaskulární úmrtností v ČR v letech 1994–2009 a analyzuje vliv kladného trendu hospitalizační úmrtnosti na pokles celkové úmrtnosti na AMI a mozkovou mrtvici.

Contents

1 Summary

1.1 Motivation

Climatic conditions and weather patterns have affected human physiology and health for centuries. However, the patterns of present and future health risks are expected to change in the context of changing climate (McMichael and Lindgren 2011). Rising mean summer temperatures are very likely to lead to an increase in the frequency, duration, and severity of heat waves in future (Ballester et al. 2010), and, even in a warming climate, the intensity and duration of extreme cold events may persist into the late 21st century (Kodra et al. 2011).

In the mid-latitudes, heat waves are the extreme weather events having the most adverse impacts on human health (Kovats and Hajat 2008). The exceptional heat waves of summer 2003 in Western Europe are examples of episodes which had a devastating impact on the population in terms of mortality (García-Herrera et al. 2010). Greater vulnerability to heat-induced stress has been associated predominantly with women, the elderly, and people with pre-existing diseases (D'Ippoliti et al. 2010; deCastro et al. 2011; Gabriel and Endlicher 2011). In contrast, the effects of low temperature extremes on human health are less understood. Extreme cold episodes are associated with excess mortality, but the effects of low temperatures on health are more complex and less direct than are those of heat waves and are confounded by epidemics of influenza and acute respiratory infections (Kyselý et al. 2009). The question also remains whether similar patterns occur for hospitalisations.

This thesis focuses on cardiovascular diseases (CVDs) because the research into cause-specific mortality impacts of high and low temperature extremes shows that CVD is particularly sensitive to both types of extremes. However, little attention has been devoted to understanding the differences in health effects of hot and cold spells with respect to individual CVDs. Recent studies on temperature–mortality/morbidity relationships have differed considerably in design, database characteristics, and methodology, including definitions of high and low temperature extremes and how possible confounding effects (such as influenza/acute respiratory infection epidemics) were taken into account. Direct comparison of their results is therefore difficult. Moreover, the comparison of mortality impacts of hot and cold spells focusing on particular cardiovascular disorders is a field of research which is so far relatively unexplored. Differences in the mortality effects of high and low temperature extremes between acute and chronic CVDs may point to diverse physiological mechanisms playing a role in temperature–mortality relationships. This may help to identify populations at the highest risk of temperature-related diseases, which is an important step in developing better-targeted national public health strategies and preventive action plans. As temperature-related illness is largely preventable, accurate early warning systems that effectively communicate health risks could reduce the burden of illness and death (Ebi 2012).

1.2 Structure of the thesis

This thesis comprises a collection of four papers, three of which address the impacts of hot and cold spells on CVD in the population of the Czech Republic with a focus on ischaemic heart disease (IHD) and cerebrovascular disease (CD). These three papers are complemented by a study analysing trends in cardiovascular mortality and hospitalisations in the Czech Republic. Three papers have already been published in peer-reviewed international journals (Climate Research, BMC Public Health, and Heart), and one has been accepted and published online in the International Journal of Biometeorology.

The first paper (Section 2) focuses on comparing the effects of hot and cold spells on mortality from CVD in the population of the Czech Republic and examines differences among population groups. The second paper (Section 3) analyses the effects of hot and cold spells on IHD mortality in the Czech population with an emphasis on differences in effects on acute myocardial infarction (AMI) and chronic IHD. The third study (Section 4) compares hot spell effects on CVD mortality and morbidity (hospital admissions) in the Czech population with an emphasis on possible differences between CD and IHD. The last paper (Section 5) examines trends in hospital admissions and in-hospital case-fatality from selected cardiovascular diagnoses, compares them with national CVD mortality during 1994–2009, and estimates the potential contribution of improved in-hospital case-fatality rates to declining mortality from AMI and stroke.

Each paper forms an individual section of the thesis, and the papers are arranged in chronological order except for the study regarding trends in CVD mortality and morbidity in the Czech Republic, which is placed at the end of the thesis.

1.3 Data and methods

1.3.1 Data on mortality and hospital admissions

Data for the analyses carried out in all of the papers presented in this thesis were obtained from the national mortality and hospitalisation registers covering the entire population of the Czech Republic. The databases were provided by the Institute of Health Information and Statistics of the Czech Republic (IHIS).

Data on mortality were collected and processed by the Czech Statistical Office, which is primarily responsible for recording the primary causes of death according to the death certificates. The dataset was then transferred to IHIS for data checking and compilation. Mortality datasets cover all deaths with CVD coded as a primary cause of death during 1986–2009 in the Czech Republic, using the International Classification of Diseases (with 9th revision (ICD-9) codes 390–459 for 1986–1993 and 10th revision (ICD-10) codes I00–I99 for 1994–2009). The following ICD-10 codes were processed: IHD: I20–I25, AMI: I21–I22, chronic IHD: I25, heart failure: I50, CD: I60–I69, and stroke: I60–I64. The national dataset covering 1986–2006 contains daily death counts stratified by gender and divided into five age groups (0–24, 25–59, 60–69, 70–79, and 85+ years). Since 1994, the national mortality database has been based on individual records (including each individual's date of death, age at death, gender, district, and primary cause of death) and therefore enables a more detailed analysis as to which particular cardiovascular disorders are associated with high and low temperature extremes. Two age groups (0–64 and 65+ years) were considered in the analysis of hot and cold spell effects on CVD, IHD, and CD (compared to the five age groups examined during 1986–2006) owing to the smaller sample sizes of data on individual CVD diagnoses as well as the shorter time period for which data were available (1994–2009). For investigations of trends in CVD mortality, data were divided into several age groups (20–49, 50–64, 65–74, and 75+ years) in order to make the analysis comparable to existing studies in this field. The reliability of the national mortality register data is supported by the fact that the autopsy rate in the Czech Republic is among the highest in Europe, with little change over the study period (World Health Organization). This suggests that data quality is at least comparable to that in Western European countries.

The hospitalisation database, obtained from the National Registry of Hospitalized Patients (administered by IHIS), includes all admissions of residents to any hospital in the Czech Republic between 1994 and 2009 having CVD as the condition most responsible for the patient's hospitalisation. Each record includes the patient's demographic information (age, gender, occupation, and district), date of admission, and primary diagnosis according to ICD-10. Since each hospitalisation was recorded at discharge, incomplete data at the end of 2009 were supplemented using discharges recorded in 2010 in order to cover fully the 16-year period of 1994–2009. The same diagnoses as for mortality were analysed with the addition of hypertension (I10–I15) and angina pectoris (I20), for which numbers of deaths were small. The age groups studied were the same as for mortality.

1.3.2 Standardisation of mortality and morbidity data

To analyse temperature–mortality/morbidity relationships, an indirect standardisation method was applied: excess daily mortality/morbidity was determined in each examined population group as deviations between observed and expected (baseline) numbers of deaths/hospital admissions (cf. Gosling et al. 2009). Estimated baseline mortality/morbidity takes into account long-term changes related to socio-economic and lifestyle changes, improvements in health care, and changes in population age structure (Figures 2.1 and 4.5) as well as short-term variations reflecting annual and weekly cycles. These confounding factors were much more pronounced in morbidity data than they were in mortality data (showing a strong seasonal pattern with excess wintertime morbidity compared to lower morbidity rates in summer, along with lower numbers of admissions at weekends than during the week; Figure 4.1).

The following equations were used to calculate the expected number of deaths/hospital admissions $M_0(y,d)$ for year y [(i) $y = 1986, \dots 2006$; (ii) $y = 1994, \dots 2009$] and day d ($d = 1, \dots 365$):

$$\text{(i) } M_0(y,d) = M_0(d).Y(y)$$

$$\text{(ii) } M_0(y,d) = M_0(d).W(y,d).Y(y)$$

The first equation was used to estimate baseline mortality in a less detailed dataset covering the 21-year period, as no apparent weekly cycle was present in mortality data (Figure 4.1). To enable comparison of mortality and morbidity, the equation was supplemented with an additional correction factor for the strong weekly cycle observed in morbidity data. $M_0(d)$ denotes the mean daily number of deaths/hospital admissions on day d in a year (computed from the mean annual cycle, with epidemics excluded from the data from which the mean annual cycle was determined); $W(y,d)$ is a correction factor for the observed weekly cycle of mortality/morbidity, calculated separately for individual days of the week and defined as the ratio of the mean mortality/morbidity on a given day to the overall mean mortality/morbidity; and $Y(y)$ is a correction factor for the observed year-to-year changes in mortality/morbidity, defined as the ratio of the number of deaths/hospital admissions in year y to the mean annual number of deaths/hospital admissions during the analysed period. The correction factors for year-to-year changes $Y(y)$ and weekly cycle $W(y,d)$ were calculated over April–November, a period when the effects of influenza and acute respiratory infections are negligible (Kynčl et al. 2005; Kyselý et al. 2009). Prior to calculating the correction factor for the weekly cycle $W(y,d)$, all public holidays were excluded.

To analyse trends in cardiovascular mortality and hospitalisation, a direct standardisation method was used to remove the long-term trend of population ageing. Annual counts of CVD hospitalisations and deaths, separately for each diagnosis, were stratified by gender and divided into 5-year age groups (from 0 to 85+ years). Age-adjusted rates of admissions, mortality, and in-hospital case-fatality per 100,000 persons were calculated using the mid-year population of the Czech Republic and the WHO European standard population as the standard.

The age standardisation was not carried out in the analysis dealing with hot and cold spells effects on mortality and morbidity for the following reasons. First, the database on CVD mortality covering 1986–2006 contained aggregated data and therefore did not enable splitting the data into 5-year age groups. Second, the analysis of different age groups with respect to gender has an important limitation due to the relatively small numbers of cases in the mortality data for individual CVD groups, resulting in insufficient statistical power.

1.3.3 Meteorological data

Daily air temperature data were provided by the Czech Hydrometeorological Institute. Since the thesis deals with the population of the entire country and did not examine possible regional differences in weather effects on mortality or morbidity (which would require a different approach and is also the subject of ongoing research), a mean air temperature series was calculated by averaging data from 46 high-quality weather stations covering the Czech Republic. Stations were selected so as to be representative for the area and population under study.

Mean daily air temperature was employed as the simplest proxy for ambient thermal conditions because it enables the use of data from a high-density station network and application of analogous definitions of hot and cold spells. Moreover, recent studies have found no significant differences between air temperature and biometeorological indices in characterizing the effects of heat on mortality (Burkart et al. 2011; Vaneckova et al. 2011; Urban and Kyselý 2014).

1.3.4 Hot and cold spells

Definitions of hot and cold spells are based on anomalies of mean daily temperature from the mean annual cycle. Hot (cold) spells were defined as periods of at least two consecutive days with anomalies of mean daily temperature above the 95% quantile (below the 5% quantile) or above the 90% quantile (below the 10% quantile). Quantiles were set from the empirical distribution of anomalies over running 61-day periods centred on a given day of the year. In the study focusing on comparing the effects of hot and cold spells on IHD mortality (Section 3), the 90%/10% quantile was set to delineate hot/cold days in preference to the 95%/5% quantile owing to smaller sample sizes (data were analysed with respect to individual diagnoses) as well as the shorter time period for which data were available (1994–2009). We found, however, that differences between results obtained using the 90%/10% versus the 95%/5% quantile were only minor.

Hot spells were analysed in summer (June–August) and cold spells in winter (December–February). The definitions led to reasonably large samples of hot and cold spells over the examined periods: 29 hot spells and 27 cold spells were identified during 1986–2006 using the definition based on the 95%/5% quantile, and the average length of individual hot (cold) spells was 2.9 (3.3) days. Between 1994 and 2009, a total of 35 hot spells and 37 cold spells were identified using the definition based on the 90%/10% quantile, and the average length of individual hot (cold) spells was 3.1 (3.8) days.

Finally, 18 hot spells were identified in summer between 1994 and 2009 using the 95% quantile, with an average length of about 2.7 days.

The term ‘hot spell’ (and not ‘heat wave’) is used in order to emphasize that the definition is a relative one, based on deviations from the mean annual cycle of temperature instead of raw temperature or heat index data (to which ‘heat waves’ usually refer).

1.3.5 Methods

Relative deviations of mortality from the baseline were averaged over all hot/cold spells, in sequences spanning from 3 days prior to (D−3) until 16 days after (D+16) the onset of a hot/cold spell. This 20-day sequence comprises a relatively long period after the end of a hot/cold spell in order to include possible lagged mortality effects. In the study of hot spell effects on mortality and hospitalisation for CVD, IHD, and CD (Section 4), the sequence of days after the onset of a hot/cold spell was extended by 4 days (up to day D+20) due to estimation of the mortality displacement effect’s magnitude.

Statistical significance was evaluated by comparison with the 90% and 95% confidence bounds around the zero line, estimated from the 2.5%, 5%, 95% and 97.5% quantiles of a distribution calculated using the Monte Carlo method. Periods in which mortality data were affected by epidemics of influenza/acute respiratory infections were excluded from all calculations.

Trends in age-standardised rates were assessed by linear regression and expressed as the mean annual relative change. Statistical significance was evaluated using a *t*-test.

1.4 Summary of results

1.4.1 Hot and cold spell effects on CVD mortality

The analysis based on national CVD mortality data covering a 21-year period (1986–2006) showed that both hot and cold spells were associated with significant excess cardiovascular mortality, but with differences in the timing and magnitude of the effects. Hot spell effects were more direct and concentrated within the few days of a hot spell, while cold spells were associated with indirect mortality impacts persisting after the end of a cold spell (Figure 2.4).

The results suggest that cold spells are events of at least similar importance for cardiovascular health as are hot spells. Although the peak of excess deaths was much smaller for cold spells, the magnitude of the overall impacts on CVD mortality, due to lagged effects, was larger for cold spells than it was for hot spells. Mean excess CVD mortality relative to the daily baseline was estimated to be 54.0% for a hot spell and

71.5% for a cold spell (both values refer to the whole population and were calculated over all spells during 1986–2006). Considering the counts of cold and hot spells during 1986–2006, this leads to an estimated mean excess number of CVD deaths associated with a single cold (hot) spell of 111 (78) in the population of the Czech Republic. These findings highlight the importance of mitigation measures to decrease the burden of cold-related cardiovascular mortality.

The results regarding the impacts of hot and cold spells with respect to gender show that daily heat-related excess mortality in females exceeded 20% while it was approximately half that level in males. The larger excess mortality in the elderly during hot spells was predominantly due to women’s increasing vulnerability with age, and the effects on mortality in men depended relatively little on age (Figure 2.7). This suggests that older age and social structure of the population as well as physiological mechanisms including pre-existing chronic diseases, which commonly manifest in elderly women, play a role in women’s reduced tolerance for heat. In contrast, relative excess mortality during cold spells was largest in the middle-aged population (25–59 years), where the mortality effects were unlagged and related to males only (Figure 2.8). In older age groups, the mortality effects of cold spells were more lagged and differences between mortality in males and females were relatively minor. This indicates that the physiological mechanisms playing dominant roles in cold-related mortality differed between the middle-aged population and older age groups.

In the middle-aged population, the rate of physiological response to cold may depend on untreated cardiovascular risk factors, such as hypertension. The Czech population has a high prevalence of hypertension; about 30% of those in the hypertensive population are unaware of their condition (Cífková et al. 2010) and are exposed to chronic cardiovascular stress. On the other hand, elderly people are vulnerable to cold due to reduced cutaneous thermal sensitivity and diminished ability to maintain core temperature (Smolander 2002). Age-related chronic diseases such as coronary atherosclerosis may also underlie cardiovascular complications associated with cold. The reduced risk of CVD in young and middle-aged women is attributable to the cardioprotective effects of oestrogens, which inhibit the development of atherosclerosis (Vaccarino et al. 2011). Healthy women have greater cardiac contractility and better preserved myocardial mass compared to men at the same age (Mendelsohn and Karas 2005), which may also contribute to better protection of women.

1.4.2 Hot and cold spell effects on IHD mortality

Overall, the magnitude and duration of IHD mortality effects of hot and cold spells were similar to those found for CVD mortality, showing that the effects of hot spells on IHD mortality were direct and concentrated within days with elevated ambient temperatures, while IHD mortality impacts of cold spells were indirect and persisted after a cold spell end (Figure 3.2).

During cold spells, relative excess IHD mortality was most pronounced in the younger age group (0–64 years), while excess IHD mortality in this age group was much lower during hot spells. In the elderly, the effects of cold exposure were more lagged, with an observed IHD mortality peak several days after the end of a typical cold spell (Figure 3.2). This finding is consistent with results for aggregated CVD mortality showing that low temperature extremes affect cardiovascular health more markedly in the middle-aged population than they do in older age groups (see Section 2.3.2 of the thesis).

The investigation of hot and cold spells effects on mortality separately by IHD subtypes revealed excess AMI and chronic IHD mortality at both temperature extremes but with different patterns, suggesting that different physiological mechanisms played dominant roles in extreme heat/cold exposures. Significant excess AMI mortality was associated predominantly with low temperatures and persisted up to almost 2 weeks after the onset of a cold spell (Figure 3.4a). The peak in excess deaths from AMI was much higher in the younger population than it was in the elderly. On the other hand, the effects of hot spells on AMI mortality were much weaker and significant on only a single day (D+2, Figure 3.3a). These findings suggest that cold exposure was a triggering factor for acute cardiac events, with younger people being more vulnerable.

For hot spells, chronic IHD was responsible for most excess deaths due to IHD for both males and females, with much more pronounced impacts in the elderly (Figure 3.3b). For cold spells, on the other hand, considerably elevated cold-related mortality due to chronic IHD was observed predominantly in the younger age group (0–64 years, Figure 3.4b). In other words, the presence of chronic IHD increases mortality risk associated with extreme heat more than that with extreme cold, and, by contrast, exposure to cold may lead to death from acute events rather than from chronic IHD in the elderly.

The analysis of the average effects of hot and cold spells on acute and chronic IHD mortality shows that IHD mortality effects of a cold spell were on average considerably larger than were those associated with a hot spell (Figure 3.5). This is consistent with the results for CVD mortality (see Section 2.3.1). In the population as a whole, the estimated excess IHD mortality associated with an average hot spell was ~40% of daily mortality while the excess IHD mortality associated with an average cold spell was ~140% of daily mortality. For hot spells, much larger cumulative excess mortality was observed for chronic IHD compared to AMI in all examined population groups. For cold spells, in contrast, cumulative excess AMI mortality substantially exceeded chronic IHD mortality in all population groups except for the younger age group (0–64 years), where the difference was small.

1.4.3 Comparison of mortality effects of hot spells on IHD and CD

The results provide evidence of an association between hot spells and significant excess mortality from CD in all examined population groups except for the younger age group (Table 4.1). Overall, for the population as a whole the pattern of heat-related excess mortality for CD was comparable to that found for heat-related CVD and IHD mortality. Nevertheless, the analysis of average effects of hot spells revealed differences between individual CVDs: CD displayed a much larger cumulative excess mortality magnitude than did IHD in the elderly, in males, and in the population as a whole (Table 4.1). It is also interesting to note that average effects of hot spells on IHD mortality were comparable in the younger population and the elderly, while for CD a large significant increase (+83%) was found only in the elderly.

In general, gender-related differences were similar to those found for CVD mortality, with women showing greater vulnerability to heat than men (Table 4.1). However, the difference was much more pronounced for IHD (significant excess deaths due to IHD in women compared to smaller excesses in men), while for CD the differences between females and males were relatively small.

The results also show that the effects of heat on deaths from IHD were more immediate (excess IHD mortality already on day D+0), while increases in deaths from CD were more lagged (excess CD mortality starting on day D+1, with a peak on day D+2 in males and D+3 in females, Figure 4.3). This suggests that temperature changes and above-average temperatures occurring at the onset of a hot spell have an immediate impact on the cardiovascular health of vulnerable people, with consequences leading to acute cardiac complications. High temperatures lasting for several days, on the other hand, cause a gradual worsening of health conditions due to accumulation of physiological changes caused by heat stress that is more likely to result in cerebrovascular accidents.

1.4.4 Hospital admissions and hot spells

Heat-related excess cardiovascular mortality was not accompanied by increases in hospital admissions, and below-expected levels of admissions following the onset of a hot spell prevailed, particularly for IHD in the elderly (Table 4.1, Figure 4.4). In addition, the average effects of hot spells on CVD, IHD, and CD admissions were mostly negligible. These findings are in agreement with current research comparing CVD mortality and morbidity during hot spells (e.g. Bustinza et al. 2013; Monteiro et al. 2013) which shows that observed increases in mortality are not associated with comparable increases in hospitalisation. This supports the hypothesis that during hot spells people die rapidly from cardiovascular causes before reaching hospital or receiving medical attention. The results of this thesis suggest that out-of-hospital deaths represent a major part of excess CVD mortality during heat and that for in-hospital excess deaths CVD is a masked comorbid condition rather than the primary diagnosis responsible for hospitalisation. This corresponds well with several studies which have included also secondary diagnoses into analyses and showed the importance of CVDs as an underlying condition in heat-related morbidity (e.g. Williams et al. 2012).

1.4.5 Harvesting effect

The results show declines in IHD mortality after hot spells, while a similar effect was not observed for cold spells (Figure 3.2). The reduction in deaths during subsequent weeks after hot spells (Figure 4.3) to some extent offsets the previous increase; this short-term displacement points to the presence of people with short life expectancy for whom the heat precipitates death. The short-term mortality displacement accounted for slightly more than half of the excess deaths due to CVD in the Czech population (Table 4.2). This harvesting effect manifested differently for individual diseases, as seen in the large difference between CD and IHD mortality (Table 4.2) where a much larger displacement effect was found for mortality due to CD than due to IHD. This difference may be associated with the comorbid diseases and generally worsened health conditions typically associated with CD, while for IHD a larger percentage of victims are among the “healthy” (and younger) population.

1.4.6 Trends in cardiovascular mortality, hospital admissions, and in-hospital case-fatality

Overall, mortality from all CVDs declined significantly between 1994 and 2009. Rapid declines were observed for deaths from AMI and stroke but not for deaths from chronic IHD and heart failure (Figure 5.1). The positive change in IHD mortality seems to be driven mainly by declining mortality from AMI across age groups and genders. In contrast to AMI, mortality from chronic IHD has increased since 2000, predominantly among people aged 75 years and older. These contradictory trends may be explained by the fact that improved treatment, leading to higher survival of patients with acute coronary events, and better secondary prevention might increase the number of people with chronic IHD. In combination with population ageing, this is likely to underlie the rising mortality rates from chronic IHD in the older population. Males were more likely to die from CVD than were females, and the difference was more pronounced in middle-aged individuals (Table 5.2). In the oldest age group (75+ years), the most common cause of death was chronic IHD. The greatest improvement in CVD mortality was achieved among young men (20–49 years) where mortality fell by 60% mainly due to declines in AMI, chronic IHD, and stroke. The corresponding mortality rates for women 20–49 years of age declined less sharply but from a lower baseline.

Age-standardised CVD hospitalisation rates remained high and relatively stable during the study period, but in-hospital case-fatality rate (CFR) declined considerably. Both angina pectoris and chronic IHD admission rates decreased steadily, while AMI admission rates experienced a more modest decline (Figure 5.2). In contrast, hospitalisations due to heart failure increased dramatically in all age groups, and by 2009 heart failure had become the most common cause of CVD hospitalisations in the elderly. It is likely that heart failure morbidity will continue rising in future because of population ageing and improved survival attributable to improved secondary prevention and treatment. A favourable change in hypertension morbidity was found only in the youngest age group (20–49 years) in men and women (Table 5.3). Among those aged 75+ years, hospitalisation rates increased continually during the study period and the rate of admission for hypertension in women was almost double that of men.

In-hospital CFR declined significantly in both males and females for all diseases examined (Table 5.1). The main cause of in-hospital deaths was stroke, despite a large annual reduction in CFR (Figure 5.3), and the largest improvement in CFR was attributed to AMI. The Czech Republic has one of the highest levels of AMI treatment in Europe, with reperfusion therapy widely available (Widimsky et al. 2010). Improvements in treatment, including percutaneous coronary angioplasty and thrombolytic therapy, have led to better survival of patients with acute coronary syndrome and significantly reduced in-hospital CFR. The estimates suggest that approximately 24% and 41% of the national decline in mortality from IHD and AMI, respectively, could have been due to reduced in-hospital CFR. The magnitude of the contribution of treatment is consistent with the approximately 40% estimated in different countries by the IMPACT model (e.g. Bennett et al. 2006; Bandosz et al. 2012). According to the calculations, a rapid decline observed in in-hospital CFR for stroke may have had a major impact on national mortality from stroke. The fact that mortality and in-hospital CFR declined for both ischaemic and haemorrhagic strokes supports the view that improved survival is probably related to improved inpatient care.

1.5 Conclusions

The analysis based on national data provides evidence that both hot and cold spells were associated with excess cardiovascular mortality in the Czech population, but the most vulnerable population groups differed and increases in mortality were related to different prevailing cardiovascular health outcomes for heat and cold.

The mortality effects of cold spells were of at least similar importance as were those of hot spells in the Czech population. Due to lagged effects, the magnitude of the overall impacts on CVD mortality was larger for cold spells than it was for hot spells in spite of a much smaller peak of excess deaths. The adverse health effects of hot spells were much more pronounced in women than they were in men and the magnitude of the effects increased with age. For cold spells, by contrast, relative excess CVD mortality was largest in the middle-aged population (25–59 years) and pronounced mortality effects in this age group were related to males only. Different patterns in the effects of hot and cold spells on AMI and chronic IHD mortality suggest that excess deaths from IHD during hot spells occurred particularly among people with histories of chronic diseases whose health had already been compromised, while cardiovascular changes induced by cold stress may have resulted in deaths from acute coronary events rather than chronic IHD. A comparison of mortality and morbidity impacts of hot spells revealed that excess mortality for IHD and CD during hot spells was not accompanied by increases in hospital admissions and below-expected levels of morbidity prevailed, particularly for IHD in the elderly. This suggests that out-of-hospital deaths represented a major part of excess CVD mortality during heat and that for in-hospital excess deaths CVD was a masked comorbid condition rather than the primary diagnosis responsible for hospitalisation. Finally, the study showed that overall CVD hospitalisation rates remained high but the in-hospital CFR declined considerably. Improved case-fatality seems to have made a substantial contribution to the decline in national CVD mortality, particularly for AMI and stroke.

