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# Acute Fatal Effects of Short-Lasting Extreme Temperatures in Stockholm, Sweden

## *Evidence Across a Century of Change*

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**Background:** Climate change is projected to increase the frequency of extreme weather events. Short-term effects of extreme hot and cold weather and their effects on mortality have been thoroughly documented, as have epidemiologic and demographic changes throughout the 20th century. We investigated whether sensitivity to episodes of extreme heat and cold has changed in Stockholm, Sweden, from the beginning of the 20th century until the present.

**Methods:** We collected daily mortality and temperature data for the period 1901–2009 for present-day Stockholm County, Sweden. Heat extremes were defined as days for which the 2-day moving average of mean temperature was above the 98th percentile; cold extremes were defined as days for which the 26-day moving average was below the 2nd percentile. The relationship between extreme hot/cold temperatures and all-cause mortality, stratified by decade, sex, and age, was investigated through time series modeling, adjusting for time trends.

**Results:** Total daily mortality was higher during heat extremes in all decades, with a declining trend over time in the relative risk associated with heat extremes, leveling off during the last three decades. The relative risk of mortality was higher during cold extremes for the entire period, with a more dispersed pattern across decades. Unlike for heat extremes, there was no decline in the mortality with cold extremes over time.

**Conclusions:** Although the relative risk of mortality during extreme temperature events appears to have fallen, such events still pose a threat to public health.

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The impact of cold and hot weather on mortality has been known for centuries. The seasonality of mortality in Sweden was studied in the 18th century using parish and national population statistics.[1] Historical data for England reveal early evidence of increased mortality during severe winters, as well as after cold spells.[2,3] More recently, seasonal fluctuations and heightened winter mortality, especially among the elderly, has been reported throughout Europe.[4,5] Contemporary research has also focused on heat mortality especially among ageing populations.[6] The frequency and duration of extreme heat events is predicted to increase.[7] The 1987 heat wave in Athens resulted in about 2000 deaths,[8] and the 2003 European heat wave caused some 70,000 deaths.[9] Although the elderly are most susceptible to heat, the fatal effects of such events are also apparent among the middle-aged and the very youngest populations.[10,11] Although not consistent, many studies suggest women face greater relative increases in mortality with heat waves.[12,13]

The means by which temperature extremes affect human physiology and performance are well documented.[12] However, the extent and drivers of adaptation to weather and climate are not well understood. Physiologic adaptation to heat occurs within days to weeks in athletes.[14] Social, societal, and behavioral adaptation can also modify a population's vulnerability to heat and cold.[15,16] Adaptation to regional ambient temperatures has been observed in a few studies of historic registers of short-term mortality caused by weather conditions.[17–19] However, changes in the temperature–mortality relationship cannot be easily separated from underlying demographic changes in the population, changing prevalence of susceptibility factors (well known to have occurred during the 20th century),[20] and extent of natural adaptation to the local environment.

We investigate whether sensitivity to temperature extremes of heat and cold changed in Sweden from the

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beginning of the 20th century to the present. We describe trends in relative risk (RR) of mortality related to temperature extremes, from all causes and stratified by sex and age.

## METHODS

We collected information on the daily numbers of deaths from all causes during the period 1901–2009 for present-day Stockholm County, Sweden (Table 1).[21] These mortality data are complete only since 1947; from 1901 through 1946 approximately 46% of original parish records have been converted to digital format. Given that mortality distributions among parishes are similar, the available data for deaths should serve as a valid proxy for fluctuations in daily total mortality of Stockholm County.

Daily mean temperature data were provided by the Swedish Meteorological and Hydrological Institute (Table 2). Observations were made at the Stockholm Observatory, where temperature data have been recorded at almost exactly the same location since 1756. We defined heat extremes as days for which the 2-day moving average of mean temperature ("lag01") was above the 98th percentile

**TABLE 1.** Daily Mortality Counts and the Mortality Distribution by Age

| | Daily Deaths No. | | | | | | Percent Distribution of Deaths by Age Years | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Decade | Mean | Standard Deviation | Median | Min | Max | Total | 0–14 | 15–65 | 65–79 | 80+ |
| 1901–1909 | 16.7 | 4.8 | 16 | 3 | 40 | 54,781 | 29 | 42 | 20 | 9 |
| 1910–1919 | 17.1 | 6.0 | 16 | 3 | 60 | 62,517 | 21 | 45 | 22 | 11 |
| 1920–1929 | 14.5 | 4.6 | 14 | 3 | 39 | 52,814 | 13 | 44 | 29 | 15 |
| 1930–1939 | 16.9 | 5.3 | 16 | 3 | 44 | 61,691 | 7 | 42 | 35 | 16 |
| 1940–1949 | 22.1 | 6.4 | 22 | 6 | 53 | 80,763 | 6 | 38 | 37 | 20 |
| 1950–1959 | 29.0 | 5.9 | 29 | 13 | 54 | 105,851 | 4 | 31 | 42 | 23 |
| 1960–1969 