The analyses yield new insights into links between temperature extremes and cause-specific cardiovascular mortality and morbidity which could help to better identify populations most at risk of temperature-related disorders. Better understanding of heat- and cold-related effects on cardiovascular health is an essential step towards developing and implementing efficient preventive measures which may mitigate the negative human health consequences of both types of extremes in future. Public health warning systems and biometeorological forecast alerts should take into account that the most vulnerable population groups as well as the most affected cardiovascular diseases differ between hot and cold spells. As the elderly constitute that segment of the population most vulnerable to temperature extremes, special consideration should be given to providing them with adequate social services.

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2 Comparison of hot and cold spell effects on cardiovascular mortality in individual population groups in the Czech Republic

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Abstract

The study compares impacts of hot and cold spells on cardiovascular mortality in the Czech Republic over 1986–2006 and examines differences between population groups. We use analogous definitions for hot and cold spells that are based on quantiles of daily average temperature anomalies and do not incorporate any location-specific threshold. Epidemics of influenza/acute respiratory infections were identified and corresponding periods excluded from the analysis. Both hot and cold spells are associated with significant excess cardiovascular mortality. The effects of hot spells are more direct (unlagged) and typically concentrated in a few days of a hot spell, while cold spells are associated with indirect (lagged) mortality impacts persisting after a cold spell ends. Although the mortality peak is less pronounced for cold spells, the cumulative magnitude of excess mortality is larger for cold than hot spells. Gender differences consist mainly in much larger excess mortality of females in hot spells and more lagged effects in females than males associated with cold spells. Effects of hot spells have a similar temporal pattern in all age groups but much larger magnitude in the elderly. For cold spells, by contrast, relative excess mortality is largest in the middle-aged population (25–59 years). The results suggest that mechanisms playing the dominant role in inducing cold-related mortality differ between this age group (in which the effects are unlagged) and older age groups (significant excess mortality at lags of around 7 days and longer). For both high and low temperature extremes, preventive measures implemented by means of warning systems and biometeorological forecast alerts should consider the varied effects in individual population groups.

Key words: Human mortality, Cardiovascular diseases, Temperature extremes, Hot spells, Cold spells, Central Europe

2.1 Introduction

Links between weather and human health are extremely complex and are not yet understood in many aspects, despite renewed interest since the early 1990s (following from research into potential impacts of climate change on health; e.g. McMichael et al. 2006) and long-term knowledge of the existence of these links.

In the mid-latitudes, hot summer periods have a greater effect on human health and mortality than any other atmospheric phenomenon, especially in large cities (Gosling et al. 2009). While the 2003 heat waves in Western Europe (García-Herrera et al. 2010) and the 2010 heat wave in Russia (Hoerling 2010) are examples of events associated with enormous heat-related mortality impacts, even ‘moderate’ hot spells often result in significant excess mortality (Huynen et al. 2001, Kyselý 2004). It is usually reported that the impacts are largest among (or confined to) the elderly while they are insignificant in the younger population.

Much less is understood about cold-related mortality, which represents another important effect of weather on human health (Eurowinter Group 1997, Huynen et al. 2001, Keatinge 2002, Kyselý et al. 2009). This is partly because the links between mortality and low temperatures are less direct and more lagged, and partly because they are to some extent ‘masked’ by such confounding effects as outbreaks of influenza and other acute respiratory infections (which have been ignored in many studies on cold-related mortality, e.g. Donaldson et al. 2001a, Cagle and Hubbard 2005, Christidis et al. 2010, even though their mortality effects are larger than those of low temperatures themselves).

The effects of both heat and cold are usually most pronounced in mortality due to cardiovascular diseases, upon which the present analysis concentrates. In the Czech Republic, mortality associated with heat waves (Kyselý 2004, Kyselý and Kříž 2008) and cold spells (Kyselý et al. 2009) has been examined, but the previous studies were based on different definitions and approaches which did not allow for a comparative analysis. The main aims of the present study were (1) to compare the effects of summer hot spells and winter cold spells on cardiovascular mortality in the population of the Czech Republic, and (2) to compare the mortality effects in different age groups and genders. We made use of a nationwide database on daily mortality, which covers – with complete records – the period since 1986. This encompasses seasons with the hottest summers on record (1992, 1994, 2003) as well as several very cold winters (1986/87, 1995/96, 2005/06).

2.2 Data and methods

2.2.1 Mortality data and their standardisation

Cardiovascular diseases (CVDs; International Classification of Diseases, 9th Revision [ICD–9] codes 390–459, 1986–1993; ICD–10 codes I00–I99, 1994–2006) represent by far the most frequent cause of death in developed countries, including the Czech Republic (located in Central Europe; population of around 10.3 million over the whole period). We deal with CVD mortality also because previous studies have reported that increases in mortality associated with high and low temperature extremes are to a large extent due to CVD (e.g. Medina-Ramón and Schwartz 2007). The dataset was provided by the Institute of Health Information and Statistics of the Czech Republic and it covers all deaths with a CVD as the primary cause of death over 1986–2006. The percentage of death certificates that are based on autopsy is relatively large (30.2% in 2006), which supports the reliability of the database.

Table 2.1 Mean annual numbers of deaths due to cardiovascular diseases (CVD) in individual population groups in the Czech Republic over 1986–2006, and their share in total (TOT, all causes) mortality in %. M = males, F = females.

	0–24 yrs	**25–59 yrs**	**60–69 yrs**	**70–79 yrs**	**80+ yrs**	**all ages**
M CVD	43.4	4256.7	6462.6	9752.3	8730.9	29246.0
TOT	1451.8	13013.7	13504.0	17340.5	13299.6	58609.5
%	[3.0%]	[32.7%]	[47.9%]	[56.2%]	[65.6%]	[49.9%]
F CVD	30.2	1387.7	3570.2	10460.0	18873.3	34321.4
TOT	763.8	5577.2	7859.1	17250.7	26187.3	57638.1
%	[4.0%]	[24.9%]	[45.4%]	[60.6%]	[72.1%]	[59.5%]

Table 2.1 summarizes mean annual numbers of deaths from CVD in individual population groups in the Czech Republic and their share in total (all causes) mortality. CVDs were the primary cause in around 55% of all deaths over 1986–2006; their share in total mortality increases with age, and it is larger in females than males in age groups 70+ years while the opposite holds true in the younger population.

Since time series of daily numbers of deaths are affected by long-term trends and seasonal changes, they need to be standardised. We applied an indirect standardisation that is commonly used in biometeorological and epidemiological studies: excess daily mortality is determined in each examined population group as deviations of the observed and expected (baseline) numbers of deaths (cf. Gosling et al. 2009). The estimated baseline mortality takes into account long-term changes related to improvements in medical care and the population’s changing health status and age structure (Figure 2.1, top left), as well as short-term variations due to the annual cycle (with mortality larger in winter than summer; Figure 2.1, top right). Note that the overall CVD mortality declined over 1986–2006 in spite of almost constant population size. This reflects improvements in medical care as well as in general health status of the population.

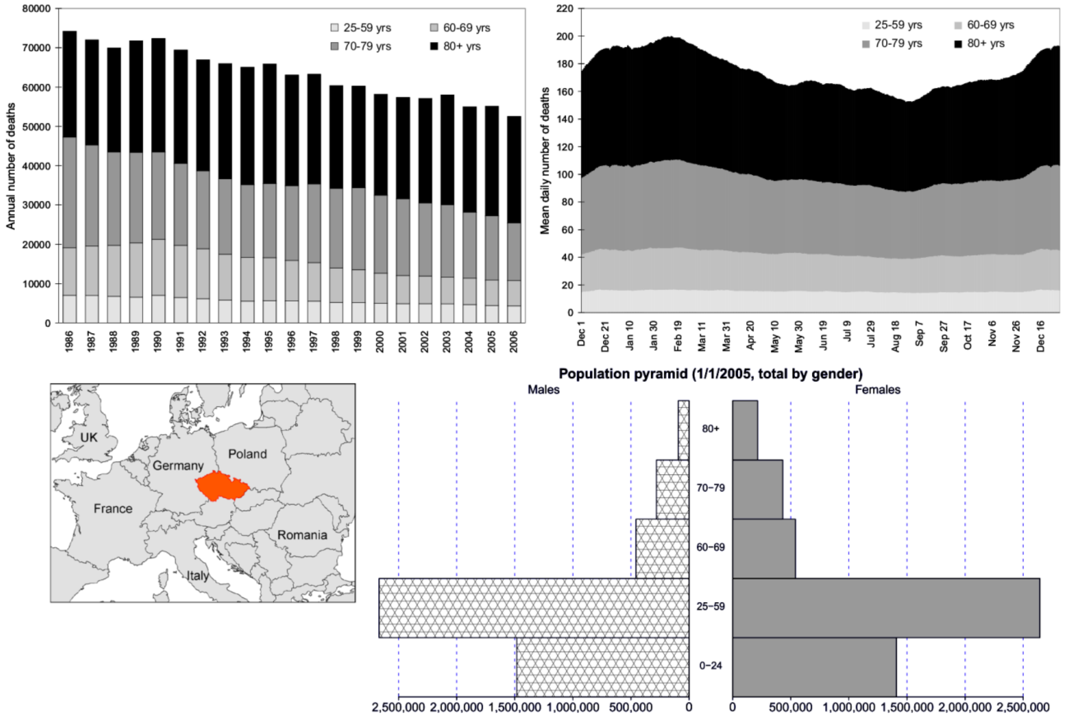

Figure 2.1 Long-term changes (top left) and mean annual cycle (top right) of cardiovascular mortality in the Czech Republic. The mean annual cycle was smoothed by 15-day running means; periods of influenza/acute respiratory infection epidemics were excluded. The study area and population pyramid with the sex-age distribution (based on data in 2005) are shown in the bottom panels.

Since the study includes cold season when the effects of influenza/acute respiratory infections on CVD mortality may be important, we identified epidemics in order to exclude corresponding periods from data before determining the mean annual cycle of mortality. This was achieved by using a dataset on morbidity from acute respiratory infections taken from the national surveillance system, applying the standard threshold of 2,000 reported ill weekly per 100,000 population (Kynčl et al. 2005a). Thirteen epidemics covering altogether 399 days were identified over 1986–2006. All these occurred during December–March, with a peak in February. The lagged relationship between mortality and morbidity was found to be strongest with a 7-day lag of mortality after morbidity (for both genders and both total and CVD mortality; Kyselý et al. 2009), which is also in accord with a previous study that reported a lag of 7–10 days (Kynčl et al. 2005b). This lag was applied when omitting mortality data affected by epidemics from the analysis.

In mathematical terms, the expected number of deaths $M_0(y,d)$ for year y (y = 1986, ... 2006) and day d (d = 1, ... 365) was set in each population group according to

$$\mathrm{M_0(y,d) = M_0(d).Y(y)},$$

where $M_0(d)$ denotes the mean daily number of deaths on day d in a year, computed from the mean annual cycle smoothed by 15-day running means, and $Y(y)$ is a correction factor for the observed year-to-year changes in mortality, defined as the ratio of the number of deaths in year y to the mean annual number of deaths during the analysed period. Correction factors for the year-to-year changes $Y(y)$ were calculated over April–November, when data are not confounded by epidemics of influenza/acute respiratory infections. The excess mortality was established for specific population groups: males (M) and females (F), and for individual age groups as specified in Table 1 (except for age group 0–24 years in which CVD mortality is very low). Ratios of excess mortality to the expected number of deaths, expressed as a percentage above or below the baseline, are evaluated throughout the text.

The method for estimating baseline mortality is the same as in Kyselý et al. (2009), and a similar standardisation procedure was applied also, for example, by Whitman et al. (1997), Guest et al. (1999), Smoyer et al. (2000), and Kyselý and Huth (2004).

2.2.2 Meteorological data

The area of the Czech Republic is relatively small (78,866 km^2), which makes it possible to use average temperature series calculated from a set of meteorological stations to describe daily variations in weather. A series of average daily air temperatures representative for the Czech Republic was calculated by averaging data from 46 high-quality weather stations. The stations were selected so that no important station moves occurred during the period examined (1986–2006), and the sites fairly evenly cover the area and population under study. We do not address possible spatial variations in weather and in the relationships between weather and mortality, as the mortality data (Section 2.2.1) are available for the population as a whole without regional detail. The mean series for the Czech Republic is superior to that used in Kyselý and Kříž (2008) since it yields a better spatial coverage of the area and population, particularly because it involves a much larger number of stations (46 compared to 7).

2.2.3 Hot and cold spells

In order to make the definitions of hot and cold spells comparable (and also easily applicable in other studies/regions), we define them both in terms of anomalies of average daily temperature from the mean annual cycle and do not incorporate any location-specific threshold. Hot (cold) spells are defined as periods of at least 2 consecutive days with anomalies of average daily temperature above the 95% quantile (below the 5% quantile). The quantiles were set from empirical distribution of the anomalies over running 61-day periods centred on a given day of the year (cf. Kyselý 2008). The definition of hot spells is identical with that used in Kyselý and Plavcová (2011). The reason for a change in the temperature parameter and the definition of hot and cold events compared to previous studies (Kyselý and Kříž 2008, Kyselý et al. 2009) was to simplify the criteria and make them analogous for both types of events. The 95% and 5% temperature quantiles were applied by Hajat et al. (2007) to examine heat- and cold-related mortality. The use of the 95% quantile to delineate hot spells is in accord with a number of other studies (e.g. Díaz et al. 2006, Gosling et al. 2007), and the threshold of 2 days corresponds with the recommendation of Robinson (2001). We found this useful also because hot spells lasting at least 2 days are associated with much larger and more significant mortality impacts than are single isolated hot days, while the differences between 3-day and 2-day hot spells are minor. We use the term ‘hot spell’ (and not ‘heat wave’) in order to highlight that the definition is a relative one, based on deviations from the mean annual cycle of temperature instead of raw temperature or heat index data (to which ‘heat waves’ usually refer). Hot spells are analysed in summer (June–July–August, JJA) and cold spells in winter (December–January–February, DJF).

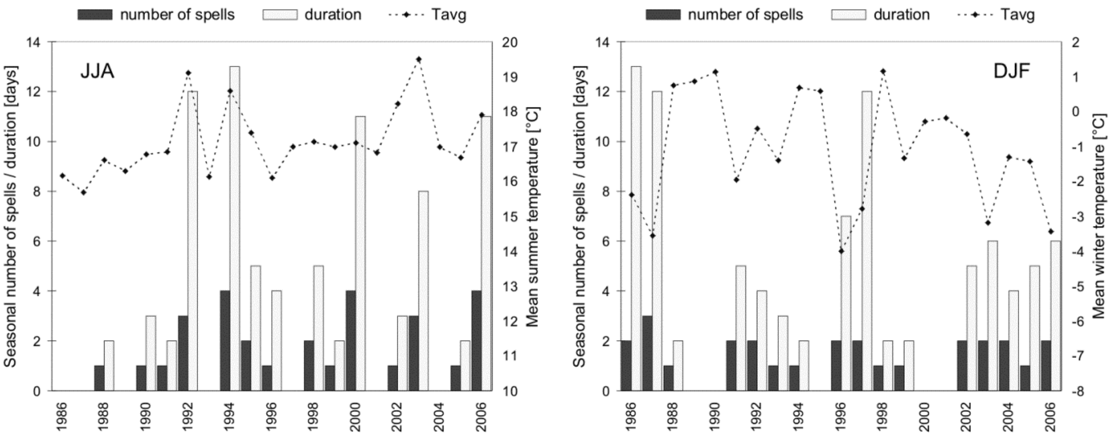

Figure 2.2 Seasonal counts and durations of hot spells (left) and cold spells (right), and mean seasonal temperatures over 1986–2006. Winter is defined by the year it ends (e.g. winter 1986/1987 is labelled as 1987). JJA: June–July–August; DJF: December–January–February.

The definitions led to reasonably large samples of hot and cold spells over the examined period: 29 hot spells and 27 cold spells were identified over 1986–2006, with total duration of 83 days (hot spells) and 90 days (cold spells). This means that on average, hot spells cover around 4.0 days in summer and cold spells around 4.3 days in winter. The average length of individual hot (cold) spells is 2.9 (3.3) days. Interannual variability of hot and cold spells as well as mean seasonal temperatures are depicted in

Figure 2.2. While mean summer temperatures show a positive trend over 1986–2006, which is to some extent also reflected in characteristics of hot spells, mean winter temperatures manifest rather decadal-scale oscillations with colder winters and enhanced cold spell characteristics around the beginning, middle and end of the examined period.

2.2.4 Methods

Relative deviations of mortality from the baseline on days D–3 (3 days before the beginning of a hot/cold spell) up to D+16 (16 days after) were averaged over the identified hot/cold spells. The 20-day sequence encompasses a few days before the beginning of a spell as well as a relatively long period after the end. We point out that mean temperature anomalies, averaged over all hot/cold spells, are close to zero already on day D+9 for both hot and cold spells (Figure 2.3), but effects on mortality may persist even longer (see Section 2.3.1).

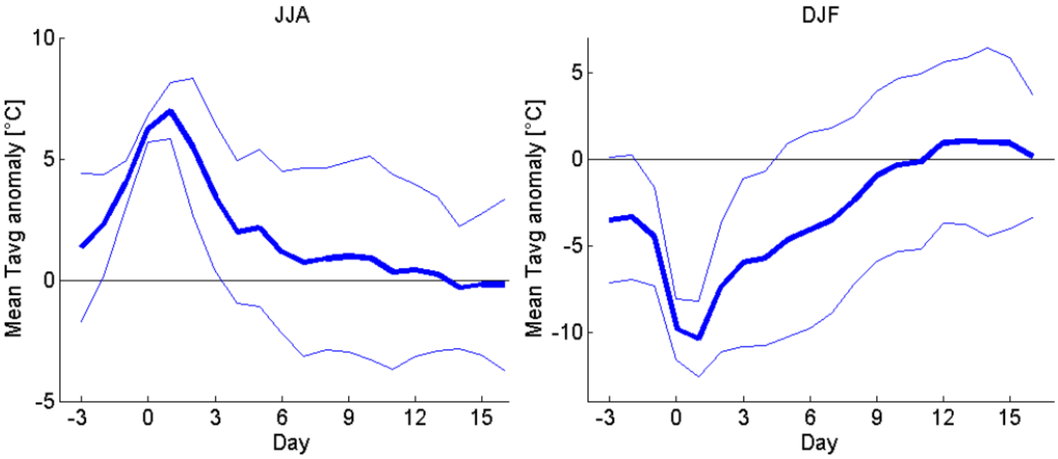

Figure 2.3 Mean daily temperature anomalies on days D–3 to D+16, averaged over hot spells (left) and cold spells (right). The upper and lower bounds show +/− one standard deviation around the mean. JJA: June–July–August; DJF: December–January–February.

Statistical significance of this mean relative deviation of mortality was evaluated by comparison with the 90% and 95% confidence interval (CI) around the zero line, estimated from the 2.5%, 5%, 95% and 97.5% quantiles of a distribution calculated by the Monte Carlo method. For each examined population group, the same numbers of 20-day sequences (D–3 to D+16) as the counts of the hot/cold spells were randomly drawn 10,000 times from the data over 1986–2006 in a given season, to estimate the corresponding quantiles. Periods in which mortality was affected by epidemics of influenza/acute respiratory infections were excluded from all calculations. This exclusion concerns only winter, in which six 20-day sequences around cold spells (from the total of 27 cold spells) were affected by epidemics, and the corresponding days (for 3 cold spells) or whole 20-day sequences (for another 3 cold spells) were omitted from the analysis.

The 95% CIs for excess mortality aggregated over hot and cold spells were calculated using the lower and upper limit factors for a Poisson-distributed variable according to Schoenberg (1983); for the number of cases larger than 100, the normal approximation was used.

2.3 Results

2.3.1 Comparison of hot and cold spell mortality effects

Mortality impacts associated with hot and cold spells, averaged over all spells during 1986–2006, are plotted in Figure 2.4 in terms of mean relative deviations from the baseline CVD mortality, separately for the whole population (M+F), males (M) and females (F), and their significance is evaluated by comparison with the 90% and 95% CIs around the zero line.

Both hot and cold spells are linked to significant excess CVD mortality, but there is a conspicuous difference in the lag: while the effects of hot spells are direct and occur on days of hot spells (significant excess mortality on days D+0 to D+3 in the whole population and M, and on days D+0 to D+4 in F), the effects of cold spells are substantially more lagged (excess mortality lies outside the 90% CI on days D+1 to D+13 in the whole population, and on most days between D+2 and D+13 also outside the 95% CI). Note that average temperature anomalies are close to zero or are positive on days around D+10 of cold spells (Figure 2.3), so the excess mortality on these days cannot be related to direct cold-stress effects.

Although the peak excess mortality is much larger for hot spells (+15.9% on day D+2) than cold spells (+8.0% on day D+4), the cumulative excess mortality is larger for cold than hot spells: if we consider the sum of excess mortality on consecutive days upon which the mean relative deviation of mortality exceeds the 95% quantile (that is, lies outside the 90% CI) as the average effect of hot and cold spells, we find average excess mortality of 54.0% (71.5%) relative to the daily baseline for the hot (cold) spells in the whole population. (The values were obtained by summing mean relative excess mortality on days D+0 to D+4 for hot spells and D+1 to D+13 for cold spells.) This suggests that the magnitude of the overall effects on CVD mortality may be larger for cold than hot spells in spite of much smaller peak excess mortality.

Pronounced differences in the impacts of hot spells are found between M and F: excess mortality is much larger in F, exceeding +20% on day D+2, while it is approximately half that level in M (Figure 2.4). The effects of cold spells are comparable in M and F as to the magnitude, but the lag tends to be slightly shorter in M than F (excess mortality lies outside the 90% CI already on days D+1 and D+2 in M while from day D+3 in F; Figure 2.4).

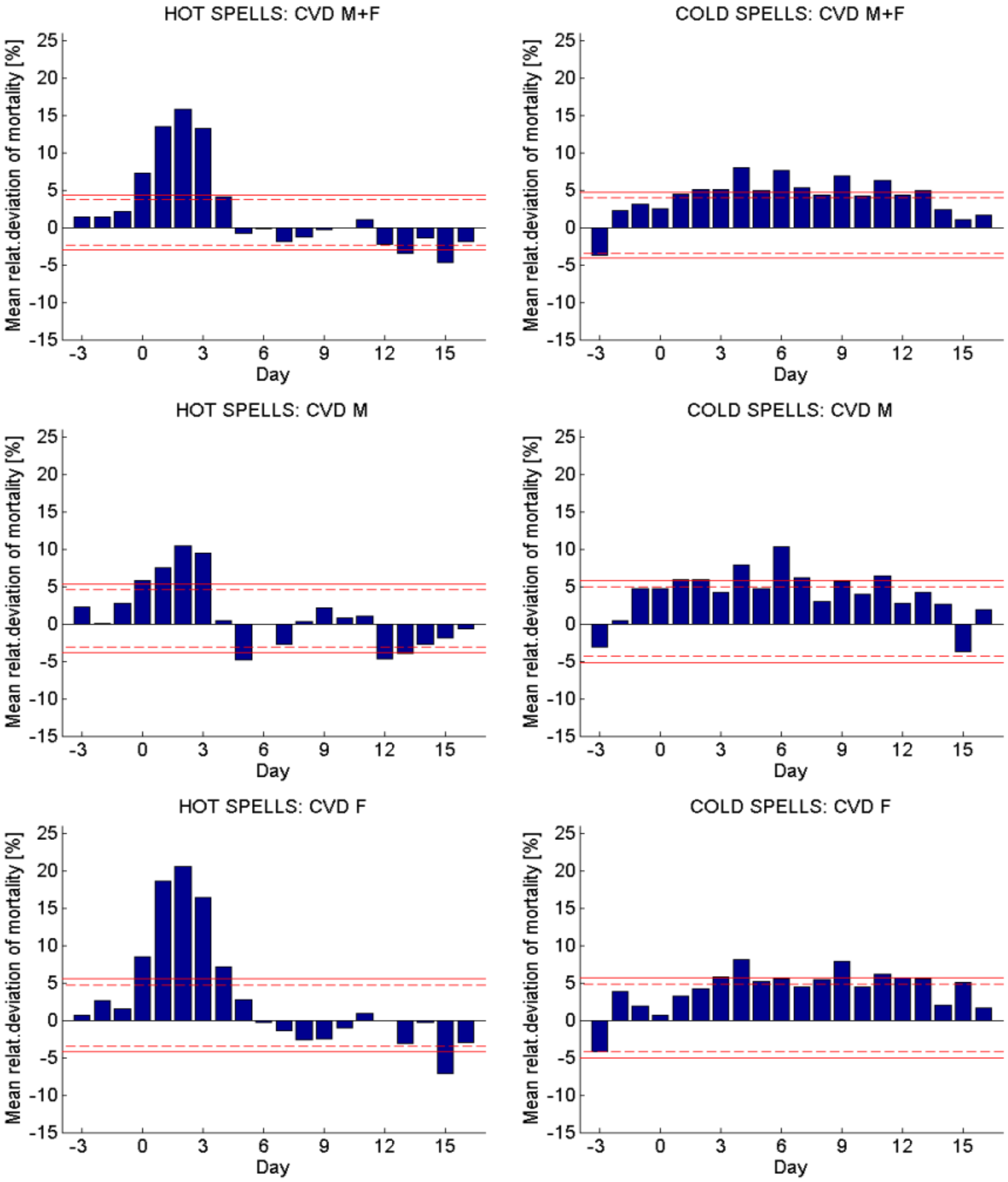

Figure 2.4 Mean relative deviations of mortality for 20-day sequences D–3 to D+16 for hot spells (left) and cold spells (right) for the whole population (M+F, top), males (M, middle) and females (F, bottom). Days are counted from the beginning of a hot/cold spell. Solid (dashed) lines denote the 2.5% and 97.5% (5% and 95%) quantiles of deviations obtained by the Monte Carlo method.

Figure 2.5 compares the effects of short hot/cold spells (2–3 days) with longer spells (4+ days). For hot spells, as expected, the magnitude of the impacts is larger in the latter case and significant excess mortality persists to day D+5, but the overall course of mortality deviations is quite similar. The pattern of excess mortality is analogous between short and longer cold spells as well, but the excess mortality is insignificant and the deviations are smaller for the latter. While this may suggest that the cumulative effects of persistent temperature anomalies are more important for hot than cold spells, the number of longer events is small for both hot (6) and cold (7) spells, and 2 out of the 7 longer cold spells were completely omitted from the analysis due to epidemics, thus making the sample even smaller. A large majority of the examined events last 2 or 3 days (i.e. most spells are very similar as to their temporal extent), which also justifies the use of averages over individual spells of extreme temperature anomalies.

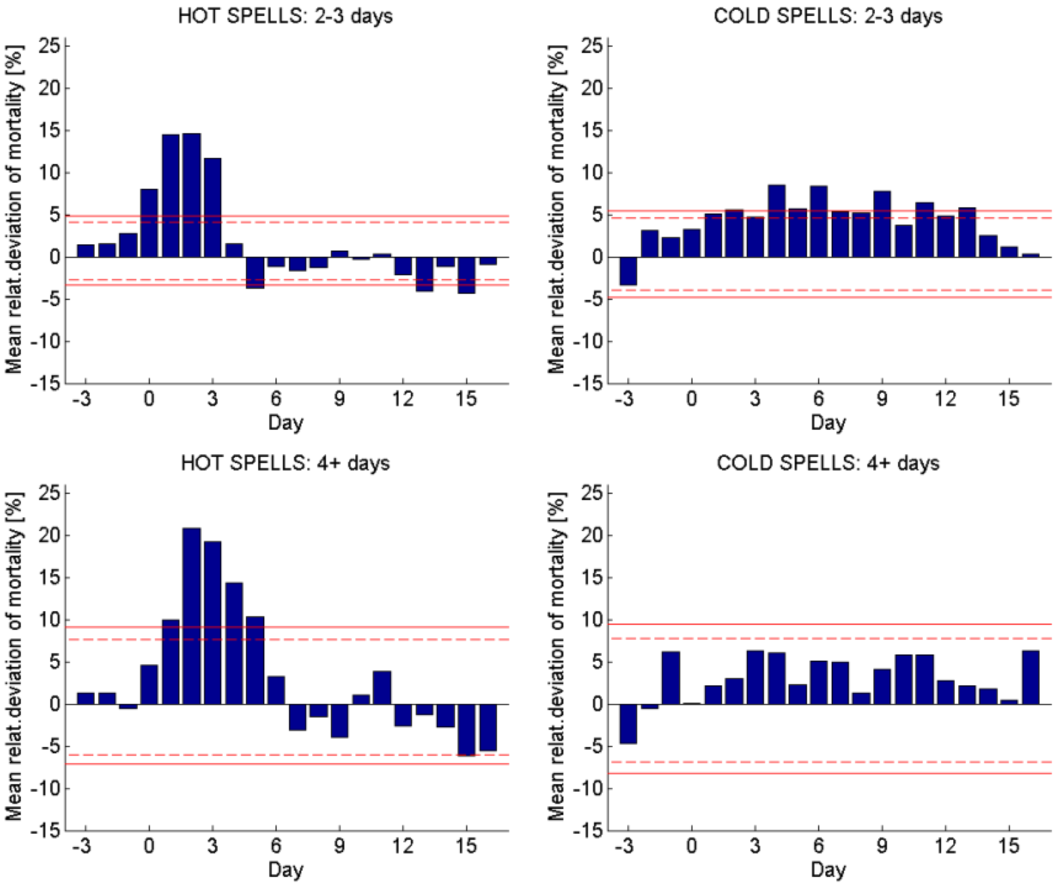

Figure 2.5 Same as in Figure 2.4 but for short spells (lasting 2–3 days, top) and longer spells (4+ days, bottom).

2.3.2 Differences in individual population groups

Figure 2.6 shows that the effects of hot spells on cardiovascular mortality increase with age. They are particularly pronounced in the oldest age group (80+ years), in which significant excess mortality occurs on all days D+0 to D+4. In spite of the different magnitude of the mortality effects, however, the patterns of mortality deviations in the sequence of days are quite similar in all age groups.

For cold spells in winter, the figure looks completely different than that for hot spells in summer. Rather surprisingly, the relative excess mortality is most pronounced in the middle-aged population (25–59 years), in which the largest excess mortality is unlagged (days D+0 and D+1). Significant excess mortality is more lagged in the older age groups. This feature is particularly well-expressed in the oldest age group (80+ years), for which significant excess mortality is found for lags D+6 to D+11 and not for lags which correspond to direct cold-stress effects. This obviously points to different physiological and/or behavioural mechanisms playing their roles in CVD's manifestation among middle-aged and elderly populations, as discussed in Section 2.4.3.

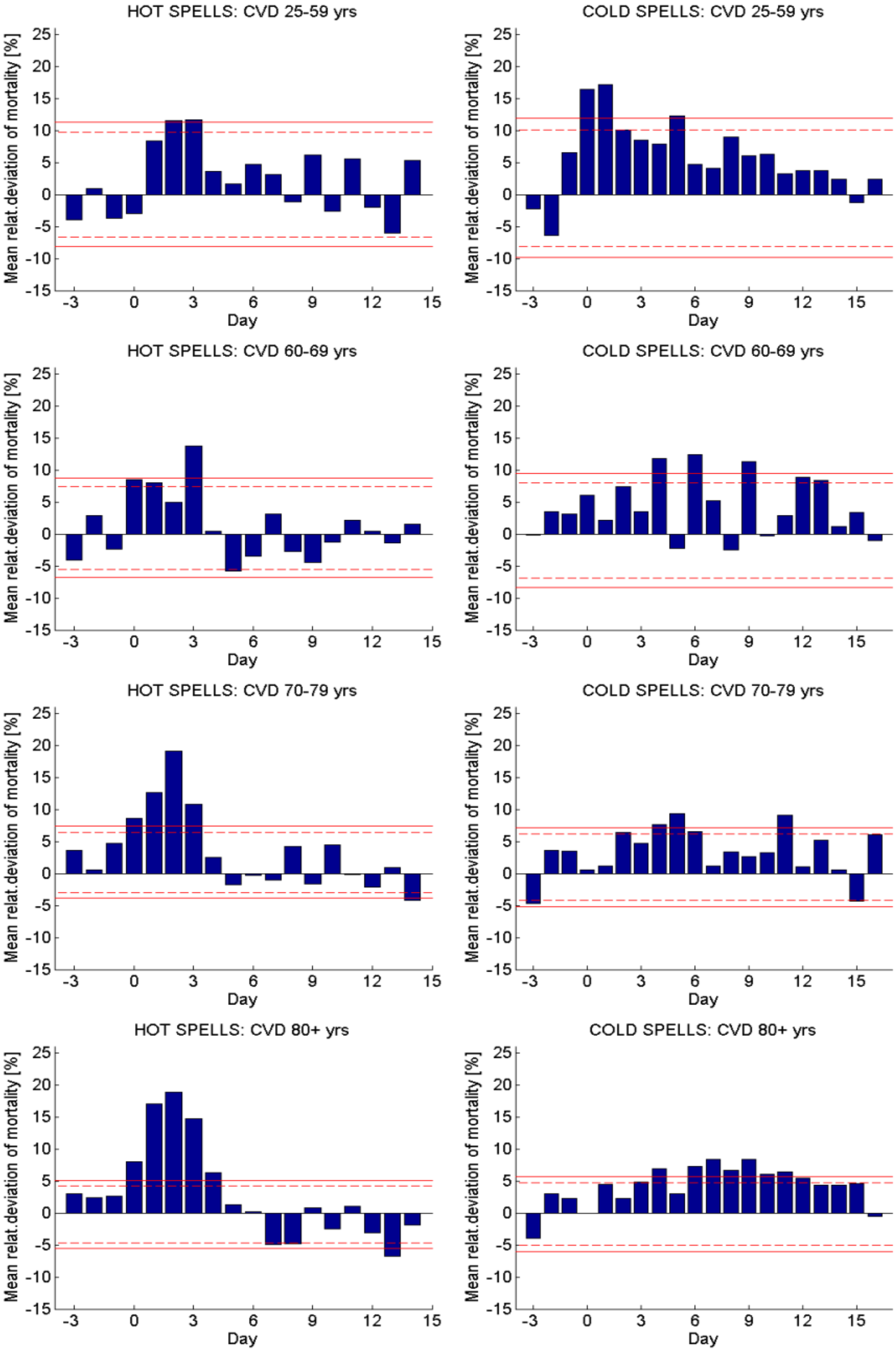

Figure 2.6 Same as in Figure 2.4 but for different age groups.

The effects in individual population groups are further differentiated by splitting the age groups by gender (Figures 2.7 and 2.8). Since differences in the sample size become quite pronounced in individual population groups, which results primarily in different widths of the 90% and 95% CIs for mean relative deviations of mortality, the y-axis was rescaled in all plots in Figures 2.7 and 2.8 so that the CIs are visually of the same width.

Figure 2.7 reveals that for hot spells, the larger magnitude of the mortality effects in the elderly is predominantly due to increasing vulnerability of females with age, while the effects in males depend relatively little on age. For cold spells (Figure 2.8), we found that the pronounced unlagged mortality effects in middle-aged population are related to males only; the effects in females are more lagged in this population group and insignificant. For older groups, differences between males and females are relatively minor in terms of magnitude as well as lag of the excess mortality.

2.4 Discussion and conclusions

2.4.1 Differences between hot and cold spell effects

The study shows that both hot and cold spells are associated with significant excess cardiovascular mortality, but there are considerable differences: the effects of hot spells are more direct (unlagged) and typically concentrated on a few days of a hot spell (significant excess mortality on days D+0 to D+4 from the beginning of a spell), while cold spells are associated with indirect (lagged) mortality impacts that persist after the end of a cold spell (significant excess mortality on days from D+1 to D+13). The shorter (longer) lag of heat-(cold-)related mortality is in agreement with findings reported by Braga et al. (2002) and Anderson and Bell (2009), and a long lag of cold-related mortality in European cities (up to 23 days) has been reported by Analitis et al. (2008). Longer lags are obviously needed to capture the impacts of low temperatures on mortality, and different lag structure is essential in time series models for cold- and heat-related mortality (cf. Anderson and Bell 2009).

Although the mortality peak is less pronounced for cold spells, the cumulative magnitude of the excess mortality is larger for cold than hot spells. The average excess CVD mortality relative to the daily baseline is estimated to be 54.0% for a hot spell while 71.5% for a cold spell (both values refer to the whole population and are calculated over all spells during 1986–2006). If observed excess mortality is summed in the same way across all cold and hot spells in 1986–2006, the total estimated number of excess CVD deaths over the 21-yr period is 3008 (95% CI: 2523–3497) for cold spells while 2261 (95% CI: 1984–2541) for hot spells. For these calculations, excess mortality on days in cold spells that were affected by epidemics was replaced using mean relative excess mortality for a given day D+x (Figure 2.4), and all days D+0 to D+4 for hot spells (D+1 to D+13 for cold spells) were counted only once in case of two events separated by only a few days. Considering the counts of cold and hot spells over 1986–

2006, this leads to an average excess number of CVD deaths associated with a single cold (hot) spell of 111 (78) in the population of the Czech Republic.

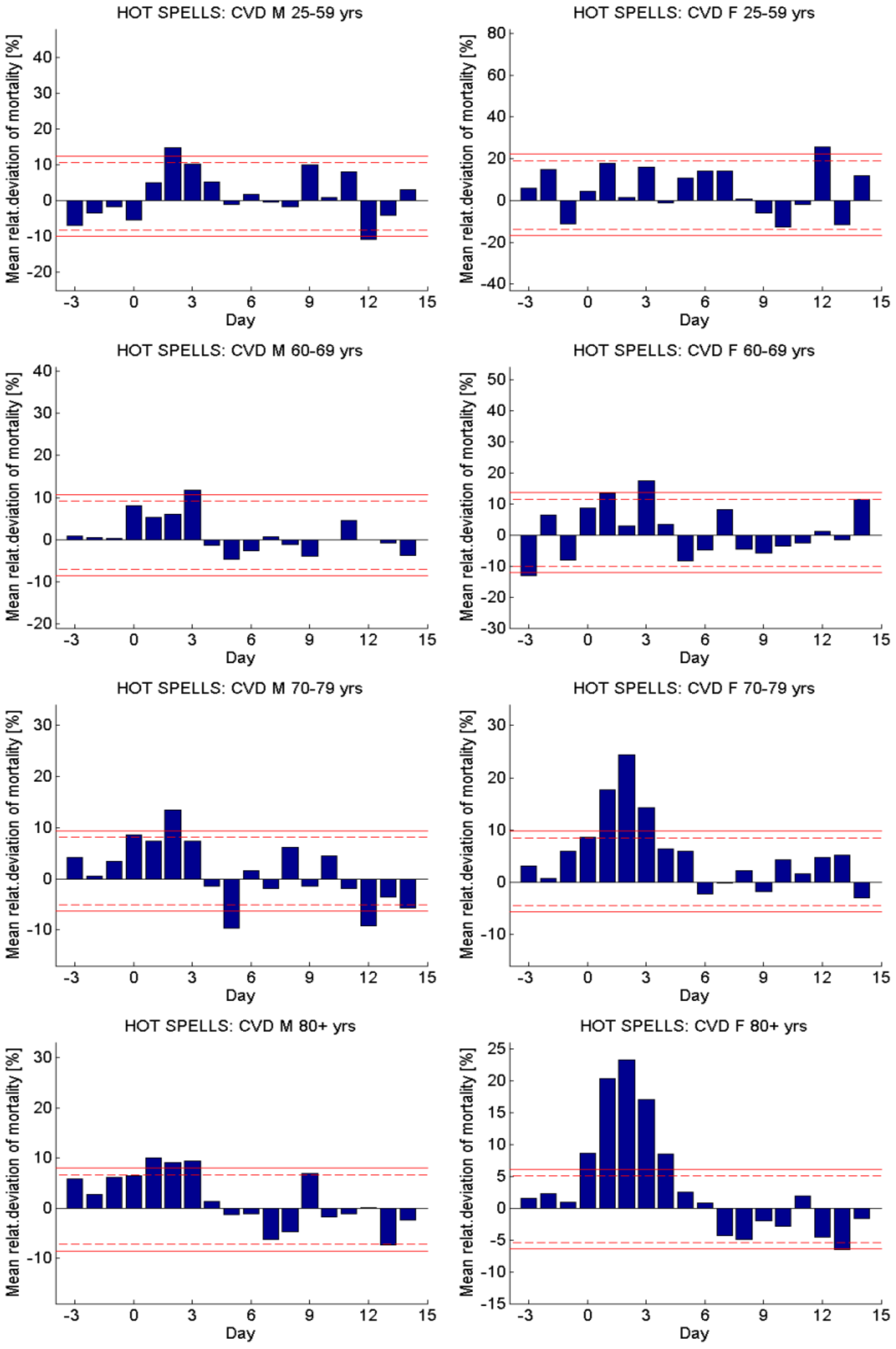

Figure 2.7 Same as in Figure 2.4 but for hot spells and different population groups. Vertical axes have been rescaled so that the width of the confidence intervals around zero is similar in all plots.

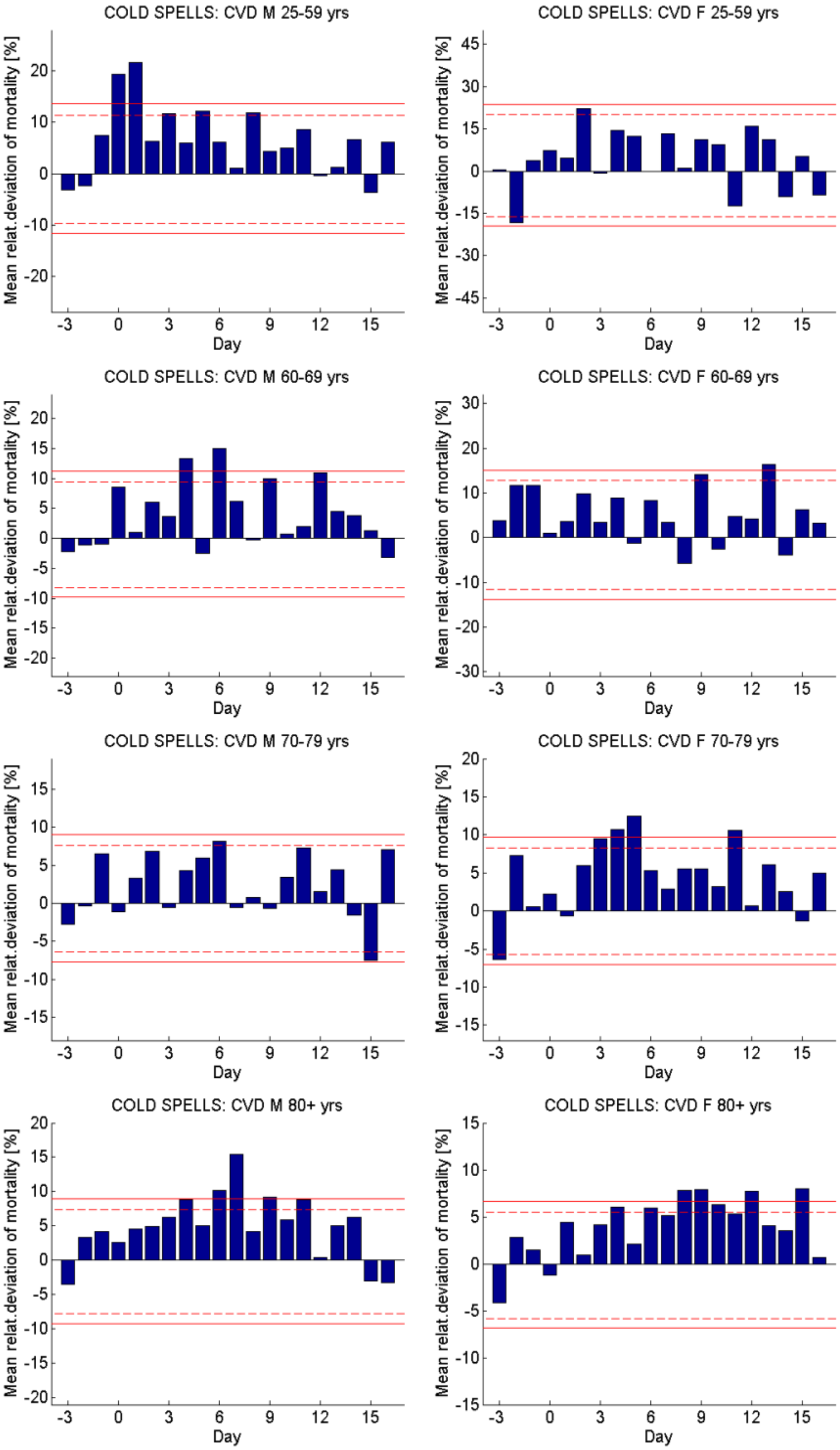

Figure 2.8 Same as in Figure 2.7 but for cold spells.

These results suggest that cold spells are events of at least similar public health concern as are hot spells (cf. similar conclusion by Analitis et al. 2008, Anderson and Bell 2009), and much attention should be devoted to mitigating their negative effects on cardiovascular health and mortality. The finding that cold extremes may have comparably large mortality effects as do hot spells contradicts most previous studies for the US and Europe that did not incorporate lag effects or underestimated the possible lag for cold-related mortality (e.g. Barnett 2007, Medina-Ramón and Schwartz 2007). Our results support the hypothesis that some previous studies underestimated the effects of cold extremes by confining the analysis to lags that were too short.

Moreover, the overall impacts of heat-related mortality are often reduced due to a 'displacement effect' (e.g. Kyselý 2004), while cold-related mortality shows no evidence of mortality displacement (Huynen et al. 2001, Braga et al. 2002, Analitis et al. 2008). Compared to hot spells, however, possible warning systems are likely to be less efficient due to the fact that the effects are mostly indirect (lagged) and to some extent confounded by prevalence of influenza and other acute respiratory infections. Warning systems also should take into account that the effects of cold spells vary for individual population groups more than those of hot spells (as discussed in Sections 2.4.2 and 2.4.3). The present study is limited by the fact that only aggregated CVD mortality data were available, which does not allow for addressing which particular CVD diagnoses are most closely associated with hot and cold extremes.

2.4.2 Differences in population groups

2.4.2.1 Males versus females

Differences between mortality impacts of hot and cold spells in males and females consist mainly in much larger excess mortality of females than males in hot spells, while more lagged effects in females than males in association with cold spells (for which the magnitude of the impacts is comparable in males and females in most age groups). Greater vulnerability to heat for females than males has been reported in a number of studies (e.g. Stafoggia et al. 2006, Hajat et al. 2007, Ishigami et al. 2008), and it is related to physiological mechanisms as well as the age and social structure of the population (e.g. a larger percentage of elderly women living alone). The physiological mechanisms include pre-existing chronic diseases, such as hypertension and diabetes (increasing the risk of CVD more markedly in women; Schenck-Gustafsson 2009, Winston et al. 2009), and adverse effects of menopause on both cardiovascular fitness and thermoregulation (altered thermoregulation, change in blood glucose control, endothelial dysfunction and vascular inflammation in postmenopausal women that all increase cardiovascular event risk in hot weather; Schwartz 2005, Rosano et al. 2007). People with diabetes have impaired thermoregulation and altered sweating response; consequently, reduced tolerance to heat together with increased demand on the circulatory system during heat stress may increase risk of fatal events (Schwartz 2005, Kenny et al. 2010). Our finding that the modification of the cold effect by gender is much smaller than that of the heat effect also agrees with previous reports (e.g. Hajat et al. 2007).

2.4.2.2 Age groups

With respect to the dependence on age, the effects of hot spells have a similar temporal pattern in all age groups but much larger magnitude in the elderly. This is also consistent with most previous studies and reported underlying physical mechanisms impairing resistance to hot weather in the elderly. Thermoregulation of skin blood flow changes with age, and altered heat-induced cutaneous vasodilation may lead to cardiovascular complications (Holowatz et al. 2010). The probability of heat-related cardiovascular deaths also increases with some pre-existing chronic diseases as discussed above. The larger magnitude of the mortality impacts of hot spells in the elderly is predominantly due to females' increasing vulnerability with age while the impacts in males depend relatively little on age.

For cold spells, on the contrary, relative excess mortality is largest in the middle-aged population (25–59 years), and mechanisms playing the dominant roles in inducing cold-related mortality differ between this age group (in which the effects are unlagged) and older age groups (having significant excess mortality at lags of around 7 days and longer; discussed in detail in Section 2.4.3). The large excess mortality in the middle-aged population is found primarily in males, and differences between mortality in males and females are relatively minor in older age groups. The present dataset does not allow for examining whether the differences between population groups are related to specific CVD diagnoses.

The comparison of the effects of hot and cold spells on cardiovascular mortality suggests that the relative importance of high and low temperature extremes depends on the population group (age and gender). In particular, cold extremes are relatively more harmful in the middle-aged population while warm extremes are in the elderly. For both high and low temperature extremes, preventive measures implemented by means of warning systems and biometeorological forecast alerts should take into account the varied effects in individual population groups. Adequate social services for the elderly, who comprise the most vulnerable population group during hot spells, should be taken into consideration as well.

2.4.3 Possible causes and mechanisms of different cold spell effects in middle-aged and elderly populations

Different mortality impacts of cold spells in the middle-aged population (25–59 years) and other age groups (60+ years) is a finding that deserves more detailed investigation as to possible causes. The relative increases in mortality are larger in middle-aged males than in any other population group, and, in contrast to all other population groups, these effects are unlagged (significant excess mortality on days D+0 and D+1). This suggests that different behavioural and/or physiological mechanisms play dominant roles during cold spells in middle-aged and elderly populations. The larger mortality effects in the middle-aged population contradict most previous studies (e.g. Analitis et al. 2008), but strong cold-related effects in those younger than 65 years have already been reported, for example by Tillett et al. (1983) in the UK and O'Neill et al. (2003) in US cities.

Although indoor temperatures may be an important factor in exposing people to cold stress in winter, too, the relatively direct relationship in middle-aged population with a short lag after cold stress points to the effects of a shorter-term exposure to low outdoor temperatures. (We also note that housing conditions of the population with respect to protecting against cold have been of a relatively good standard over the analysed period, with the large majority of houses being equipped with central heating.) One of the reasons for much more pronounced direct effects of cold weather in middle-aged population relates to the fact that people of productive age usually cannot adapt their daily schedules according to the weather. They cannot avoid being exposed to low ambient temperatures and large temperature contrasts between heated interiors of buildings and outdoor conditions, for example, during morning travel to work when temperatures are usually close to their daily minima. Exposure to cold induces acute physiological responses and may lead to direct cardiovascular stress due to changes in blood pressure, vasoconstriction, and increase in blood viscosity and levels of red blood cell count, plasma cholesterol, and plasma fibrinogen (Keatinge and Donaldson 1995, Stewart et al. 2002). In addition, plasma concentrations of inflammatory markers (fibrinogen and C-reactive protein, predictors of acute coronary syndromes in unstable angina pectoris) are elevated in winter (Woodhouse et al. 1994, Thompson et al. 1995). The rate of physiological response to cold may also depend on untreated cardiovascular risk factors, which probably play a larger role in the middle-aged population than the elderly (in whom medical treatment is more widespread; Andrawes et al. 2005). Untreated hypertension, accompanied by increase in arterial stiffness, blood pressure and inflammatory markers (Kampus et al. 2006), may lead to intracerebral haemorrhage (I61) in cold months (Saloheimo et al. 2009). In the Czech population, the prevalence of hypertension is high (50% in men, 37% in women), and it has decreased significantly only in women over the last two decades. About 30% of hypertensive population are unaware of their condition (Cífková et al. 2010) and are exposed to chronic cardiovascular stress. An ecological study comparing CVD risk factors of Czech, Bavarian and Israeli middle-aged men (Bobák et al. 1999) showed an unfavourable risk profile in Czech men that is related to high blood pressure and elevated levels of fibrinogen, triglycerides and D-dimer, a thromboembolic disease marker reflecting an activation of coagulation and predicting subsequent cardiovascular death (Morange et al. 2006).

Some underlying cardiovascular diseases (such as angina pectoris, I20) may lead to severe deterioration in health conditions after a sudden change of ambient temperature (from heated interior to very cold outdoor conditions) that may ultimately cause myocardial ischemia, acute myocardial infarction and sudden death (Lassvik and Areskog 1979, Hong et al. 2003). The large effects in middle-aged males compared to females may be related to larger prevalence of CVD in middle-aged males (cf. CVD mortality in this age group in Table 2.1) and to gender-specific physiology. Reduced risk of CVD in young and middle-age women is attributable to cardioprotective effects of estrogens, which improve coronary and peripheral endothelial function, inhibit atherosclerosis development, and decrease vascular resistance (Vaccarino et al. 2011). Healthy women have greater cardiac contractility and better preserved myocardial mass than do men at the same age (Mendelsohn and Karas 2005), which may also contribute to better protection of women.

Another factor playing a role is the much larger percentage of males working outdoors and exposed to low temperatures for longer time periods. The hypothesis on the role of occupational exposure is supported by results for the city of Prague where the percentage of people working outdoors is smaller than in other regions and the impacts of cold spells on mortality are lower in the middle-aged population (Plavcová and Kyselý 2009).

Cold weather may also contribute to CVD mortality by reducing access to a hospital or increasing physical activity (e.g. shovelling snow; Medina-Ramón and Schwartz 2007). Overexertion in cold weather may trigger changes in blood pressure that could lead to coronary plaque rupture and subsequent coronary thrombosis (Arntz et al. 2001) as a result of a hypercoagulable state (Morange et al. 2006). Since physical activity is greater in the middle-aged population, this may also contribute to the higher relative excess mortality in middle-aged males than in the elderly.

Finally, the excess deaths associated with direct exposure to cold may partly be those of homeless people who are particularly vulnerable to cold, many of whom are middle-aged males. While official statistics are not available, the numbers of homeless people were relatively small in the Czech Republic compared to western European countries in the beginning of the examined period but started to increase from the 1990s. Statistics for deaths of homeless people are incomplete and available only since 2000; over 2000–2006, they include only 6 deaths on days in which mortality may have been associated with a cold spell (i.e. days D+0 to D+13), of which 4 were due to CVD (and only 3 were males 25–59 years of age). This suggests that deaths of homeless people do not significantly affect the overall statistics of excess CVD mortality over the examined period.

In contrast to the middle-aged population, the impacts of cold spells on the elderly tend to be lagged and they persist for many days after the end of a cold spell. This suggests that cold weather may typically severely worsen cardiovascular health, which may result in death after several days. Compared to young adults, elderly people are more vulnerable to cold due to their reduced cutaneous thermal sensitivity, diminished ability to maintain core temperature, and weakened cold-induced metabolic thermogenesis (Smolander 2002). Age-related increase in central arterial stiffness, coronary atherosclerosis and hypertension together with cold-induced haemoconcentration (elevated plasma fibrinogen and plasma cholesterol levels, high red blood cell count) may result in cardiovascular complications leading to death (Hess et al. 2009, Cheng and Su 2010). Attenuated immunity resulting from winter infectious diseases may also play a role in cold-induced cardiovascular stress and, thus, the impact of cold exposure on cardiovascular health may be indirect. Compared to people of productive age, older people spend more time indoors and can customize their daily schedules to avoid direct cold exposure, which may partly explain why the mortality impacts have different temporal patterns. However, the reason for the much longer lag of cold-related mortality in the elderly is not fully understood and requires further investigation.

2.4.4 Climate change effects on mortality associated with hot and cold spells

The 21-year period analysed is characterized by a warming trend in summer (+0.67°C/decade, significant at the 0.1 level, $p = 0.06$) while there is no clear trend in winter temperatures (which are dominated by decadal-scale variations; cf. Figure 2.2) over the same period. If we assume, however, that both summer and winter temperatures increase in a warmer climate, as projected by climate models for Europe (Buser et al. 2010, Kjellström et al. 2011), this would enhance the characteristics of hot spells while reducing the frequency and severity of cold spells. This may result in increasing heat-related mortality but declining cold-related mortality, and some studies provide arguments that the overall effect would be an increase in mortality (Kalkstein and Greene 1997, McMichael et al. 2003, Koppe 2005, Medina-Ramón and Schwartz 2007, Doyon et al. 2008) while others argue that the declines in cold-related mortality would almost compensate for (Cheng et al. 2004) or even more than offset heat-related increases (Keatinge et al. 2000, Donaldson et al. 2001b, Davis et al. 2004).

The relationships between temperature extremes and associated mortality impacts are non-stationary, as highlighted by numerous recent studies, and observed links cannot be simply extrapolated into the future. Christidis et al. (2010) discuss the crucial role of adaptation, which in the UK prevented a significant increase in heat-related mortality and considerably enhanced a significant decrease in cold-related mortality. On the one hand, it is likely that developed societies are able to mitigate negative impacts of hot spells to some extent, and this effect has probably contributed to decline in heat-related mortality reported in the developed world over the past few decades (e.g. Davis et al. 2002, 2003, Donaldson et al. 2003, Sheridan et al. 2009, DeCastro et al. 2011), including the population under study (Kyselý and Plavcová 2011). On the other hand, this positive tendency may in some regions already have reached its limits, both physiological and technological (Sheridan et al. 2009), and possible future warming, together with the effect of an ageing population that is becoming more vulnerable, may lead to a reversal in the favourable trends. There is also some evidence (e.g. Anderson and Bell 2009) that persistent hot spells are associated with larger effects on mortality than are short-term spells (while no such pattern is found for cold spells, cf. Section 2.3.1), which may further exacerbate heat-related mortality in a warmer climate because such events would probably become more frequent and more severe.

The present study shows that cold spells have on average larger effects on mortality than hot spells, if both types of events are defined in analogous quantile-based terms and the lagged effects of cold weather are captured. In the context of climate change, substantial reductions in cold-related mortality are very likely in mid-latitudinal regions, particularly if societies' increasing adaptability to weather is taken into account (cf. Christidis et al. 2010), and it is probable that the reductions in cold-related mortality will be more important than possible increases in heat-related mortality. This holds true at least in developed countries that have capacities for reducing the negative effects of hot weather conditions by implementing efficient preventive and mitigation measures (including heat-watch warning systems, better standards for urban design and planning, protection of buildings against heat and cold, etc.). On the other hand, since cold-related mortality is greater in warmer than colder European regions and less in regions with larger temperature variability (Analitis et al. 2008), its importance may increase due to the 'adaptation' to milder winters and consequent changes in individuals' behaviour and outdoor clothing (cf. Donaldson et al. 2001a).

In any case, many questions remain open. Further research is needed towards (1) better understanding physiological mechanisms of the links between cold weather and human health, particularly as to the differences between population groups; (2) comparative studies on the effects of hot and cold weather conditions on human health and mortality, which rarely have been carried out in a systematic way; and (3) revealing and understanding non-stationarity of the weather-human health links and the role of long-term adaptation, which may also be substantially distorted by extreme events such as the 2003 heat waves in western Europe and the 2010 heat waves in Russia. One should also keep in mind that climate change may alter seasonality patterns of 'baseline' mortality as well as the spread of infectious diseases (including common respiratory infections), which also might substantially influence the human health effects of cold and hot spells in a possible warmer climate.

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3 Impacts of hot and cold spells differ for acute and chronic ischaemic heart diseases

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Abstract

Background: Many studies have reported associations between temperature extremes and cardiovascular mortality but little has been understood about differences in the effects on acute and chronic diseases. The present study examines hot and cold spell effects on ischaemic heart disease (IHD) mortality in the Czech Republic during 1994–2009, with emphasis upon differences in the effects on acute myocardial infarction (AMI) and chronic IHD.

Methods: We use analogous definitions for hot and cold spells based on quantiles of daily average temperature anomalies, thus allowing for comparison of results for summer hot spells and winter cold spells. Daily mortality data were standardised to account for the long-term trend and the seasonal and weekly cycles. Periods when the data were affected by epidemics of influenza and other acute respiratory infections were removed from the analysis.

Results: Both hot and cold spells were associated with excess IHD mortality. For hot spells, chronic IHD was responsible for most IHD excess deaths in both male and female populations, and the impacts were much more pronounced in the 65+ years age group. The excess mortality from AMI was much lower compared to chronic IHD mortality during hot spells. For cold spells, by contrast, the relative excess IHD mortality was most pronounced in the younger age group (0–64 years), and we found different pattern for chronic IHD and AMI, with larger effects on AMI.

Conclusions: The findings show that while excess deaths due to IHD during hot spells are mainly of persons with chronic diseases whose health had already been compromised, cardiovascular changes induced by cold stress may result in deaths from acute coronary events rather than chronic IHD, and this effect is important also in the younger population. This suggests that the most vulnerable population groups as well as the most affected cardiovascular diseases differ between hot and cold spells, which needs to be taken into account when designing and implementing preventive actions.

Keywords: Epidemiology, Cardiovascular diseases, Mortality, Environment, Climate

3.1 Introduction

Heat waves and high temperature extremes have long been recognised to have serious impacts on human health. Mortality effects of heat waves and high ambient temperatures have been reported in many parts of the world, including North America (Basu and Ostro 2008; Barnett et al. 2012), Europe (Grize et al. 2005; Robine et al. 2008), Asia (Tan et al. 2007; Kyselý and Kim 2009) and Australia (Williams et al. 2012), and identification of population groups most at risk has become an important step towards better understanding effects of projected increasing occurrence of heat waves on human morbidity and mortality (McMichael and Lindgren 2011). Recent studies in Europe have documented heat-related excess deaths both in large cities (D'Ippoliti et al. 2010; Baccini et al. 2011; Rocklöv et al. 2011) and less urbanised regions, e.g. in Spain (deCastro et al. 2011), Germany (Gabriel and Endlicher 2011), and England and Wales (Gasparrini et al. 2012), mostly focusing on all-cause, cardiovascular and respiratory mortality. Increased vulnerability to heat has been found predominantly in the elderly (Grize et al. 2005; Gabriel and Endlicher 2011), in females (deCastro et al. 2011; Kyselý et al. 2011), and in persons with pre-existing diseases (Rey et al. 2007; D'Ippoliti et al. 2010).

Studies regarding the impacts of low temperature extremes on human health have been less numerous (Rocklöv et al. 2011; Barnett et al. 2012), although effects of cold spells on mortality from cardiovascular disease (CVD) may be of at least similar importance as are those of hot spells (Kyselý et al. 2011). In Europe, relationships have been found between cold exposure and organic-cause mortality (Miron et al. 2012), CVD mortality (Huynen et al. 2001; Kyselý et al. 2009; Kyselý et al. 2011; Rocklöv et al. 2011) and ischaemic heart disease (IHD) mortality (McGregor et al. 2004; Barnett et al. 2005; Keatinge et al. 1997). While extreme cold episodes significantly increase mortality, impacts of low temperatures on health are more complex compared to those of heat waves, less direct, and confounded by such other factors as epidemics of influenza and acute respiratory infections (Díaz et al. 2005; Kyselý et al. 2009; Kyselý et al. 2011; Barnett et al. 2012).

Cardiovascular diseases, which comprise the largest proportion of total mortality and morbidity in developed countries (Labarthe 2011), have widely been examined as to their association with excess mortality during high and low temperature extremes (Rey et al. 2007; Rocklöv et al. 2011; Barnett et al. 2012). In most studies dealing with effects of thermal environment on cause-specific mortality, CVD was found to be particularly sensitive in both cold (Huynen et al. 2001; Ma et al. 2013) and hot exposures (Rey et al. 2007; Basu and Ostro 2008). Nevertheless, little attention has been devoted to date as to which particular CVDs are most affected by hot and cold spells. A few examples of such attempts are seen in recent studies by Gasparrini et al. (2012), who specified pulmonary heart disease, heart failure, arrhythmias and atrial fibrillation as possible causes of increased cardiovascular risks in high temperatures, and Bhaskaran et al. (2010), who reported that excess mortality in low temperatures could be due to acute myocardial infarction (AMI).

Ischaemic heart diseases comprise a major part of CVD mortality globally (Labarthe 2011). Despite a substantial decline over the last two decades, IHD remains the leading cause of death in the Czech Republic (Cífková et al. 2010), and it accounted for 43% of all CVD deaths during 1994–2009. Elevated cold-related IHD mortality has been reported in the European population (Keatinge et al. 1997; McGregor et al. 2004), and increased risk for heat-related IHD mortality has been documented in England and Wales (Gasparrini et al. 2012), as well as in California (Basu and Ostro 2008). However, none of the previous studies compared IHD mortality effects of hot and cold spells. Moreover, when analysing hot and cold spell effects on individual IHDs, one may compare the effects on acute fatal events (AMI mortality) and on deaths of those individuals with previous histories of IHD (chronic IHD mortality), which may differ in hot and cold exposures. This may point to physiological mechanisms manifested in heat- and cold-related health outcomes, and hence also to vulnerable population groups. Identification of those population groups would allow for development of better targeted and probably more efficient warning systems that can play an important role in reducing weather-related mortality (Schneider et al. 2008; Ebi 2012).

The present analysis makes use of a recently completed national dataset and complements previous work concerning mortality associated with hot and cold spells in the population of the Czech Republic. Up to now, studies for the Czech population have dealt with all-cause mortality (e.g. Kyselý (2004), Kyselý and Kříž (2008)) or CVD mortality as a whole (Kyselý et al. 2009; Kyselý et al. 2011), because available data did not allow for more detailed analysis by examining individual diagnoses. Data covering the entire population of the Czech Republic since 1994 and including the detailed causes of death for all cases when IHD was cited as the primary cause have recently been released by the Czech Statistical Office and the Institute of Health Information and Statistics of the Czech Republic. This allows for studying individual IHDs and their association with hot and cold spells, a topic which, to our knowledge, has not been addressed in a comparative way (hot vs. cold effects, acute vs. chronic diseases) for any population. Such a study may yield new insight into heat and cold stress effects on cardiovascular health of vulnerable population groups.

3.2 Data and methods

3.2.1 Mortality data

Daily data on IHD mortality in the population of the Czech Republic (totalling 10.5 million as of 2009 and having changed only little since 1994) were collected and processed by the Czech Statistical Office and the Institute of Health Information and Statistics of the Czech Republic. The data cover the period 1994–2009. Each record includes the day of death, age at death, gender, region of residence, and primary cause of death according to the International Classification of Diseases (10th revision, ICD-10; used in the Czech Republic since 1994). The following ICD-10 codes were processed: all ischaemic heart diseases (I20–I25), acute myocardial infarction (I21–I22), and chronic ischaemic heart disease (I25).

Mortality due to IHD comprised 23% of all-cause mortality during 1994–2009 in the Czech Republic. A total of 400,063 deaths from IHD were recorded in the national registry during that period, with AMI (chronic IHD) accounting for 39.6% (59.1%) of those deaths. The remaining 1.3% consisted mainly of deaths from angina pectoris (I20) and other acute IHDs (I24) that are not analysed as separate groups owing to their small sample sizes (Table 3.1). The mortality database and trends in the rates of death from AMI and chronic IHD during 1994–2009 were described in detail in Davídkovová et al. (2013).

3.2.2 Standardisation of mortality data

To remove the effects of long-term changes in mortality (related to demographic, health care, and lifestyle changes) as well as short-term variations due to annual and weekly cycles (Figure 3.1), the daily numbers of deaths must be standardised. Analogously to previous studies (e.g. Kyselý et al. (2011)), series of daily excess mortality were established by calculating deviations of the observed and expected (baseline) mortality for each day of the examined period.

The expected number of deaths $M_0(y,d)$ for year y (y = 1994, ... 2009) and day d (d = 1, ... 365) was set according to

$$M_0(y,d) = M_0(d).W(y,d).Y(y),$$

where $M_0(d)$ denotes the mean daily mortality on day d in a year (computed from the mean annual cycle over 1994–2009, with epidemics of influenza/acute respiratory infections excluded from the data from which the mean annual cycle was determined, with a 7-day lag of mortality after epidemics; cf. Kynčl et al. (2005); Kyselý et al.

(2009)); *W(y,d)* is a correction factor for the observed weekly cycle of mortality, calculated separately for individual days of the week and defined as the ratio of the mean mortality on a given day to the overall mean mortality; and *Y(y)* is a correction factor for the observed year-to-year changes in mortality, defined as the ratio of the number of deaths in year *y* to the mean annual number of deaths during the analysed period. The correction factors for the weekly cycle *W(y,d)* and the year-to-year changes *Y(y)* were calculated over the April–November period when the effects of influenza/acute respiratory infections in the data are negligible.

A similar standardisation procedure (except for that epidemics had not been controlled for) had been used by, for example, Guest et al. (1999), Whitman et al. (1997), and Kyselý (2004).

Table 3.1 Numbers of ischaemic heart disease deaths in the Czech Republic over 1994–2009

	Acute myocardial infarction	Chronic ischaemic heart disease	Angina pectoris	Other acute ischaemic heart diseases	All ischaemic heart diseases
	(I21–I22)	**(I25)**	**(I20)**	**(I24)**	**(I20–25)**
1994	14834	15384	53	412	30683
1995	13772	16057	97	516	30442
1996	12797	14344	74	630	27845
1997	10108	15335	131	552	26126
1998	11697	12058	83	202	24040
1999	11847	12489	72	113	24521
2000	11347	11851	65	121	23384
2001	10665	12069	79	158	22971
2002	9807	12473	80	144	22504
2003	9237	12921	58	69	22285
2004	8083	12809	35	129	21056
2005	7352	15732	48	235	23367
2006	6871	15773	58	250	22952
2007	6667	19276	120	215	26278
2008	6789	18750	70	235	25844
2009	6677	18903	78	107	25765

Primary cause of death is according to the International Classification of Diseases (ICD-10).

3.2.3 Meteorological data

Daily air temperature data were provided by the Czech Hydrometeorological Institute. Mean temperature series were calculated by averaging data from 46 high-quality weather stations covering the area of the Czech Republic. The stations were selected so that they are representative for the area and population under study (the same methodology and the same set of stations was used in Kyselý et al. (2011)). We employed mean daily air temperature as the input variable because it allows for using analogous definitions of hot and cold spells (see below), and because high-quality input variables needed for application of more complex biometeorological indices are available only for a small subset of the stations.

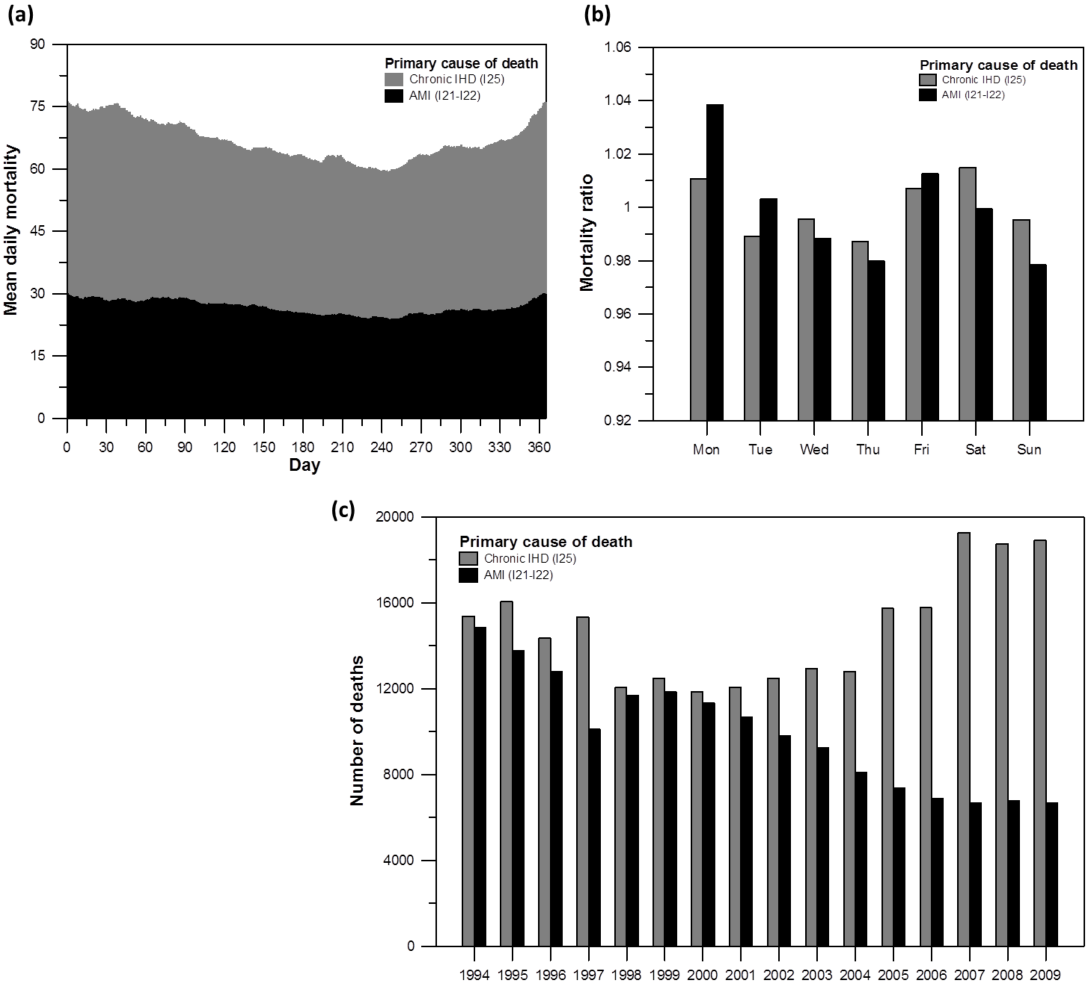


Figure 3.1 Mean annual cycle (a), mean weekly cycle (b) and long-term changes (c) in mortality due to chronic ischaemic heart diseases (chronic IHD) and acute myocardial infarction (AMI) over 1994–2009, for the whole population. The weekly cycle of mortality (b) is expressed by the ratio of the mean mortality on a given day to the overall mean mortality.

3.2.4 Definitions of hot and cold spells

We use analogous definitions of hot and cold spells based on quantiles of the distribution of temperature anomalies as in our previous study for the same population and CVD mortality as a whole (Kyselý et al. 2011). Hot and cold spells were defined as periods of at least two consecutive days with anomalies of average daily temperature from the mean annual cycle above the 90% quantile (below the 10% quantile); the quantiles were set from the empirical distribution of the anomalies over running 61-day periods centred on a given day of the year (Kyselý et al. 2011). The threshold values of average daily temperature corresponding to the given quantiles of anomalies are approximately 23°C (–8°C) in mid-summer (mid-winter) while 20°C (–4°C) in the beginning and end of summer (winter). The 90%/10% quantile was set to delineate hot/cold days in preference to the 95%/5% quantile used in the previous studies (Kyselý et al. 2011; Kyselý and Plavcová 2012), owing to the smaller sample sizes examined (the data were analysed with respect to individual diagnoses) and also due to the shorter time period of 1994–2009 for which the data were available. However, differences between results obtained with the 90%/10% quantile and the 95%/5% quantile are minor (not shown). Hot spells were analysed in summer (June–July–August, JJA) and cold spells in winter (December–January–February, DJF). A total of 35 hot spells and 37 cold spells were identified, and the average length of individual hot (cold) spell was 3.1 (3.8) days.

3.2.5 Methods

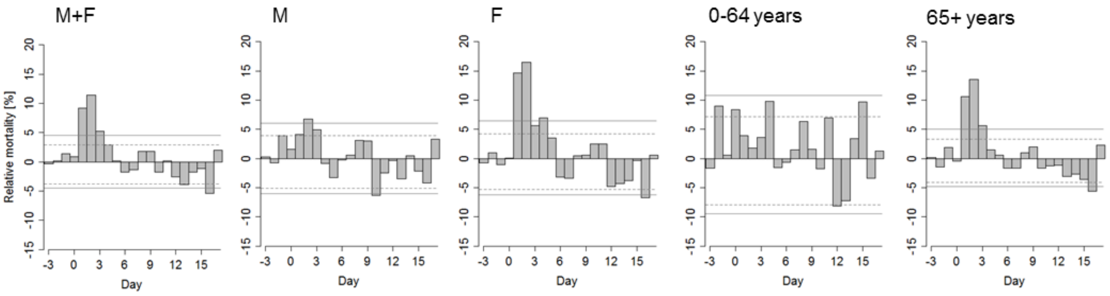
Relative deviations of IHD mortality from the baseline were averaged over all hot/cold spells identified over 1994–2009, in sequences spanning 3 days before (D–3) to 17 days after (D+17) the onset of a hot/cold spell. This 3-week sequence comprises a relatively long period after the end of a hot/cold spell, in order to include possible lagged mortality effects. Statistical significance was evaluated by comparison with the 90% and 95% confidence interval (CI) around the zero line, estimated from the 2.5%, 5%, 95% and 97.5% quantiles of a distribution calculated by the Monte Carlo method. For each population group examined, the same numbers of 21-day sequences as the counts of the hot/cold spells were randomly drawn 10 000 times from the data over 1994–2009 in a given season, and corresponding quantiles were estimated. Periods in which mortality data were affected by epidemics of influenza/acute respiratory infections were excluded from all calculations.

3.3 Results

3.3.1 Effects of hot and cold spells on IHD mortality

Relationships between hot and cold spells and IHD mortality in the whole population, males, females, younger age group (0–64 years) and the elderly (65+ years) are shown in Figure 3.2. Both hot and cold spells were associated with excess IHD mortality, with different magnitude, duration and lag of the effects. For hot spells and the population as a whole, IHD mortality increased markedly from day D+1 to D+4, with peak on D+2. For cold spells, by contrast, the excess IHD mortality was less significant on individual days but persisted for a longer period (up to almost two weeks after cold spell onset; significant on most days D+0 to D+13 in the whole population). We note that excess mortality on days around D+10 for cold spells is due to lagged effects, not direct exposure to cold, as mean temperature anomalies become close to zero around 9 days from the beginning of cold spells (Kyselý et al. 2011).

(a) Hot spells



(b) Cold spells

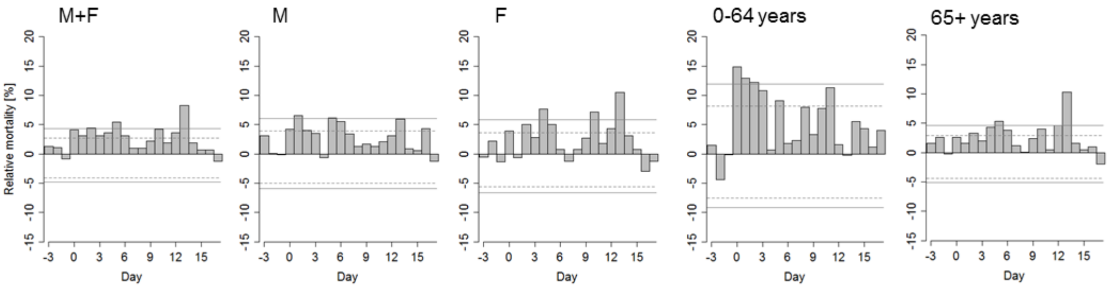


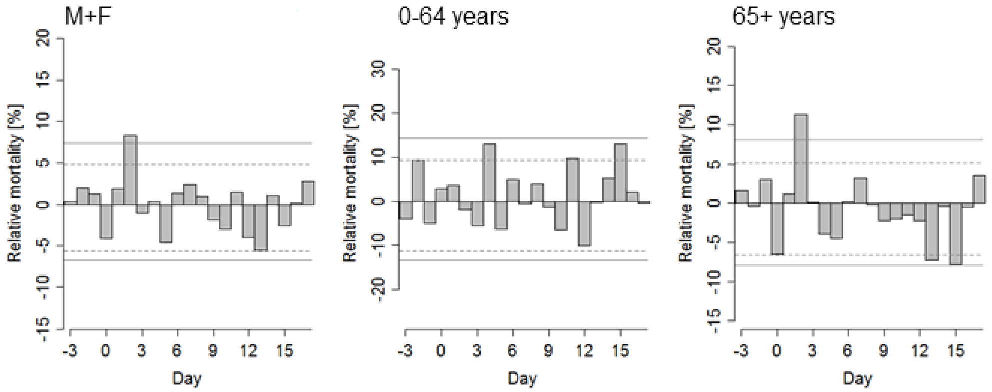
Figure 3.2 Mean relative deviations of ischaemic heart disease mortality for 21-day sequences spanning 3 days before to 17 days after the onset of hot spells (a) and cold spells (b) for the whole population (M+F), males (M), females (F), younger population (0–64 years) and the elderly (65+ years). Solid (dashed) lines denote the 2.5% and 97.5% (5% and 95%) quantiles of deviations obtained by the Monte Carlo method.

Hot and cold spells were linked to excess IHD mortality in both male and female populations. During hot spells, much larger increase in IHD mortality was found for females (more than 15% excess mortality on D+2) compared to males, and in the elderly. The effect of cold spells on IHD mortality was comparable in women and men as to the magnitude of excess mortality, with a tendency towards longer lags in women.
The effects of cold spells on IHD mortality were more direct and more pronounced in the younger age group (0–64 years); on four consecutive days after the onset of a cold spell (from D+0 to D+3), mean relative excess mortality exceeded 10%. By contrast, effects of extreme heat on IHD mortality in this age group were much less pronounced.
We did not find any dependence of the excess IHD mortality on intensity (measured by mean temperature) or duration of a hot/cold spell.

3.3.2 Comparison of impacts of hot and cold spells on AMI and chronic IHD mortality

Effects of hot and cold spells on mortality from AMI and chronic IHD in the population as a whole, the younger age group (0–64 years), and the elderly (65+ years) are shown in Figures 3.3 and 3.4. For hot spells, the patterns for acute and chronic IHD are clearly different (Figure 3.3). Mortality due to chronic IHD increased sharply on the first day after the onset of a hot spell (excess mortality about 15% on D+1) and high excess mortality persisted for 5 days, whereas excess mortality from AMI was significant on a single day only (D+2) and the increase was much lower (excess mortality about 8%) compared to chronic IHD mortality.

(a) AMI



(b) Chronic IHD

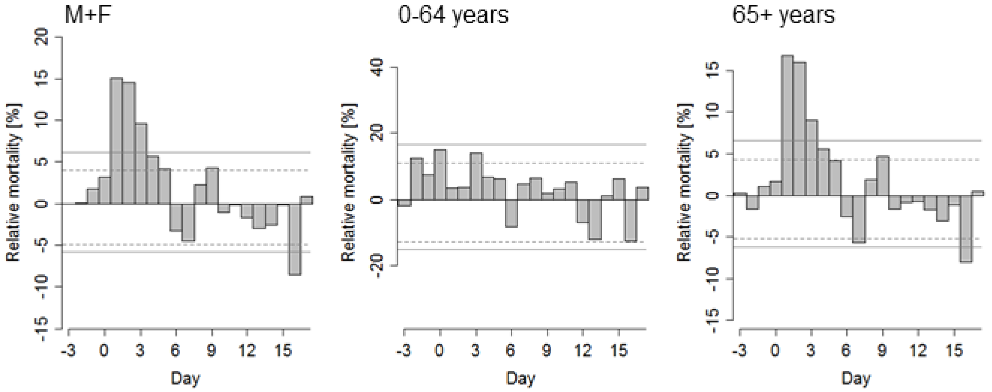
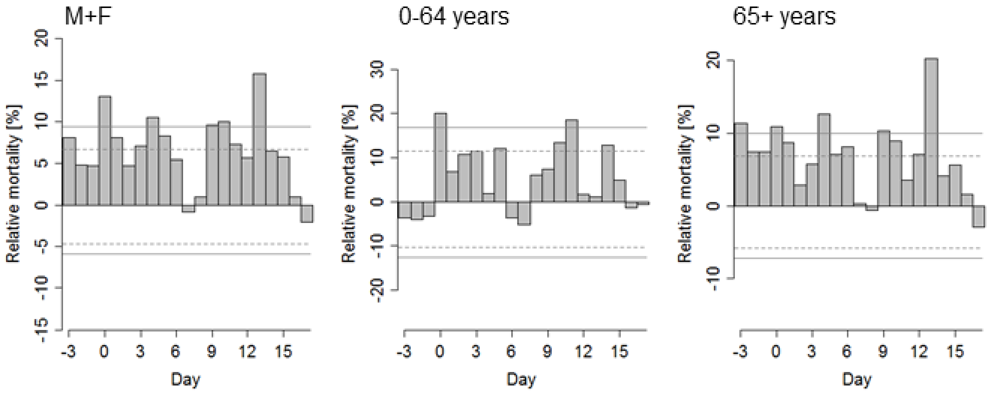


Figure 3.3 Mean relative deviations of mortality for acute myocardial infarction (AMI, a) and chronic ischaemic heart disease (chronic IHD, b) in hot spells. The range of y-axis is adjusted so that the width of confidence bounds is visually the same in all plots. Other details as in Figure 3.2.

In contrast to hot spells, the mortality impacts of cold spells were more pronounced for AMI than chronic IHD (Figure 3.4). The differences between AMI and chronic IHD were manifested mainly in the elderly while they were relatively minor in the younger population. Mortality due to AMI was elevated in both age groups and the effect of cold was immediate (excess mortality of 20% on D+0 in the younger age group), whereas excess chronic IHD mortality was observed predominantly in the younger age group and was more lagged (mortality increased by more than 20% on day D+1). Excess AMI mortality occurring already 3 days before the beginning of a cold spell is probably related to typical weather patterns on days preceding the onset of a cold spell (when temperatures may already be below normal).

(a) AMI



(b) Chronic IHD

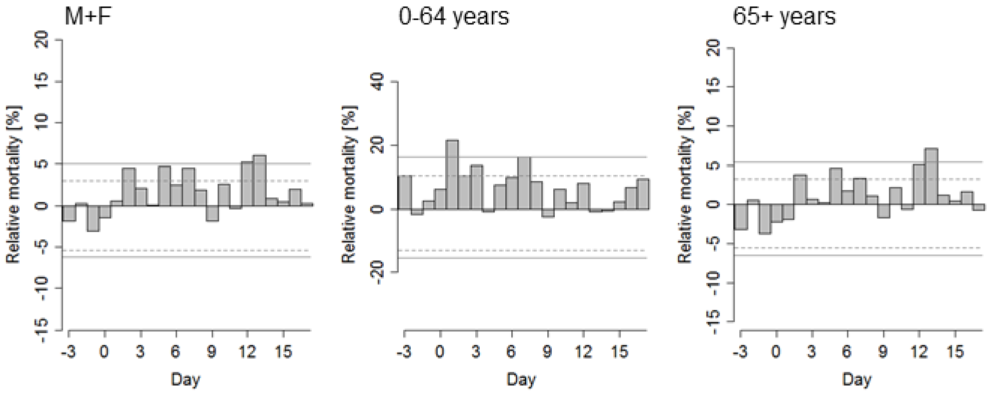


Figure 3.4 Mean relative deviations of mortality for acute myocardial infarction (AMI, a) and chronic ischaemic heart disease (chronic IHD, b) in cold spells. Other details as in Figures 3.2 and 3.3.

To compare the average effects of hot and cold spells on acute and chronic IHD mortality, we computed cumulative excess mortality by summing mean relative excess deaths from D+0 to D+14 for hot and cold spells (Figure 3.5). For hot spells, much larger cumulative excess mortality was observed for chronic IHD compared to AMI in all examined population groups. On the contrary, for cold spells, cumulative excess AMI mortality substantially exceeded IHD mortality in all population groups, except for the younger age group (0–64 years) where the difference was small. Plausible modifications of the periods over which mean cumulative excess mortality is summed for hot and cold spells do not affect this contrasting pattern. These results also suggest that the IHD mortality effects of a cold spell are on average considerably larger than those associated with a hot spell. In the population as a whole, the estimated excess mortality associated with an average hot spell is ~40% of daily mortality while the excess mortality associated with an average cold spell is ~140% of daily mortality

(Figure 3.5). We note that for hot spells, the cumulative excess mortality over days D+0 to D+14 reflects also the mortality displacement effect; however, if mean excess mortality is summed over days D+0 to D+4 only, when mortality deviations are positive (Figure 3.2), the estimate of excess mortality associated with an average hot spell rises only slightly (~50% of daily mortality). Given that the number of hot and cold spells is comparable (see above) and the baseline daily IHD mortality is higher in winter than summer (Figure 3.1), the estimates suggest that cold spells were associated with 3 to 4 times more excess deaths due to IHD compared to hot spells.

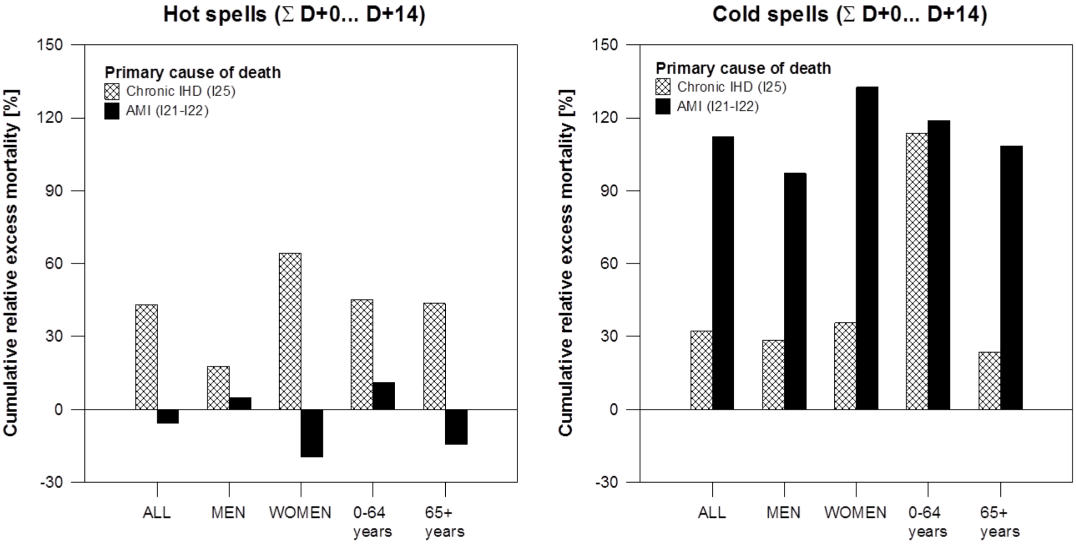


Figure 3.5 Cumulative relative excess mortality (∑D+0… D+14) for acute myocardial infarction (AMI) and chronic ischaemic heart disease (chronic IHD) in hot spells (left) and cold spells (right) in different population groups.

3.4 Discussion

3.4.1 Hot and cold spell effects on IHD mortality

The results show that both hot and cold spells have significant impacts on IHD mortality, but differences were found between genders and age groups. In hot spells, the peak excess IHD mortality was much larger while the duration of the effects of heat on IHD mortality was shorter and concentrated on days with elevated ambient temperatures. Impacts of cold spells on IHD mortality were less pronounced and persisted for a longer period after the end of a cold spell.

With respect to gender, heat-related excess IHD mortality was much larger in women than in men, while excess IHD mortality associated with cold spells was less significant and more lagged in females compared to males. A number of studies have shown that women are more vulnerable to heat than are men (D'Ippoliti et al. 2010; deCastro et al. 2011; Kyselý et al. 2011), while gender-related differences in cold-related mortality are less understood (Morange et al. 2006; Wolf et al. 2009). Greater vulnerability of females to heat is probably related to older mean age and pre-existing chronic diseases, as discussed in detail, for example, by Hajat et al. (2007), Kyselý and Kříž (2008), and Schneider et al. (2008).

For winter cold spells, larger relative excess IHD mortality was observed in the younger age group (0–64 years). In the elderly, effects of cold exposure were more lagged, with the IHD mortality observed to peak several days after the end of a typical cold spell. This finding is consistent with results from the previous study for aggregated CVD mortality showing that low temperature extremes affect cardiovascular health more markedly in the middle-aged population compared to the older age groups (Kyselý et al. 2009).

Several physiological mechanisms could play a role in IHD’s meteorological sensitivity. Exposure to extreme temperatures could induce changes in contractility of veins, blood viscosity and blood pressure, and it may lead to altered blood coagulation (Morange et al. 2006). Consequent changes in heart function may result in myocardial ischemia and could cause acute cardiovascular events such as AMI, particularly in people with pre-existing chronic diseases (Schneider et al. 2008).

3.4.2 Different impacts of hot and cold spells on AMI and chronic IHD mortality and possible physiological mechanisms

Both high and low temperature extremes were linked to excess mortality for AMI and chronic IHD but different patterns were found, thus suggesting different physiological mechanisms playing dominant roles in extreme heat/cold exposures.

3.4.2.1 AMI mortality in hot and cold spells

Significant excess AMI mortality was associated predominantly with low temperatures and persisted up to almost two weeks after the beginning of a cold spell, while the effects of hot spells on AMI mortality were much weaker and significant only on a single day (D+2).

A similar pattern was recently reported in England and Wales by Bhaskaran et al. (2010). They found increasing incidence of non-fatal AMI associated with cold exposure and no risk of AMI associated with heat. Moreover, effects of cold exposure were observed from 2 to 14 days after decrease of temperature (Bhaskaran et al. 2010), which is consistent with our results for Central-European population. A study from Germany also documented lagged effects of low temperatures on non-fatal AMI and more direct effect of cold on fatal AMI (Wolf et al. 2009). An association between low temperature and higher incidence of AMI was recently reported also in the Netherlands (Verberkmoes et al. 2012). These findings suggest that changes in thermoregulation induced by cold ambient temperatures may cause severe deterioration in health, leading to acute coronary events and death in a short time. The elderly population and people with histories of previous IHD have been shown to be most at risk of AMI in the cold (Bhaskaran et al. 2010). Moreover, cold-related cardiovascular symptoms such as arrhythmias and chest pain have been found predominantly in elderly people with pre-existing coronary heart disease or cardiac insufficiency (Nayha et al. 2011). In our study, the effects of cold exposure on AMI mortality were observed in both age groups, and larger excess AMI mortality at the beginning of a cold spell was seen in the younger population than in the elderly. Younger age and higher cholesterol levels have been reported as risk factors for AMI during unusually cold winter in a study from Northern Europe (Wanitschek et al. 2013), documenting an increase in incidence of acute coronary angiographies with a mean temperature decrease of 7.5°C between a warm winter and a cold winter. These findings suggest that cold exposure is a triggering factor for acute cardiac events, with younger people being more vulnerable.

3.4.2.2 Chronic IHD mortality in hot and cold spells

The results further suggest that the presence of chronic IHD increases mortality risk associated with extreme heat more than for extreme cold. During hot spells excess mortality due to chronic IHD was much larger than excess AMI mortality. Women and the elderly population (65+ years) were most at risk of dying from chronic IHD during heat exposure. The findings confirm the previously reported results that excess deaths during hot spells are mainly among people with chronic diseases whose health has been compromised before the hot spell (Rey et al. 2007; D'Ippoliti et al. 2010). The impact of hot weather on cardiovascular health is unlagged and may cause severe deterioration of health leading to death in a short time, especially in those people with chronic CVD. In extreme heat, an increase in blood viscosity and cardiac output followed by hypotension, dehydration and renal failure could result in thromboembolic disease, malignant cardiac arrhythmias and sepsis-like shock leading to death (Flynn et al. 2005; Nawrot et al. 2005).

In cold spells, excess mortality due to chronic IHD was more lagged and less significant. A considerably elevated mortality due to chronic IHD was observed in the younger age group (0–64 years), while in the elderly effects of cold exposure on chronic IHD mortality were insignificant. Exposure to cold may lead to death from acute events rather than from chronic IHD in the elderly. Cold stress could trigger symptoms of angina pectoris, cardiac arrhythmias and chest pain in stable IHD (Nayha et al. 2011), caused by such cold-related changes as vasoconstriction and/or increases in blood pressure, blood viscosity, red blood cell counts and plasma cholesterol (De Lorenzo et al. 1999). Together with heightened haemoconcentration and elevated coagulation potential, these changes could lead to thrombosis and plaque rupture resulting in acute coronary event (Nagelkirk et al. 2012). Therefore, the risk of acute ischaemic event is increased in the cold, particularly in people with pre-existing IHD.

3.4.3 Mortality displacement effect

The results also show declines in mortality after hot spells, while similar effect was not observed for cold spells (Figure 3.2). The fact that the overall mortality impacts of hot spells are reduced due to a displacement effect has been documented in many studies (e.g. Kyselý (2004); Baccini et al. (2008); Baccini et al. (2013); Zaninović and Matzarakis (2014)); the peak of heat-related deaths is followed by a period of up to 3 weeks with negative deviations of mortality. In the present study, the harvesting effect of individual hot spells was not considered and all spells identified according to the given definition were involved in the analysis. The short-term mortality displacement, observed after the peak in heat-related deaths (Figure 3.2), points to the presence of very susceptible persons for which the heat exposure precipitates death. The results further showed that despite the presence of harvesting, excess mortality for chronic IHD was found in all examined population groups when considering the period of two weeks after a hot spell as a whole (Figure 3.5).

3.4.4 Limitations of the study

We note that data based on death certificates may contain non-negligible levels of noise, and this may be the case especially for IHD for which it is often difficult to discern between AMI and chronic IHD as the primary cause of death. It is plausible that many deaths from AMI, especially among older persons who die out of hospital, are coded as chronic IHD while deaths from AMI occur in persons who already had pre-existing IHD. This is a limitation for any study of IHD mortality based on death certificates. However, the autopsy rate in the Czech Republic is among the highest in Europe and changed little over the study period (from 34% in 1994 to 29% in 2009, Davídkovová et al. (2013)), which suggests that the quality of the national mortality register data is at least comparable to western-European countries. While negative or insignificant results (as to differences between effects of temperature extremes on acute and chronic IHD) would not necessarily mean that the effects do not exist (they may be masked by the noise), the observed clear pattern of differences between hot and cold spell effects on acute and chronic IHD – found in spite of the data limitations – cannot be interpreted as an artefact due to possible errors in death certificates. Different impacts of temperature extremes on acute and chronic CVD have been found also for the UK population (Bhaskaran et al. 2010; Gasparrini et al. 2012), and studies for other regions with available data are needed.

Effects of the air pollution on mortality were not controlled for since the analysis was carried out for a population majority of which lives in cities with less than 50 000 inhabitants or in a rural environment, while only a small portion (21%) in large cities with more than 100,000 inhabitants (Czech Statistical Office 2008). This also makes the analysis different from the majority of other studies on heat-related mortality, which usually deal with urban populations. We do not suggest that the effects of air pollution are negligible in a population with a relatively small level of urbanization; however, it is difficult to collect high-quality and homogeneous air pollution data that may be representative for such population living in very diverse environments. While ambient temperature anomalies are usually similar for distances of many dozens or even hundreds km, air pollution data – due to local effects such as heating, transportation, local industrial and agricultural activities, etc. – may not be representative for distances exceeding few hundred meters. Focusing on urban population only (the city of Prague) would decrease the size of the mortality data samples by an order of magnitude, and hence lessen the significance of results. Anyway, the issue of regional differences in the effects of hot and cold spells, which may be related to environmental as well as socio-economic factors, is an important topic attracting growing interest worldwide and also subject of ongoing research in Central Europe (Gabriel and Endlicher 2011, Urban et al. 2014).

3.5 Conclusions

The results yield new insight into links between temperature extremes and mortality due to acute and chronic forms of IHD. We show that both hot and cold spells were associated with excess IHD mortality in the Czech Republic, but the most affected population groups differed and the excess mortality was due to different prevailing health outcomes for heat and cold. In hot spells, increases in IHD mortality were most pronounced in the elderly (65+ years) and in females, while in cold spells, significant excess IHD mortality was found also in the younger age group (0–64 years). For summer hot spells, the largest excess mortality was related to chronic IHD while the increase in mortality from AMI was much smaller. For winter cold spells, by contrast, impacts were observed mainly for AMI mortality.

Different patterns in the mortality effects of hot and cold spells observed for AMI and chronic IHD suggest several different mechanisms involved in physiological processes leading to excess deaths. Prolonged exposure to heat stress may result in thermoregulatory failure followed by heat-related disorders (such as hyperthermia, dehydration, hypotension, heat exhaustion and consequent renal failure) leading to cardiovascular complications resulting in death, and mainly in those individuals with pre-existing IHD. On the other hand, cold-related deaths are associated predominantly with acute cardiac events, irrespective of age group and gender, most probably due to changes in blood coagulation that result in thrombosis during cold stress. Better understanding of those risk factors and physiological mechanisms playing roles in the development of cardiovascular problems in extreme temperatures could help identify individuals most at risk and better focus preventive actions, including biometeorological forecast and alerts.

The results of studies on temperature–mortality relationships are difficult to compare due to differences in study designs, characteristics of datasets and methodology, including definitions of hot and cold spells and how possible confounding effects (such as epidemics of influenza/acute respiratory infections) are addressed. This underlies the need for further comparative studies dealing with the effects of both hot and cold spells on cause-specific mortality in different countries and climates that are directed to improving prevention strategies for reducing the mortality risk in extreme temperatures. Nevertheless, in spite of differences in study designs and methods, the emerging pattern of different impacts of temperature extremes on acute and chronic cardiovascular diseases has been found for populations living in different climatic and socio-economic conditions (the UK, Central Europe).

Rising mean summer temperatures are very likely to lead to an increase in the frequency, duration and severity of heat waves in future (Ballester et al. 2010; Kyselý 2010), and, even in a warming climate, intensity and duration of extreme cold events may persist into the late 21st century (Kodra et al. 2011). This suggests that both heat waves and cold spells will represent major public health concerns, with impacts probably exacerbated due to the population’s ageing and increasing level of urbanisation. Better understanding of the observed heat- and cold-related effects on cardiovascular health is an essential step towards understanding how climate change may modify these effects, and, as an ultimate goal, towards designing and implementing efficient measures to reduce the negative consequences on public health of both types of extremes.

Abbreviations

IHD: Ischaemic heart disease; AMI: Acute myocardial infarction; CVD: Cardiovascular disease

Competing interests

The authors declare that they have no competing interests.

Authors’ contributions

HD and JKys participated in the design of the study and wrote the manuscript. HD researched the data and drafted the manuscript. EP was responsible for most statistical analyses. All authors participated in interpretation of the data and reviewed/edited the manuscript. All authors read and approved the final version of the manuscript.

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4 Contrasting patterns of hot spell effects on morbidity and mortality for cardiovascular diseases in the Czech Republic, 1994–2009

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Abstract

The study examines effects of hot spells on cardiovascular disease (CVD) morbidity and mortality in the population of the Czech Republic, with emphasis on differences between ischaemic heart disease (IHD) and cerebrovascular disease (CD) and between morbidity and mortality. Daily data on CVD morbidity (hospital admissions) and mortality over 1994–2009 were obtained from national hospitalisation and mortality registers and standardised to account for long-term changes as well as seasonal and weekly cycles. Hot spells were defined as periods of at least two consecutive days with average daily air temperature anomalies above the 95% quantile during June to August. Relative deviations of mortality and morbidity from the baseline were evaluated.

Hot spells were associated with excess mortality for all examined cardiovascular causes (CVD, IHD and CD). The increases were more pronounced for CD than IHD mortality in most population groups, mainly in males. In the younger population (0–64 years), however, significant excess mortality was observed for IHD while there was no excess mortality for CD. A short-term displacement effect was found to be much larger for mortality due to CD than IHD. Excess CVD mortality was not accompanied by increases in hospital admissions and below-expected-levels of morbidity prevailed during hot spells, particularly for IHD in the elderly. This suggests that out-of-hospital deaths represent a major part of excess CVD mortality during heat and that for in-hospital excess deaths CVD is a masked comorbid condition rather than the primary diagnosis responsible for hospitalisation.

Keywords: Hot spells, Cardiovascular disease, Cerebrovascular disease, Ischaemic heart disease, Mortality, Morbidity, Central Europe

4.1 Introduction

Elevated mortality associated with high temperature extremes in summer is well documented globally. Increases in mortality due to cardiovascular disease (CVD) during hot spells have been reported in North America (Davis et al. 2003; O'Neill et al. 2003; Medina-Ramón et al. 2006), Asia (Burkart et al. 2014; Wang et al. 2014), Australia (Williams et al. 2012) and in many European countries (Hajat et al. 2007; Kyselý and Kříž 2008; Stafoggia et al. 2008; Schifano et al. 2009; D'Ippoliti et al. 2010; Gasparrini et al. 2012; Monteiro et al. 2013a; Zaninović and Matzarakis 2014; Zacharias et al. 2014). Much less is known about which particular cardiovascular disorders are most influenced by hot spells and whether similar patterns occur for morbidity (Åström et al. 2011). Increases in hospital admissions and emergency department visits during extreme heat are mostly attributed to dehydration, hyperthermia, renal failure, ischaemic stroke, heat stroke, diabetes, and fluid and electrolyte imbalances (Mastrangelo et al. 2007; Josseran et al. 2009; Knowlton et al. 2009; Khalaj et al. 2010).

The association of hot spells and hospitalisation due to CVD is less understood, and past findings are contradictory. While any association between hot spells and hospital admissions for CVD was found to be weak or non-existent in many studies in Europe (Kovats et al. 2004; Linares and Díaz 2008; Mastrangelo et al. 2007; Michelozzi et al. 2009; Monteiro et al. 2013a), North America (Knowlton et al. 2009; Li et al. 2012; Bustinza et al. 2013) and Australia (Williams et al. 2012), CVD admissions were shown to be important in heat-related morbidity by Schwartz et al. (2004) and Lin et al. (2009) in the US, Bayentin et al. (2010) in Canada and Nitschke et al. (2007) in Australia (namely regarding hospitalisation for ischaemic heart disease [IHD]). Hospital admissions for acute myocardial infarction (AMI), a component of IHD, were observed to be elevated when ambient temperature exceeded a specific threshold in Australia (Loughnan et al. 2010), but overall, the majority of studies regarding the effects of heat on AMI/IHD have found small or no associations between high temperatures and AMI/IHD admissions (Green et al. 2010; Verberkmoes et al. 2012; Monteiro et al. 2013b; Zacharias et al. 2014). An increase in cerebrovascular disease (CD) admissions was attributed rather to temperature variations than to absolute temperature (Kyobutungi et al. 2005; Wang et al. 2009).

Various geographical locations and climates, populations with different degrees of adaptability to heat stress, as well as differences in study designs, characteristics of databases and methodology may contribute to the inconsistency in conclusions among studies regarding heat-related morbidity. This emphasizes the importance of comparative analyses on heat-related mortality and morbidity. To our knowledge, this is the first study comparing CVD mortality and morbidity impacts of hot spells in the region of Central Europe using national data registers. Previous studies on heat-related cardiovascular mortality in the population of the Czech Republic were either based on aggregated data that did not allow for a stratified analysis by individual cardiovascular disorders (Kyselý et al. 2011; Kyselý and Plavcová 2012) or focused on differences between urban and rural areas (Urban et al. 2014) and thus represented relatively small parts of the Czech population. The most recent study compared IHD mortality impacts of hot and cold spells, focusing on differences between acute and chronic IHDs (Davídkovová et al. 2014).

The main aim of this paper is to compare effects of hot spells on mortality and morbidity (hospital admissions) for CVD in the Czech population between 1994 and 2009, with emphasis on possible differences between cerebrovascular and ischaemic heart diseases.

4.2 Data and methods

4.2.1 Mortality data

Daily mortality data were collected and processed by the Czech Statistical Office. The primary cause of death was established according to the death certificate. The dataset was then transferred to the Institute of Health Information and Statistics (IHIS), where the data were checked and compiled. The database covers all deaths in the Czech Republic between 1994 and 2009 listing CVD as the primary cause, altogether 930,659 records. Each record includes the date of death, age at death and gender. The primary cause of death was determined according to the International Classification of Diseases, version 10 (ICD-10), adopted in the Czech Republic since 1994. Deaths from CVD comprised 53.1% of national all-cause mortality during 1994–2009.

The ICD-10 codes used for the analysis were those for all CVD (I00–I99), ischaemic heart disease (IHD, I20–I25), and cerebrovascular disease (CD, I60–I69). IHD and CD deaths accounted for 43.0% and 26.8% of CVD mortality, respectively.

4.2.2 Morbidity data

Data on morbidity were obtained from the National Registry of Hospitalized Patients, administered by IHIS. The database consists of all admissions of residents to any hospital in the Czech Republic between 1994 and 2009 having CVD as a condition most responsible for a patient’s hospitalisation. Each record includes patient demographic information (age, gender), date of admission and primary diagnosis according to ICD-

10 (coded on discharge from hospital). Over the 16-year period, a total of 5,409,407 admissions for CVD were recorded, with IHD and CD admissions, respectively, accounting for 31.6% and 18.1% of CVD hospitalisations. Registration of all discharged patients into the National Registry of Hospitalized Patients is mandatory, and the data are coded by physicians. As each hospitalisation was recorded at discharge, the incomplete data at the end of 2009 were supplemented using discharges recorded in 2010 so that the examined period of 1994–2009 is covered fully.

The database on mortality/morbidity and trends in the rates of death/hospital admission due to CVD, IHD and CD during 1994–2009 are described in detail in Davídkovová et al. (2013).

4.2.3 Standardisation of mortality and morbidity data

We applied an indirect standardisation method similar to that used for mortality data (e.g. Whitman et al. (1997), Smoyer et al. (2000) and Kyselý (2004)). Daily counts of deaths and hospital admissions were standardised to account for long-term changes (reflecting socio-economic, health care and lifestyle changes) and short-term variations related to annual and weekly cycles. These confounding factors are much more pronounced in morbidity compared to mortality data (showing a strong seasonal pattern with wintertime excess morbidity compared to lower morbidity rates in summer, along with lower numbers of admissions on weekends than during the week; Figure 4.1). A series of daily excess mortality/morbidity was established separately for the population as a whole, the elderly (65+ years), males and females by calculating deviations of the observed and expected (baseline) mortality/morbidity for each day of the examined period.

The expected number of deaths/hospital admissions $M_0(y,d)$ for year y (y = 1994, ... 2009) and day d (d = 1, ... 365) was set according to

$$M_0(y,d) = M_0(d).W(y,d).Y(y),$$

where $M_0(d)$ denotes the mean daily mortality/morbidity on day d in a year (computed from the mean annual cycle over 1994–2009). $W(y,d)$ is a correction factor for the observed weekly cycle of mortality/morbidity, calculated separately for individual days of the week and defined as the ratio of the mean mortality/morbidity on a given day to the overall mean mortality/morbidity, and $Y(y)$ is a correction factor for the observed year-to-year changes in mortality/morbidity, defined as the ratio of the number of deaths/hospital admissions in year y to the mean annual number of deaths/hospital admissions during the analysed period. The correction factors for the year-to-year changes $Y(y)$ and weekly cycle $W(y,d)$ were calculated over April–November, which is the period when the effects of influenza and acute respiratory infections are negligible (Kynčl et al. 2005; Kyselý et al. 2009). Before calculating the correction factor for the weekly cycle $W(y,d)$, all public holidays had been excluded.

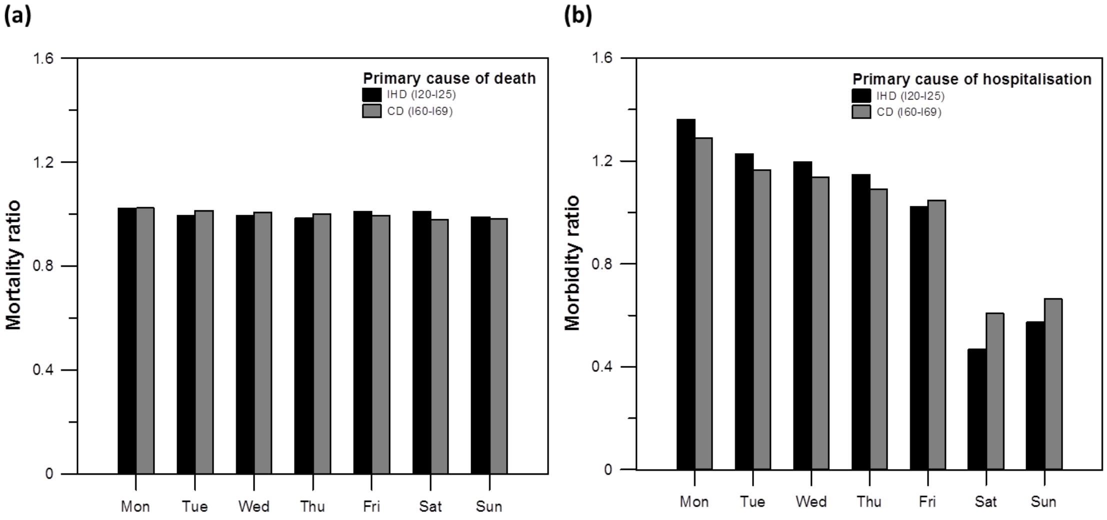


Figure 4.1 Mean weekly cycle in mortality (a) and morbidity (hospital admissions, b) due to ischaemic heart disease (IHD) and cerebrovascular disease (CD) over 1994–2009 for the population as a whole. The weekly cycle is expressed by the ratio of the mean mortality or morbidity on a given day to the overall mean mortality or morbidity

4.2.4 Meteorological data

Daily air temperature data were provided by the Czech Hydrometeorological Institute. A mean air temperature series was calculated by averaging data from 46 high-quality weather stations covering the area of the Czech Republic. The stations were selected so that they are representative for the area and population under study, and the set of stations was the same as that in Kyselý et al. (2011). We employ air temperature as the simplest proxy for ambient thermal conditions because it allows for using data from a high-density station network and recent studies have found no significant differences between air temperature and biometeorological indices in characterizing effects of heat on mortality (Burkart et al. 2011; Vaneckova et al. 2011; Urban and Kyselý 2014).

4.2.5 Definition of hot spells

The definition of hot spells is the same as that used previously in Kyselý et al. (2011). A hot spell was defined as a period of at least two consecutive days with anomalies of average daily temperature (from the mean annual cycle) above the 95% quantile. The quantile was set from the empirical distribution of the anomalies over running 61-day periods centred on a given day of the year. A total of 18 hot spells were identified in summer (June–August) between 1994 and 2009, with an average length of about 2.7 days. Daily mean temperature anomalies on days D–3 (3 days before a hot spell onset) up to D+20 (20 days after) averaged over all hot spells during 1994–2009 are shown in Figure 4.2.

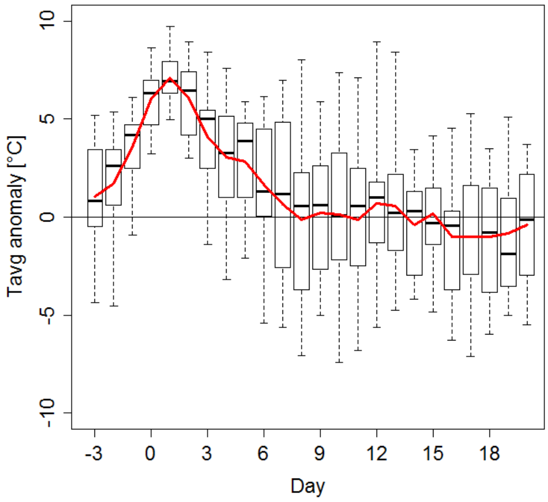


Figure 4.2 Daily mean temperature anomalies on days D–3 (3 days before a hot spell's onset) up to D+20 (20 days thereafter) averaged for all hot spells occurring over 1994–2009. In the box plots, the horizontal bold black line denotes the median, the boxes denote the interquartile range, and the top and bottom whiskers denote maximum and minimum values

4.2.6 Methods

Relative deviations of CVD, IHD and CD mortality/morbidity from the baseline on days D–3 up to D+20 were averaged over all hot spells. Statistical significance of these mean relative deviations was evaluated by comparison with the 90% and 95% confidence bounds around the zero line, estimated from the 2.5%, 5%, 95% and 97.5% quantiles of a distribution calculated by the Monte Carlo method (cf. Plavcová and Kyselý 2010).

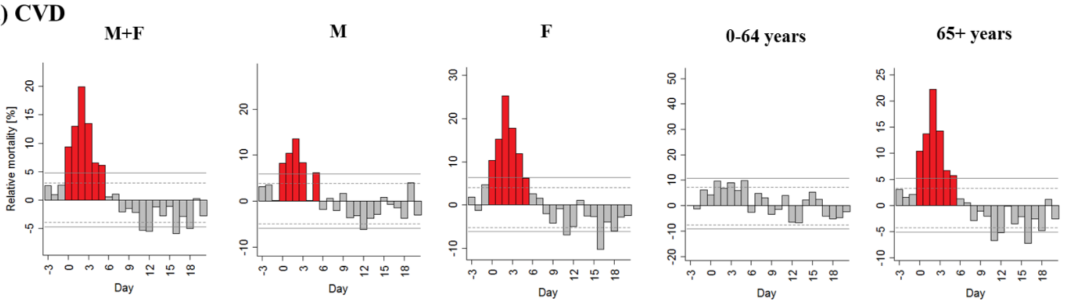
4.3 Results

The impacts of hot spells on mortality/hospital admissions due to CVD, IHD and CD for the whole population, males, females, younger age group (0–64 years) and the elderly (65+ years) are presented in Figures 4.3 and 4.4, respectively, in terms of averages for days D–3 to D+20 over the sample of 18 hot spells. Table 4.1 presents mean cumulative effects of hot spells on CVD, IHD and CD mortality and hospital admissions.

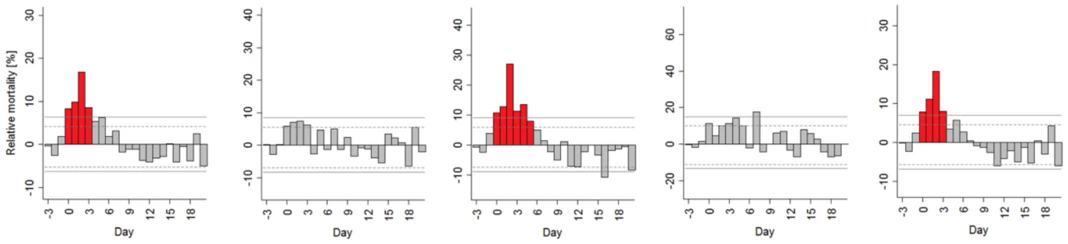
4.3.1 Mortality effects of hot spells

We found that hot spells were associated with significant excess mortality in all examined cardiovascular events and population groups, except for CD mortality in the younger population (Table 4.1). For the population as a whole, increase in CVD, IHD and CD mortality was observed during the first 6 days (D+0 to D+5) after onset of a hot spell and thereafter it decreased below expected levels (Figure 4.3). The increase in mortality was highest on days D+1 to D+3, with a peak on day D+2 for CVD (+20% excess mortality), IHD (+17% excess mortality), as well as CD (+22% excess mortality).

(a) CVD



(b) IHD



(c) CD

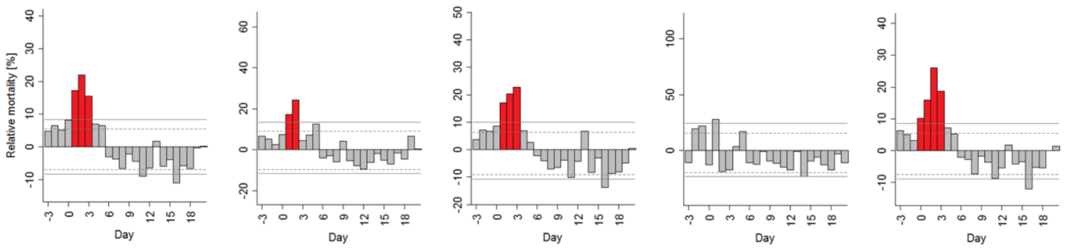
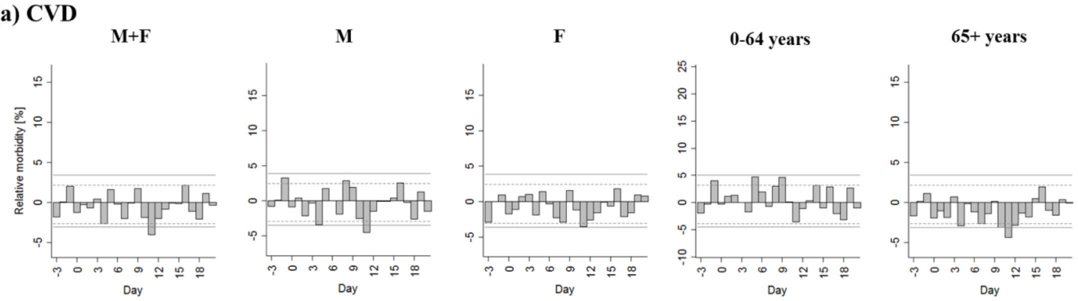


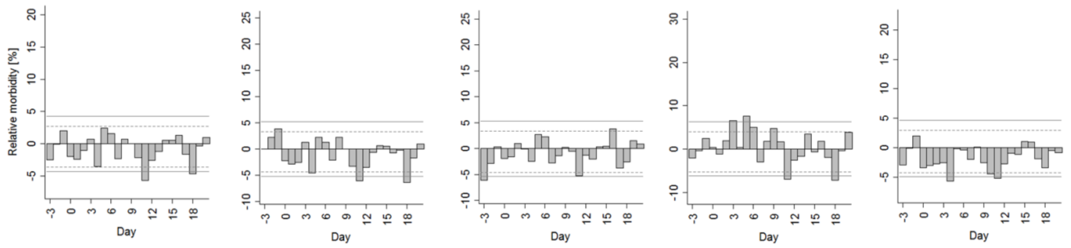
Figure 4.3 Mean relative deviations of cardiovascular disease (a), ischaemic heart disease (b) and cerebrovascular disease (c) mortality for 24-day sequences D–3 to D+20 for hot spells, across the whole population (M+F) and for males (M), females (F), younger age group (0–64 years) and elderly (65+ years). Solid (dashed) lines denote the 2.5% and 97.5% (5% and 95%) quantiles of deviations obtained by the Monte Carlo method. Sequences of days in which the deviations exceed the 97.5% quantile are highlighted in red. The range of y-axes is adjusted so that the width of the confidence bounds around zero is visually the same in all plots.

Higher excess mortality was observed for CD compared to IHD, except in the younger population (Table 4.1). The effects of hot spells on CD tended to be more lagged compared to IHD, and deaths from CD occurred more frequently on the second and third days after the onset of a hot spell (Figure 4.3). Females were more affected by heat-related cardiovascular disorders than males, as seen in higher relative excess mortality as well as higher numbers of excess deaths, and this holds true for both IHD and CD (Table 4.1). However, the gender-related difference was much more pronounced in IHD (significant excess deaths due to IHD on days D+0 to D+5 in women, compared to smaller excesses in men), while for CD the differences between females and males were relatively small.

(a) CVD



(b) IHD



(c) CD

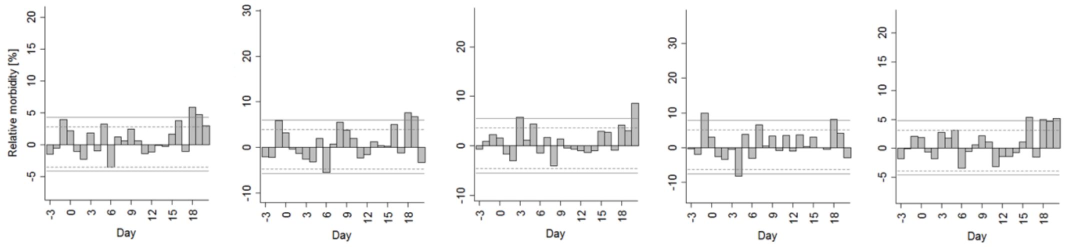


Figure 4.4 Same as in Figure 4.3 but for morbidity (hospital admissions).

4.3.2 Hospital admissions and hot spells

In contrast to heat-related mortality, excess morbidity for CVD, IHD and CD in association with hot spells was weak and mostly insignificant (Figure 4.4). A small significant increase in hospital admissions for CD was observed 1 day before the beginning of a hot spell (D–1) in males (excess CD morbidity around 6%) and in the younger age group (excess CD morbidity around 10%, Figure 4.4). This might be related to above-average temperatures (which typically occur already on day D–1, Figure 4.2) and large positive day-to-day temperature changes. Particularly interesting is that the onset of a hot spell was followed by a period of admissions for IHD that was below the expected level in the elderly (Table 4.1). This effect is further discussed in Section 4.4.

Table 4.1 Cumulative excess mortality and morbidity due to CVD, IHD and CD averaged over hot spells for individual population groups in the Czech Republic, 1994–2009

		Males and females				Males				Females				0–64 years				65+ years			
				%				%				%				%				%	
Mortality	CVD	103.7	*	68.5	*	32.2	*	46.8	*	71.5	*	86.8	*	9.9	*	45.3	*	94.7	*	73.2	*
	IHD	35.4	*	54.8	*	9.4	*	28.4	*	26.3	*	83.3	*	7.0	*	61.8	*	29.0	*	54.5	*
	CD	32.7	*	76.3	*	12.3	*	72.8	*	20.2	*	78.2	*	0.0		–0.9		32.3	*	83.2	*
Hospital admissions	CVD	–24.8		–2.9		–19.3		–4.4		–6.2		–1.5		16.0		5.1		–38.8		–7.2	
	IHD	–17.2		–5.9		–14.3		–8.8		–3.1		–2.4		16.3		15.8		–33.3	**	–17.5	**
	CD	5.1		3.1		–1.7		–2.2		7.1		8.2		–3.4		–7.7		8.5		7.0	

Cumulative excess mortality / morbidity was calculated by summing excess deaths / hospital admissions on days from D+0 to D+5 for all hot spells over 1994–2009, and the values were averaged over hot spells. Columns labelled % denote mean relative cumulative excess mortality / morbidity (with respect to the baseline). * (**) denote mean cumulative excess mortality / morbidity above the 97.5% quantile (below the 2.5% quantile) of a distribution calculated by the Monte Carlo method. CVD, cardiovascular disease; IHD, ischaemic heart disease; CD, cerebrovascular disease

4.3.3 Mean cumulative effects of hot spells on mortality and hospital admissions

To compare the average effects of hot spells on mortality and hospital admissions due to CVD, IHD and CD, we calculated (relative) cumulative excess mortality and morbidity for days D+0 to D+5 and averaged them over all hot spells in 1994–2009 (Table 4.1). Overall, much larger relative cumulative excess mortality was found for CD (+76%, with respect to mean daily baseline) compared to IHD (+55%). The difference between CD and IHD was observed predominantly in males, for which the relative cumulative excess mortality due to CD and IHD was 73% and 28%, respectively, while in the female population the cumulative excess mortality was similar for CD (+78%) and IHD (83%, Table 4.1). It is also interesting to note that the mean cumulative effects of hot spells on IHD expressed in terms of relative excess mortality were comparable in the younger population (+62%) and the elderly (+55%), while for CD a large significant increase (+83%) was found only in the elderly.

In terms of the absolute number of excess deaths, the cumulative effects of hot spells on mortality due to IHD and CD were comparable (35 and 33 excess deaths per hot spell for IHD and CD, respectively; Table 4.1). Considering the number of hot spells, this leads to around 600 excess deaths due to both IHD and CD associated with hot spells over 1994–2009. Another third of excess CVD mortality was primarily due to diseases other than IHD and CD (Table 4.1), and the estimated total burden of excess CVD deaths in the Czech population associated with hot spells reached almost 1900 over 1994–2009. However, this is partly offset by the mortality displacement effect (see Section 4.4.4).

Cumulative effects of hot spells on CVD, IHD and CD morbidity were mostly negligible. An inverse relationship was found between hot spells and hospital admissions for IHD, with a significant decline in morbidity in the elderly (65+ years; relative cumulative deficit of IHD morbidity was –17.5%).

4.4 Discussion

4.4.1 Contrasting pattern of hot spell effects on CVD mortality and hospital admissions

Heat-related excess mortality – found across age groups and genders for all cardiovascular causes examined – was not accompanied by increases in hospital admissions for CVD in the population of the Czech Republic. This fact is in agreement with recent epidemiological studies comparing CVD mortality and morbidity during hot spells across Europe (Kovats et al. (2004) in London, UK; Linares and Díaz (2008) in Madrid, Spain; Michelozzi et al. (2009) in 12 European cities; and Monteiro et al. (2013a) in Porto, Portugal) and in Québec, Canada (Bustinza et al. 2013), in which observed increases in mortality were not associated with comparable increases in hospitalisation.

A possible explanation is in the hypothesis that during hot spells people die rapidly from cardiovascular causes before reaching hospital or receiving medical attention (Kovats et al. 2004; Linares and Díaz 2008; Michelozzi et al. 2009). Out-of-hospital deaths account for a substantial part of heat-related mortality (O’Neill et al. 2003; Kovats et al. 2004; Medina-Ramón et al. 2006), and CVD is associated with an increased risk of death outside a hospital during extreme heat (Medina-Ramón et al. 2006). In such cases, heat stress causes severe deterioration of cardiovascular health and leads to death in a short time. This hypothesis is supported by a French study reporting increased risk of out-of-hospital sudden cardiac death in people with heart disease during the 2003 heat wave (Empana et al. 2009). Among cardiovascular disorders, atrial fibrillation as a comorbid condition and heart failure as the main cause of hospitalisation have been closely linked to heat-related deaths (Medina-Ramón et al. 2006; Stafoggia et al. 2008).

An alternative explanation for the fact that high ambient temperatures do not increase hospital admissions for CVD could be the inclusion only of primary discharge diagnosis in the analysis (cf. Michelozzi et al. 2009). A different approach would be to consider secondary diagnoses, accounting for comorbid conditions and health complications accompanying the main disease responsible for hospitalisation. Semenza et al. (1999) showed that CVD was a masked comorbid condition when secondary diagnoses were taken into account. Diseases of the circulatory system (mainly cardiac diseases) as underlying conditions in heat-related morbidity were also reported by Schifano et al. (2009) and Khalaj et al. (2010), who noted increased risk of hospital admission for those older than 65 years. This could partially explain the observed patterns for morbidity, since only the main diagnosis responsible for a patient’s hospitalisation was included into the analysis.

In our study, morbidity was expressed by hospital admissions. The most recent studies have shown that significant increases in heat-related morbidity for cardiovascular disorders occurred when emergency department visits were taken into account (Knowlton et al. 2009; Williams et al. 2012). Lower severity and more acute state of emergency in comparison to hospital admission may better reflect the impact of heat stress on health, which could be therefore captured earlier (Ye et al. 2012). Data on emergency department visits in the Czech Republic were not available, and therefore we were not able to cover individuals affected by heat and to evaluate heat-related CVD morbidity from this point of view.

4.4.2 Different effects of hot spells on ischaemic heart disease and cerebrovascular disease

The findings of our study indicate that in addition to IHD mortality, cerebrovascular deaths represent an important part of the excess CVD mortality during hot spells. A larger increase in terms of relative cumulative excess mortality was observed for CD compared to IHD in the elderly, in males, as well as in the population as a whole. These results are consistent with a recent study from England and Wales (Gasparrini et al. 2012) reporting a higher risk of stroke compared to IHD (2.5% and 1.7% increase in stroke and IHD mortality, respectively, per 1°C increase above a specific heat threshold). The results further showed that while in the younger age group (0–64 years) excess mortality was associated with IHD and not CD, in the elderly (65+ years) higher relative excess heat-related mortality was attributed to CD.

Several studies have shown increased risk of cerebrovascular death in the elderly during heat waves (D'Ippoliti et al. 2010; Gasparrini et al. 2012). In people aged 65+ years, a history of CD has been found to increase the susceptibility to heat (Stafoggia et al. 2008; Schifano et al. 2009; Khalaj et al. 2010). Moreover, elderly patients hospitalized with stroke have been shown to have increased risk of in-hospital death during hot spells (Stafoggia et al. 2008). Advanced age is associated with accumulation of cardiovascular risk factors and comorbidities, thus increasing the risk of cardiovascular events. In the Czech Republic, levels of treatment for IHD are among the highest in Europe, with reperfusion therapy of AMI widely available (Widimsky et al. 2010). Together with secondary prevention and medication, improvements in treatment of AMI (including percutaneous coronary angioplasty and thrombolytic therapy) could play a role in a patient’s better ability to cope with extreme heat. Patients with IHD typically are under the supervision of their physicians, are more aware of their health conditions and are well informed about the health risks, while cerebrovascular diseases usually appear as sudden events that may not be preceded by signs of cardiovascular disorders and may therefore remain untreated. This may explain the larger relative increases in CD than IHD mortality in the elderly during hot spells.

In the younger population, the main risk factors for CD (such as advanced atherosclerotic changes, hypertension and diabetes, O'Donnell et al. (2010)) occur less frequently and the occurrence of stroke is relatively low in this age group (Davídkovová et al. 2013). On the other hand, since treatment of chronic CVDs is more widespread among older people in the Czech population (Seidlerová et al. 2014), younger individuals could be more at risk of unrecognized and untreated CVD. Younger people who are not aware of their health status and suffer from common chronic CVDs are at risk of developing cardiac complications during heat. This probably explains the observed increases in mortality from IHD and not from CD in this age group.

The results also showed that effects of heat on deaths from IHD were more immediate (excess IHD mortality already on day D+0), while increases in deaths from CD were more lagged (excess CD mortality starting on day D+1, with a peak on day D+2 in males and D+3 in females). This suggests that temperature changes and above-average temperatures occurring at the onset of a hot spell have an immediate impact on cardiovascular health of vulnerable persons, with consequences leading to acute cardiac complications. High temperatures lasting several days, on the other hand, cause a gradual worsening of health conditions due to accumulation of physiological changes caused by heat stress that is more likely to result in cerebrovascular accidents.

Although elderly people were at an increased risk of death from CVD, IHD and CD in association with hot spells, their hospital admissions due to CVD and IHD decreased below expected levels. The observed decline in hospitalisation in the elderly is consistent with the results of Schwartz et al. (2004), who reported a short-term displacement of morbidity for heart diseases several days after a hot spell in people aged 65+ years. These findings further complement the hypothesis discussed above that people die rapidly before they are admitted to hospital.

An increase in hospital admissions due to CD was observed 1 day before onset of a hot spell (D–1) in males and in the younger age group (0–64 years; Figure 4.4). This could be explained by large positive day-to-day temperature changes occurring typically on the days preceding a hot spell (Figure 4.2). The studies on heat-related CD morbidity support this hypothesis and show that cerebrovascular admissions are associated with temperature variations rather than absolute temperatures (Kyobutungi et al. 2005; Wang et al. 2009). One must interpret the finding of significant results for morbidity on individual days with caution, however, as a large number of variables are tested on rather long sequences of days. Apparently significant results may appear simply as a result of random variability. This effect also probably explains occurrence of several other rather isolated values exceeding the critical threshold in Figure 4.4.

4.4.3 Impacts of hot spells in individual population groups

The results showed much larger effects of hot spells on mortality in females than in males across all examined cardiovascular causes. The majority of studies considering gender-related differences in the temperature–mortality relationship have reported that females were more affected by extreme heat than males (Schifano et al. 2009; D'Ippoliti et al. 2010; Zacharias et al. 2014). In general, heat-related mortality in female population is mostly attributed to increasing age, a history of chronic diseases, unfavourable effects of menopause on cardiovascular health and thermoregulation (Rosano et al. 2007), along with social factors (e.g. marital status, living alone, being widowed) which play a role in predisposing women to greater vulnerability to heat stress (Hajat et al. 2007).

Elevated cardiovascular mortality associated with hot spells was found predominantly in the elderly. Advanced age is associated with a greater vulnerability to heat stress due to pre-existing chronic diseases and reduced ability to maintain body temperature (Holowatz and Kenney 2010; Kenny et al. 2010). Attenuated reflex cutaneous vasodilation response, altered skin blood flow, reduced ability of sweat glands to regulate the body temperature, changes in blood pressure and endothelial dysfunction accompanied by chronic CVD could contribute to an increase in CVD mortality risk associated with extreme heat exposure in the elderly (Kenney and Munce 2003; Nawrot et al. 2005; Holowatz and Kenney 2010).

People living alone, widowed or those living in nursing homes are particularly vulnerable to heat stress (Stafoggia et al. 2008). In the Czech Republic, the social care system includes both facilities providing long-term care to the elderly and comprehensive home care services which are provided by nurses and supervised by physicians (Bryndová et al. 2009). The number of beds in long-term health care facilities (a total of 7,200 beds as of 2007) is constantly insufficient and does not match the need for such care. Elderly people are largely dependent on home health care provided by family and relatives. Widowed, single and divorced elderly people living alone are more prone to underestimating their health risks associated with heat and neglecting appropriate fluid intake. Therefore, they could easily suffer from dehydration and related health complications (such as increase in blood viscosity, changes in heart rate, increased blood pressure and electrolyte imbalance; Kovats and Hajat (2007); Schneider et al. (2008); Kenny et al. (2010)) leading to heat illness. All these factors probably play a role in the elevated mortality among the elderly.

4.4.4 Harvesting effect

Excess mortality is followed by a reduction in deaths during the subsequent weeks after hot spells (Figure 4.3), which compensates for the previous increase to some extent. This short-term displacement points to the presence of persons with a short life expectancy for which the heat precipitates death. The declines in overall mortality impacts of hot spells related to harvesting have been documented in many studies (e.g. Kyselý (2004); Saha et al. (2014); Zaninović and Matzarakis (2014)); the negative deviations of mortality were observed for up to 3 weeks after the peak of heat-related deaths.

To obtain the first guess of the magnitude of the mortality displacement effect, we summed daily mortality deviations over days D+0 to D+5 (to estimate the average overall effect of the period of high temperatures, cf. Figures 4.2 and 4.3) and over the following 15 days (D+6 to D+20). The short-term mortality displacement accounted for slightly more than half of the excess deaths due to CVD in the Czech population (Table 4.2). A much larger magnitude of the displacement effect was found for mortality due to CD compared to IHD: the displaced deaths represented around 88% of the excess deaths during hot spells for CD while only 43% for IHD. The difference may be associated with comorbid diseases and generally worse health condition typically associated with CD, while for IHD, a larger percentage of victims is among “healthy” (and younger) population.

These figures may be compared with results of a recent study estimating the impact of high temperatures on years of life lost in Europe, in which a reduction in the overall impact of heat by 75% was reported when the harvesting effect was taken into account (Baccini et al. 2013). On the other hand, some studies have reported little evidence of the mortality displacement during the weeks following hot spells (e.g. Le Tertre et al. (2006); Kyselý and Kim (2009); Basu and Malig (2011)). The difference in the estimated magnitude of the displacement effect may be related to differences in the study design and examined populations but also to the definition of heat events (the magnitude of the effect probably tends to be larger for less severe events). The harvesting effect is manifested differently for individual diseases as shown by the large difference between CD and IHD mortality.

Table 4.2 Comparison of cumulative excess mortality (number of deaths) for CVD, IHD and CD during and after an average hot spell in the Czech Republic, 1994–2009

	ΣD+0… D+5	ΣD+6… D+20	Displaced mortality (%)
CVD	103.7	–53.7	51.8
IHD	35.4	–15.2	42.9
CD	32.7	–28.6	87.5

Cumulative excess mortality was calculated by summing mean deviations from the baseline number of deaths on days D+0 to D+5 and D+6 to D+20 for all hot spells over 1994–2009, and the values were averaged over hot spells. CVD, cardiovascular disease; IHD, ischaemic heart disease; CD, cerebrovascular disease.

4.4.5 Strengths and limitations of the study

An important advantage of this study is that the analysis was based on national mortality and hospitalisation registers covering the entire population of the Czech Republic (about 10.3 million inhabitants). The majority of European studies regarding effects of heat on mortality and/or morbidity have focused on populations of specific cities or smaller geographic and administrative units such as counties (Basu 2009; Ye et al. 2012).

Mortality data used in the present study are based on death certificates. The autopsy rate in the Czech Republic is among the highest in Europe and has remained relatively high (around 30%), with little changes over 1994–2009 (Davídkovová et al. 2013). This suggests that the data quality is at least comparable to that in western European countries.

Analysis based on hospitalisation data has several important limitations. Hospital admissions can increase only to a maximum which corresponds to the number of available beds. Limited capacity of hospitals, changes in payment policy for hospital services, fixed payments per bed, and such social factors as patients' behaviour (as seen, for example, in a typical weekly cycle for morbidity data, Figure 4.1) may confound analysis of the temperature–morbidity relationship.

Another limitation of the study is that we were not able to distinguish between planned and acute admissions in the morbidity data. Nevertheless, diagnoses of AMI and stroke (both of which are acute forms of CVD) represented major parts of IHD and CD, so it is unlikely that the reported pattern is governed by planned admissions (that are obviously not associated to weather).

Finally, age-adjustment of mortality and morbidity data was not carried out in this study, due to relatively small numbers of cases in the mortality data for individual groups of CVD. Although the present approach that makes use of an indirect standardisation is widely applied, it imposes limitations with respect to comparability of results between males and females. This is also why we focused on the comparison between IHD and CD mortality effects within the female or male population rather than evaluating differences between females and males. While the percentages of males and females are balanced in the younger age group (0–64 years) in the Czech population (50.7%/49.3 for males/females, respectively, as of 2009) and depend little on age, the share of females increases with age in the elderly (65+ years) and reaches 72.6% for the 85+ years age group (Figure 4.5), which contributes to larger heat-related effects in the female population. Nevertheless, other factors play a role in higher vulnerability of females to heat stress, too, as discussed e.g. by Kyselý and Kříž (2008).

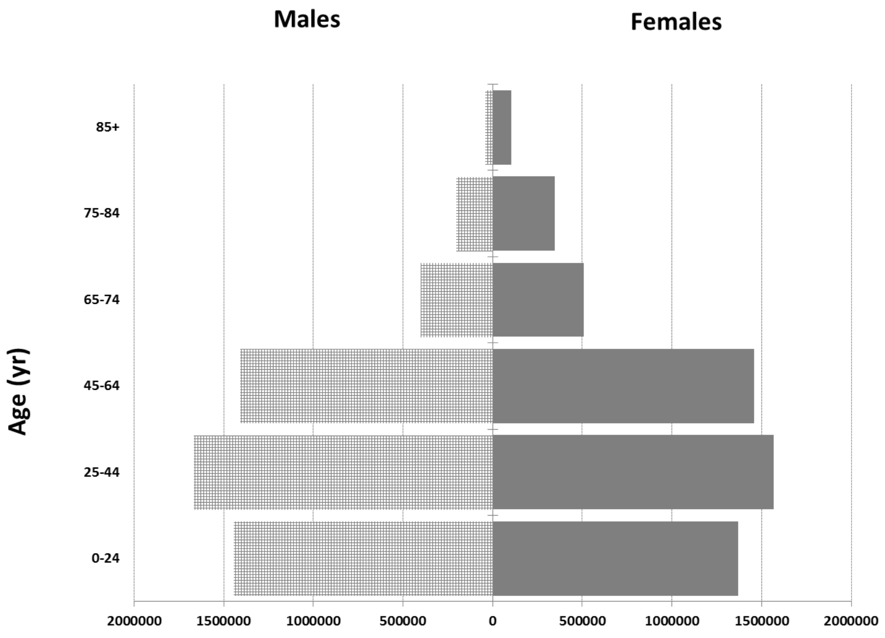


Figure 4.5 Population pyramid by age and gender showing the total population of the Czech Republic in 2009

4.5 Conclusions

The study showed a contrasting pattern of effects of hot spells on CVD mortality and hospital admissions. Mortality increased significantly for all examined cardiovascular causes, while the relationship between hot spells and hospital admissions due to CVD was weak and mostly insignificant. The effects were more pronounced for CD than IHD mortality in most population groups, but especially so in males and the elderly (65+ years). In the younger population (0–64 years), by contrast, significant excess mortality was observed for IHD while no excess mortality was seen for CD. In the case of morbidity, a small increase in hospital admissions due to CD was found in males and in the younger age group on days preceding a hot spell, while below-expected levels of morbidity prevailed during hot spells for IHD in the elderly. This suggests that out-of-hospital deaths represent a major part of excess CVD mortality during heat and that for in-hospital excess deaths CVD is a masked comorbid condition rather than the primary diagnosis responsible for hospitalisation.

High temperature extremes are projected to increase in the future. Since heat waves represent extreme weather events with the most adverse effects on human health in the mid-latitudes (Kovats and Hajat 2008), identification of populations at risk has become an important step in developing better targeted national public health strategies and prevention programmes in the context of changing climate. The present study provides new insight into relationships between heat and cause-specific cardiovascular mortality and morbidity, and this can help in better targeting vulnerable individuals at risk for heat-related disorders. Further research is needed which utilizes national registers encompassing entire populations and providing more-detailed information on such patient characteristics as comorbidities and medication. Socio-economic factors need to be addressed as well and they represent a topic of ongoing research. In addition to hospital admissions, data on emergency department visits should be considered as they may provide additional information on the manifestation of heat effects on morbidity and the physiological mechanisms involved.

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5 Trends in cardiovascular mortality and hospitalisations, and potential contribution of in-hospital case-fatality rates to changes in national mortality in the Czech Republic 1994-2009

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Abstract

Objectives To analyse trends in cardiovascular disease (CVD) mortality and hospitalisations in the Czech Republic in 1994-2009 and to assess the contribution of in-hospital case-fatality rates (CFR) to changes in national CVD mortality.

Design National hospitalisation and mortality registers were used to estimate rates of hospital admissions and mortality for hypertension, angina pectoris, acute myocardial infarction (AMI), chronic ischaemic heart disease, heart failure and stroke.

Patients All hospitalisations and deaths for CVD during 1994-2009.

Main outcome measures Average annual relative changes in age-standardised mortality, hospital admission and in-hospital CFR.

Results Between 1994 and 2009, 5,409,407 hospital admissions and 930,659 deaths from CVD were recorded. The age-standardised CVD mortality rate fell from 561 to 357 per 100,000 population (mean annual decline 3.1%) but hospitalisation rates remained relatively stable, with 2800 admissions per 100,000 per year (annual decline 0.7%). In-hospital CFR decreased significantly in all examined diagnoses but most rapidly for AMI (by 5.5% per year) and stroke (4.2% per year). The improvements were larger in the younger population than in elderly persons. Calculations based on unlinked mortality and hospitalisation data suggest that decline in in-hospital CFR may explain about 24%, 41% and 61% of the decline in national deaths from ischaemic heart disease, AMI and stroke, respectively.

Conclusions During the study period, the overall CVD hospitalisation rates remained high but in-hospital CFR declined considerably. The improved case-fatality seems to have made a substantial contribution to the decline in the national CVD mortality, particularly for AMI and stroke.

Keywords: Heart failure, Hypertension, Myocardial ischaemia and infarction, Coronary artery disease, Stroke

5.1 Introduction

Despite declining trends in cardiovascular disease (CVD) mortality, incidence and case fatality in most European countries (Tunstall-Pedoe et al. 1999; Levi et al. 2009; Jennings et al. 2012), CVD remains the leading cause of illness and death in Europe (Graham et al. 2007). Over the last several decades, mortality rates from ischaemic heart disease (IHD) and stroke have been considerably higher in Central and Eastern Europe than in Western Europe (Bobák and Marmot 2005; Müller-Nordhorn et al. 2008; Levi et al. 2009). In the Czech Republic, a decrease in mortality from CVD in men and women (25–64 years of age) has been reported since 1984 (Škodová et al. 1997; Cífková et al. 2010a); the declining trend has been attributed to improvement and control of CVD risk factors, such as hypertension and high cholesterol (Cífková et al. 2010a). This is consistent with estimates for IHD decline in Poland and other European countries (Bandosz et al. 2012), although the contribution of improved treatment in the Czech Republic remains unknown.

A major limitation of most studies on population level of CVD is the reliance on routine mortality registration; since the termination of the WHO MONICA project (in 1990), information on trends in non-fatal CVD is sparse in most European countries. The lack of data on non-fatal CVD is important, since it hampers answering crucial questions about trends in rates of overall (fatal plus non-fatal) and non-fatal disease and about the contribution of improved survival. Indeed, most estimates of the role of treatment and survival in overall mortality are based on modelling (Capewell and O'Flaherty 2008) rather than directly observed data.

The aim of this study is to shed light on the levels and trends in fatal and non-fatal CVD in the Czech Republic. In particular, we investigated trends in hospital admissions and in-hospital case-fatality of selected cardiovascular diagnoses, compared them with national CVD mortality in 1994–2009, and estimated the potential contribution of improved case-fatality rates (CFR) to declining mortality from acute myocardial infarction (AMI) and stroke.

5.2 Data and methods

5.2.1 Data on mortality

Data on mortality were collected and processed by the Czech Statistical Office; the database was transferred to the Institute of Health Information and Statistics (IHIS) which provided to us deaths from CVD. The database covers all deaths with CVD coded as the primary cause of death over 1994–2009 in the Czech Republic using ICD-10 classification (adopted in the Czech Republic since 1994), a total of 930,659 records. The autopsy rate in the Czech Republic remains relatively high (29%), with little change since 1994 (World Health Organization). Each record includes the day of death, age at death, gender and district. The following ICD-10 codes were analysed: all CVD: I00–I99; AMI: I21–I22; chronic IHD: I25; heart failure: I50; and stroke: I60–I64.

5.2.2 Data on hospital admissions and in-hospital case-fatality rates

Data on hospitalisation for CVD were obtained from the National Registry of Hospitalised Patients, administered by IHIS. The database consists of admissions for a CVD event among all resident people to any hospital in the Czech Republic from 1994 to 2009, a total of 5,409,407 records. Each record includes patient demographic information (age, gender, occupation and district), date of admission and primary diagnosis according to ICD-10. The primary diagnosis is defined as the condition most responsible for a patient’s hospitalisation and coded on discharge from hospital. Registration of all discharged patients in the National Registry of Hospitalised Patients is mandatory, and data are coded by physicians. The same diagnoses as for mortality were analysed; in addition, hypertension (I10–I15) and angina pectoris (I20), for which numbers of deaths were small, were also included.

Possible multiple records of a single CVD episode were merged to a single record (processed by IHIS) to avoid double-counting. Since each hospitalisation was recorded at a discharge, the incomplete data at the end of 2009 were supplemented using discharges recorded in 2010 so that the 16-year period of 1994–2009 is covered fully. Total CVD admissions were defined as all hospital admissions for CVD, including those resulting in death. In-hospital CFR was defined as the proportion of deaths among admissions to hospital with CVD being primarily responsible for hospitalisation.

5.2.3 Statistical analysis

The population of the Czech Republic was 10,336,162 in 1994 and 10,491,492 in 2009 (Czech Statistical Office 2010). Annual counts of CVD hospitalisations and deaths, for each diagnosis separately, were stratified by gender and five-year age groups (from 0 to 85+ years), and age-adjusted hospital rates of admissions, mortality and in-hospital CFR per 100,000 persons were calculated by the direct method, using mid-year population of the Czech Republic and the standard WHO European population as the standard. In addition, we also calculated age-specific hospitalisation and death rates per 100,000 population in several age bands: 20–49, 50–64, 65–74, and 75+ years. Trends in age-standardised rates were assessed by linear regression and expressed as the average annual relative change. The statistical significance of the trends was evaluated using t-test.

The contribution of declining in-hospital CFR to changes in total number of deaths between 1994 and 2009 was estimated for IHD (I20, I21, I22, I25), AMI and stroke (diagnoses with sufficient numbers of events). First, we calculated the predicted reduction in absolute number of deaths between 1994 and 2009 by subtracting the estimated number of deaths in 2009 (obtained by multiplying the observed number of deaths in 1994 by the ratio of age standardised mortality rates in 2009 to 1994) from observed deaths in 1994. Second, we estimated the reduction of in-hospital deaths by multiplying the observed number of admissions in 1994 by the 2009 CFR and subtracting it from the number of observed in-hospital deaths in 1994. Finally, the reduction in in-hospital deaths was divided by reduction in all deaths to obtain the proportion of the national mortality reduction that could be explained by reduction in in-hospital deaths.

5.3 Results

5.3.1 Mortality

In men and women combined, the age-standardised mortality from all CVD declined from 561 in 1994 to 357 per 100,000 in 2009, with annual relative reduction of about 3.1% (Table 5.1). Rapid declines were observed for deaths from AMI and stroke (annual relative reduction of 6.8% and 5.1%, respectively) but not for deaths from chronic IHD and heart failure (Figure 5.1). As expected, men were more likely to die from CVD than women (accounting for 60% of CVD deaths), and the difference was more pronounced in middle-aged persons (Table 5.2). In the oldest age group (75+ years), the most common cause of death was chronic IHD, with more than 2000 deaths per 100,000 men and women. In age stratified analyses, chronic IHD death rates decreased noticeably only at younger ages (20-49 years) and in the 65-74 years age group but mortality from AMI and stroke fell in all age groups (Table 5.2).

5.3.2 Hospital admissions

The age-standardised hospitalisation rate for all CVD increased between 1994 and 1996, remained high from 1997 to 2004, and declined slightly thereafter (to 2438 per 100,000 in 2009). A large decline was observed in both angina pectoris and chronic IHD admission rates, with average annual decrease of about 5.4% and 4.2%, respectively (Table 5.1, Figure 5.2); for both diagnoses the age-standardised rates decreased by more than 50% over 1994-2009. AMI admission rates experienced a more modest decline (average annual decrease of about 1.7%). In contrast, the age-standardised rate for heart failure increased steadily during the study period (by 5.7% per year), and heart failure became the third most common cause of CVD hospitalisation in 2009, while it was the least frequent of the examined diagnoses in 1994. The age-standardised rate for stroke declined slightly (by 1.2% per year), and admissions for hypertension increased slightly (by 0.6% per year).

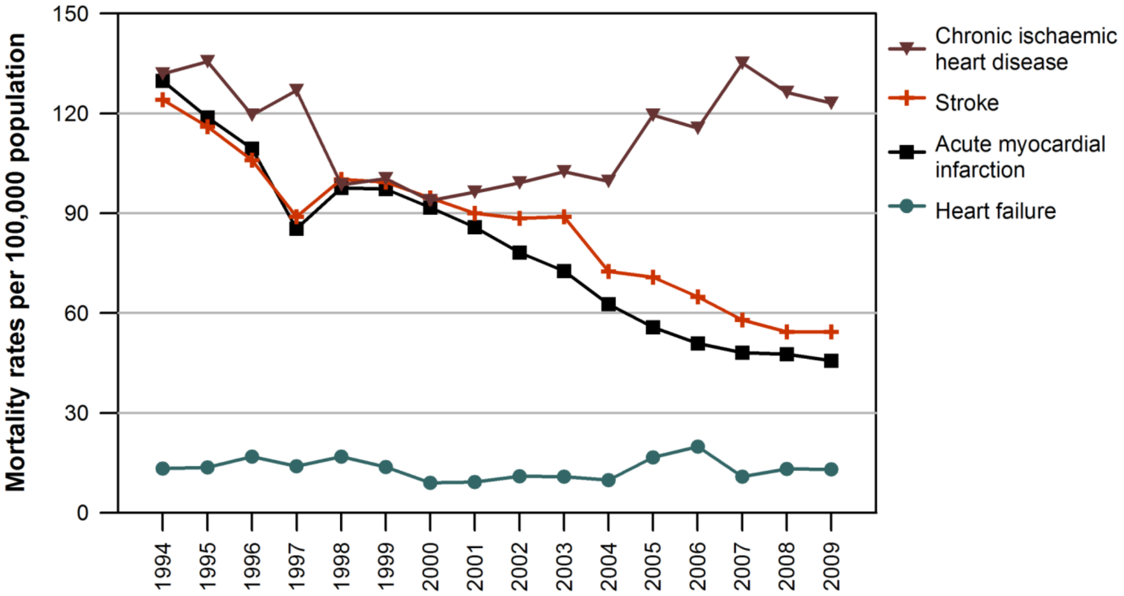

Figure 5.1 Age-standardised cardiovascular mortality rates by primary cause of death per 100,000 population in the Czech Republic, in 1994–2009. Rates are calculated using the European population as the standard.

Trends in age-standardised rates of hospital admissions for the examined CVD by age group and gender are shown in Table 5.3. Men accounted for 60% of all CVD hospitalisations and this tendency was increasing over the study period (from 58% in 1994 to 61% in 2009). CVD admission rates declined in most age groups in both men and women, except for heart failure (all age groups) and hypertension (65+ years); the decreases were less pronounced in the elderly (75+ years) and most significant in younger age groups (20–49, 50–64 years). The largest reductions were found for angina pectoris in the youngest age groups in both males and females. In both male and female population, chronic IHD was the most frequent cause of hospitalisation. Women had more hypertension admissions than men and the risk was higher in older age groups.

5.3.3 In-hospital case-fatality rates

A significant decrease in in-hospital case-fatality occurred in both men and women in all diseases examined (Table 5.1). A greater decline was seen in men with average annual reduction of about 3.3% (not shown in Table 5.1). Stroke was the main cause of in-hospital deaths, despite large annual reduction in the CFR (4.2% per year) (Figure

5.3). CFR for AMI improved most dramatically (average annual decline 5.5%), particularly after 2001; for heart failure it decreased only slightly and it remained stable for angina pectoris and hypertension.

5.3.4 Contribution of in-hospital CFR to decline in national mortality

For AMI at all ages, in-hospital CFR declined by 59%, which is equivalent to over 2000 fewer deaths; this reduction represents approximately 41% of the decline in deaths from AMI reported in the national mortality register (Table 5.4). For all IHD and stroke, the contribution of decreased CFR to the reduction of total deaths was 24% and 61%, respectively.

5.4 Discussion

Our analyses of Czech national data show a marked decline in mortality from AMI and stroke but stable or increasing mortality trends for chronic IHD and heart failure. For hospital admissions, marked decline was only seen for chronic IHD but not for other diagnoses. In-hospital CFR declined for all examined diseases, and the improved CFR seem to have made an important contribution to declining national mortality from AMI and stroke.

5.4.1 Strengths and limitations

This study has several limitations. First, data on mortality and hospitalisation are collected independently and the data cannot be linked. Second, we were unable to link the discharge records with clinical data and treatments, and the hospitalisation dataset did not include information on co-morbidity. Finally, we cannot distinguish between first and recurrent admissions and to calculate the incidence of diseases in the population. All this limits our ability to investigate the determinants of the changes in the incidence of the disease, particularly at the individual level.

On the other hand, this is, to our knowledge, the first study of CVD hospitalisations and in-hospital CFR at the national level in any of the Central and Eastern European countries. A major strength of this study is the availability of national registers, because they avoid biases related to using data from selected hospitals (Bobák and Hemingway 2009) and because they provide empirical test of modelling-based estimates (Capewell and O'Flaherty 2008).

Table 5.1 Cardiovascular disease mortality, hospital admissions and in-hospital case-fatality in the Czech Republic, 1994–2009

	Mortality		**Hospital admissions**		**In-hospital case-fatality**
Disease	Number of cases	Age-standardised rate	Number of cases	Age-standardised rate	%
Cardiovascular disease (I00–I99)					
1994	65132	561.3	290993	2615.2	8.7
2009	54100	357.0	334513	2438.2	5.6
Annual relative change, %	**-1.6****	**-3.1****	0.6	-0.7	**-2.8****
Acute myocardial infarction (I21–I22)					
1994	14834	129.8	25156	227.8	14.3
2009	6677	45.7	23700	173.5	5.8
Annual relative change, %	**-5.4****	**-6.8****	-0.2	**-1.7***	**-5.5****
Chronic ischaemic heart disease (I25)					
1994	15384	131.9	68216	598.0	6.9
2009	18903	123.1	45261	323.9	3.6
Annual relative change, %	1.8	0.0	**-2.9****	**-4.2****	**-4.4****
Heart failure (I50)					
1994	1528	13.3	7885	67.8	17.7
2009	1942	13.1	34559	232.0	11.9
Annual relative change, %	1.2	-0.4	**7.1****	**5.7****	**-1.9****
Stroke (I60–I64)					
1994	14593	124.2	36449	321.0	21.4
2009	8309	54.3	41406	291.0	10.8
Annual relative change, %	**-3.6****	**-5.1****	0.2	**-1.2****	**-4.2****
Hypertension (I10–I15)					
1994			15724	147.3	1.8
2009			19820	147.0	0.9
Annual relative change, %			**2.0****	0.6	**-3.9****
Angina pectoris (I20)					
1994			21628	199.0	1.6
2009			11837	87.3	0.5
Annual relative change, %			**-4.2****	**-5.4****	**-6.3****

Stars denote the significance value (**$p \leq 0.01$; *$p \leq 0.05$). Trends significant at $p \leq 0.05$ are highlighted in bold. Age-standardised rates are per 100,000 population. In-hospital case-fatality (%) is calculated as a ratio between age-standardised rate of in-hospital deaths and age-standardised rate of all hospital admissions. Mortality from hypertension (I10–I15) and angina pectoris (I20) are not shown due to small sample sizes.

Table 5.2 Cardiovascular disease mortality per 100,000 population in the Czech Republic, 1994–2009

Primary cause of death / Population group	**Men and women**	**MEN**					**WOMEN**				
		20-49	**50-64**	**65-74**	**75+**	**Overall**	**20-49**	**50-64**	**65-74**	**75+**	**Overall**
Cardiovascular disease (I00–I99)											
1994	561.3	65.9	731.5	2684.6	8726.3	707.3	19.0	260.9	1450.5	7968.0	456.8
2009	357.0	26.7	417.4	1348.1	5702.9	436.0	10.2	134.3	697.8	5512.8	296.2
Annual relative change, %	**-3.1****	**-5.9****	**-4.0****	**-4.8****	**-3.2****	**-3.3****	**-4.6****	**-4.8****	**-5.3****	**-2.8****	**-2.9****
Acute myocardial infarction (I21–I22)											
1994	129.8	25.7	308.9	895.2	1621.1	193.1	4.4	84.8	378.3	1088.3	83.8
2009	45.7	5.4	95.9	246.8	662.6	65.3	1.4	22.3	101.4	484.8	30.8
Annual relative change, %	**-6.8****	**-9.1****	**-7.7****	**-8.4****	**-5.9****	**-7.0****	**-8.9****	**-8.8****	**-8.9****	**-5.3****	**-6.6****
Chronic ischaemic heart disease (I25)											
1994	131.9	10.2	137.6	601	2255.4	164.4	1.8	43.2	311.0	2079.6	109.0
2009	123.1	5.2	124.3	430.6	2152.2	151.4	0.8	32.8	208.7	2037.4	101.9
Annual relative change, %	0.0	**-5.2****	-0.8	**-2.2***	0.1	-0.2	**-4.6****	-2.2	**-3.0****	0.2	0.1
Heart failure (I50)											
1994	13.3	3.6	20.3	55.7	210.7	17.7	1.8	8.0	32.1	155.7	10.3
2009	13.1	1.4	20.5	56.6	187.7	16.6	0.8	6.9	28.8	172.9	10.5
Annual relative change, %	-0.4	-2.9	-0.3	-1.4	-0.4	-0.4	-4.4	-1.7	-2.6	0.2	-0.5
Stroke (I60–I64)											
1994	124.2	9.0	115.6	544.8	1982.5	144.6	4.5	60.2	355.8	1939.2	110.2
2009	54.3	3.3	52.9	193.8	819.9	60.6	2.1	22.8	115.5	901.2	48.8
Annual relative change, %	**-5.1****	**-6.6****	**-5.5****	**-6.3****	**-5.7****	**-5.4****	**-5.1****	**-6.2****	**-6.8****	**-5.0****	**-4.9****

Stars denote the significance value (**$p \leq 0.01$; *$p \leq 0.05$). Trends significant at $p \leq 0.05$ are highlighted in bold.

Table 5.3 Cardiovascular disease hospital admissions per 100,000 population in the Czech Republic, 1994–2009

Disease / Population group	**Men and women**	**MEN**					**WOMEN**				
		20-49	**50-64**	**65-74**	**75+**	**Overall**	**20-49**	**50-64**	**65-74**	**75+**	**Overall**
Cardiovascular disease (I00–I99)											
1994	2615.2	1006.4	5521.8	11908.5	20184.9	3098.2	862.6	3261.0	8530.4	17630.4	2243.9
2009	2438.2	714.0	5498.6	12125.8	20945.2	3037.3	567.6	2532.8	7440.5	17560.9	1943.0
Annual relative change, %	-0.7	**-2.4****	-0.5	-0.1	0.0	-0.4	**-2.7****	**-1.7****	-1.2	-0.3	**-1.1****
Acute myocardial infarction (I21–I22)											
1994	227.8	97.7	714.5	1386.8	1582.6	326.5	22.5	258.1	717.2	1144.4	148.2
2009	173.5	63.1	535.8	987.1	1580.8	257.0	14.2	150.9	432.8	1035.9	103.3
Annual relative change, %	**-1.7****	**-3.0****	-1.6	**-2.1****	0.0	-1.4	**-3.5****	**-3.5****	**-3.3****	-0.4	**-2.3****
Chronic ischaemic heart disease (I25)											
1994	598.0	124.5	1151.0	3052.1	6194.0	717.1	54.1	651.8	2358.8	5453.5	506.4
2009	323.9	58.0	933.6	2101.3	3170.7	464.9	13.5	277.8	993.2	2159.1	208.3
Annual relative change, %	**-4.2****	**-5.6****	**-2.1****	**-2.4***	**-4.6****	**-3.1****	**-8.1****	**-5.4****	**-5.3****	**-6.4****	**-5.8****
Heart failure (I50)											
1994	67.8	6.8	106.1	422.7	842.3	85.1	3.5	54.4	259.8	700.5	55.7
2009	232.0	19.6	368.4	1253.9	3315.5	300.0	7.2	132.4	690.0	2706.9	180.8
Annual relative change, %	**5.7****	**6.4****	**6.3****	**4.7****	**6.3****	**5.8****	**5.3****	**4.0****	**4.0****	**6.4****	**5.4****
Stroke (I60–I64)											
1994	321.0	82.2	640.2	1765.1	3142.3	398.1	43.2	350.9	1139.7	2695.7	263.1
2009	291.0	53.6	584.2	1486.1	2878.9	350.9	42.6	270.9	942.7	2745.7	240.0
Annual relative change, %	**-1.2***	**-3.0****	**-1.2****	**-1.5****	-1.1	**-1.3****	-0.8	**-2.1****	**-1.9****	-0.6	**-1.2***
Hypertension (I10–I15)											
1994	147.3	94.4	291.2	327.8	325.6	138.7	86.3	318.1	479.6	482.4	151.2
2009	147.0	48.6	243.5	420.1	648.5	126.0	38.1	249.3	673.3	1221.3	158.5
Annual relative change, %	0.6	**-3.2****	-1.0	1.4	**4.0****	-0.2	**-3.8****	-0.9	**2.4***	**5.4****	1.1
Angina pectoris (I20)											
1994	199.0	84.8	572.5	953.4	1003.7	244.1	40.2	342.7	733.3	851.4	160.9
2009	87.3	22.2	281.6	564.7	729.2	128.2	5.6	93.6	273.0	402.0	53.6
Annual relative change, %	**-5.4****	**-8.7****	**-4.9****	**-4.1****	-2.5	**-4.6****	**-11.5****	**-7.6****	**-6.2****	**-4.5****	**-6.6****

Stars denote the significance value (**p ≤ 0.01; *p ≤ 0.05). Trends significant at p ≤ 0.05 are highlighted in bold.

Table 5.4 Contribution of improved case-fatality rates to reduction of national mortality from acute myocardial infarction, stroke and ischaemic heart disease.

All ages	1994 observed	2009 estimated	Age adj. reduction in deaths absolute	Contribution to reduction in all deaths
Acute myocardial infarction (I21–I22)				
All deaths	14834	9611	5223	
Hospital deaths	3597	1459	2138	40.9%
Stroke (I60–I64)				
All deaths	14593	8213	6380	
Hospital deaths	7800	3936	3864	60.6%
Ischaemic heart disease (I20,I21,I22,I25)				
All deaths	30271	10706	19565	
Hospital deaths	9017	4370	4647	23.8%

5.4.2 CVD trends

Consistently with previous reports from the Czech Republic (Škodová et al. 1997; Cífková et al. 2010a), we found that CVD mortality declined significantly between 1994 and 2009. Nevertheless, CVD mortality at the end of the study period was still at least twice of that in Western Europe (Müller-Nordhorn et al. 2008) and Canada (Tu et al. 2009; de Fatima Marinho de Souza et al. 2012) and approximately 50% higher than in the US (Roger et al. 2011). Although CVD mortality has also declined in many other former communist countries over the last decade (Bandosz et al. 2012; World Health Organization), the rates in the Czech Republic are among the lowest in the region; for example, CVD mortality in the Czech Republic was less than half of that in Russia in 2010 (World Health Organization).

The positive change in IHD mortality seems driven mainly by declining mortality from AMI across age-groups in both men and genders. By contrast, mortality from chronic IHD, accounting for between one half and three quarters of all CVD deaths, has increased since 2000, predominantly in the persons aged 75 and older. These contradictory trends may be explained by the fact that improved treatment, leading to higher survival of patients with acute coronary events, and better secondary prevention might increase the number of people with chronic form of IHD. This, combined with population ageing, is likely to underlie the rising mortality rates from chronic IHD in older persons.

5.4.3 Trends in acute myocardial infarction

Both hospital admissions and mortality from AMI decreased significantly over 1994–2009. This is similar to reports from Sweden (Lundblad et al. 2008; Stewart et al. 2010), Ireland (Jennings et al. 2012), Scotland (MacIntyre et al. 2006), the Netherlands (Koek et al. 2006) and the US (Yeh et al. 2010), whereas increase in AMI morbidity was found in Greece (Chimonas et al. 2009) and Canada (Hall et al. 2003). Mortality from IHD has also declined in most of central and eastern Europe recently (World Health Organization) but we are not aware of reliable recent data on trends in AMI incidence or hospitalisations in the region. The Czech Republic has one of the highest levels of treatment of AMI in Europe, with reperfusion therapy widely available (Widimsky et al. 2010). Improvements in treatment, including percutaneous coronary angioplasty and thrombolytic therapy, have led to better survival of patients with acute coronary syndrome and significantly reduced in-hospital CFR. Patients surviving the first event are at higher risk of recurrent events, and as we were not able to distinguish between first and recurrent events, rehospitalisation could be responsible for increased AMI admission rates observed in the elderly.

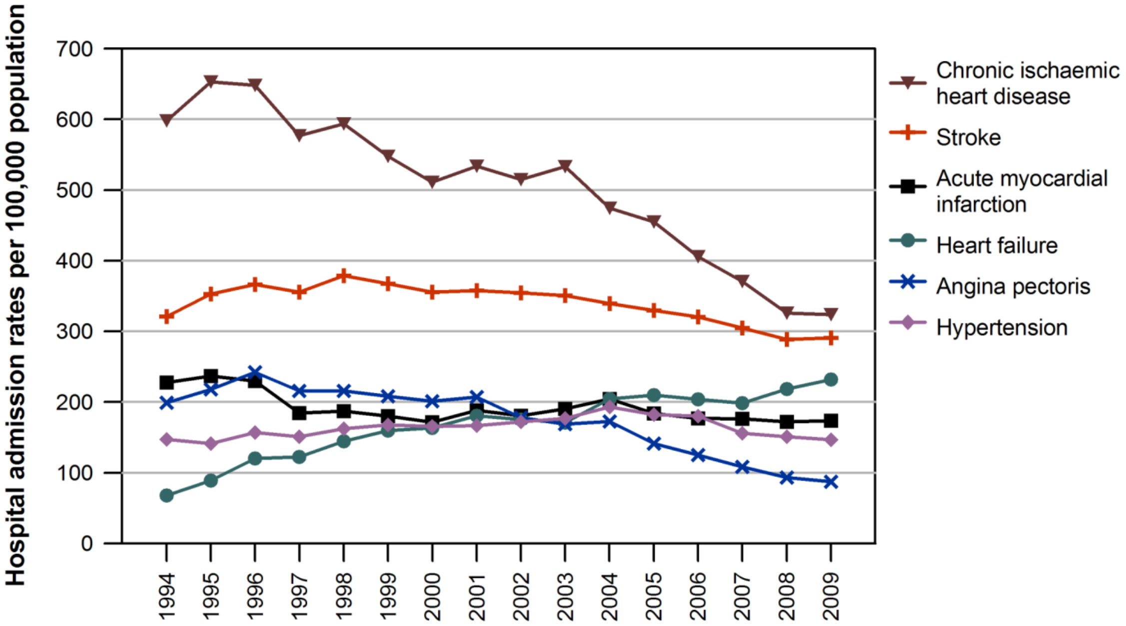

Figure 5.2 Age-standardised rates of hospital admissions by cardiovascular disease per 100,000 population in the Czech Republic, in 1994–2009. Rates are calculated using the European population as the standard.

Our estimates suggest that approximately 24% and 41% of the national decline in mortality from IHD and AMI, respectively, could have been due to reduced in-hospital CFR. As the mortality and hospitalisations were assessed in two different datasets, which could not be linked, these calculations provide only a rough guidance. Nevertheless, the magnitude of the contribution of treatment is consistent with the approximately 40% estimated in different countries by the IMPACT model (Capewell et al. 1999; Bennett et al. 2006; Bandosz et al. 2012).

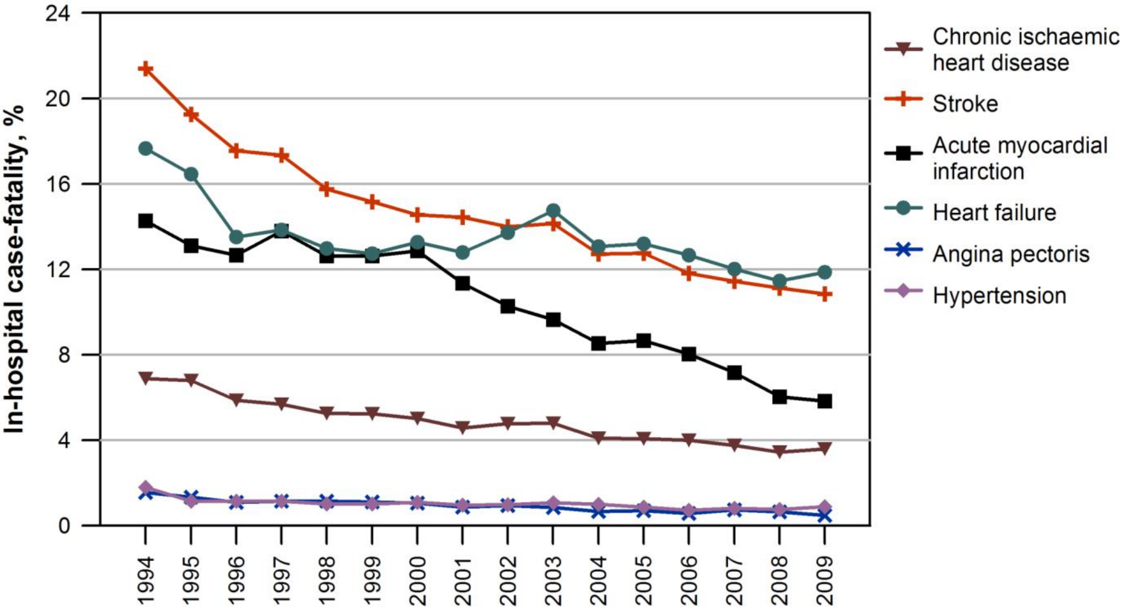

Figure 5.3 In-hospital case-fatality by cardiovascular disease in the Czech Republic, in 1994–2009. In-hospital case-fatality (in percentage) is calculated as a ratio between age-standardised rate of in-hospital deaths and age-standardised rate of all hospital admissions.

Trends in AMI incidence depend on changes in diagnostic criteria. In our data, an increase in admissions was observed between 1997 and 2004; this is likely to be due to the introduction of troponin testing in the Czech Republic (Widimsky et al. 2002), following new criteria for diagnosis of AMI (Antman et al. 2000). It has previously been shown that the inclusion of troponin to diagnostic criteria for AMI resulted in an increased number of diagnosed AMI (Antman et al. 2000; Tu et al. 2009). Consequently, hospitalisations for AMI have decreased more slowly during the last decade than they would have had if the diagnostic criteria would not have changed. In addition, the new criteria diagnose as AMI events with lower CFR, such as unstable angina. This could lead to overestimation of the fall in CFR of hospitalised AMI and to overestimation of the contribution of CFR to trends in national AMI mortality.

5.4.4 Trends in stroke

Diverging trends in stroke morbidity and mortality have been documented globally (Tu et al. 2009; Lee et al. 2011; Olsson et al. 2013). In general, higher burden of stroke was reported in eastern than western Europe (Bejot et al. 2007), although over the last 10 years or so mortality from stroke has been declining in most post-communist countries (World Health Organization). In the Czech population, stroke mortality fell significantly in all age groups, while hospitalisations for stroke declined more rapidly in young and middle aged persons. Despite lower occurrence of stroke in women, the course of illness in women is more severe than in men (Appelros et al. 2009), most likely due to increased age and higher prevalence of co-morbidity and other risk factors, such as hypertension (Barengo et al. 2009). The admission data also suggest a rapid decline in in-hospital CFR which, according to our calculations, could have made a major impact on the national mortality from stroke. Our data on trends are consistent with reports of declining stroke CFR from a number of populations; the improved survival is probably related to improved inpatient care (Cífková 2005). The fact that mortality and in-hospital CFR declined for both ischaemic and haemorrhagic strokes supports the view that improved treatment played a major role.

5.4.5 Trends in hypertension

A favourable change in hypertension morbidity was found only in the youngest age group (20–49 years) in men and women. Among those aged 75+ years, hospitalisation rates increased continually from 1994 to 2009 and the rate of admission for hypertension in women was almost double compared to men. In the Czech Republic, the prevalence of hypertension has been high over the last two decades (Cífková et al. 2010b), and control of hypertension has been unsatisfactory both in the general population (Bobák et al. 2005) and in people suffering from IHD, stroke and diabetes (Grassi et al. 2011). The favourable trend in hypertension admissions, observed in the youngest age group, may be related to the higher usage of antihypertensive medication in this group (Cífková et al. 2010b).

5.4.6 Trends in heart failure

Hospitalisations for heart failure as the primary diagnosis increased dramatically in Czech population from 1994 to 2009 in all age groups, most in the elderly. Some studies documented an epidemic of increasing heart failure morbidity in Western Europe in the 1980s and 1990s (Reitsma et al. 1996; Hobbs et al. 2009). Heart failure hospitalisation rates declined in Canada (Tu et al. 2009) and Sweden (Stewart et al. 2010) but in the last decade the rates increased in the US (Fang et al. 2008), Germany (Neumann et al. 2009), Italy (Gigli et al. 2009) and Spain (Gomez-Soto et al. 2011). In the Czech population, hospitalisations due to heart failure increased in all age groups and by 2009 it became the most common cause of CVD hospitalisations in the elderly. It is likely that heart failure morbidity will continue rising in the future because of population ageing (Nizze 2009) and improved survival attributable to improved secondary prevention and treatment (Fang et al. 2008; Neumann et al. 2009). Mortality rates for heart failure in the Czech population were comparable to those in Canada (Tu et al. 2009) and remained stable during the study period.

5.4.7 Trends in individual population groups

The greatest improvement in CVD mortality was achieved in young men (20–49 years); in this age group mortality fell by 60%, mainly due to declines in AMI (79%), chronic IHD (49%) and stroke (63%). The corresponding mortality rates in women 20–49 years old declined less sharply, but from a lower baseline. These results are consistent with trends in young adults population in 12 European countries over 1980–2007 (Bertuccio et al. 2011); the steepest declines were found in males and in the Czech Republic. In young women (20–49 years), stroke and hypertension were the most common causes of hospitalisations, and there was no decline in stroke admissions.

5.5 Conclusions

The declines in in-hospital CFR for several major CVD in the Czech Republic were substantial and the data suggest that improvement in treatment and acute case management made a significant contribution to the fall in the national CVD mortality. In addition to positive trends in cardiovascular risk factors during the post-communist transition, there have been dramatic improvements in the availability of modern diagnostic and treatment methods, particularly in cardiology. For example, by 2005, the Czech Republic was among the top 10 European countries with the highest use of coronary angiograms percutaneous coronary interventions (Widimsky et al. 2007). These favourable developments may provide encouragement for other countries in the region because they suggest that the combined effects of population-level approach towards risk factors and high availability of modern treatments have a major impact on public health, even in countries undergoing post-communist transition.

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Competing interest
The authors declare that they have no competing interests.

Data sharing statement
The authors declare that there are no additional data.

Contributorship statement
HD, JK and MB participated in the design of the study and wrote the manuscript. HD researched the data, made statistical analyses and drafted the manuscript. JK, MB, PV and BK participated in interpretation of the data and reviewed/edited the manuscript. All authors read and approved the final version of the manuscript.

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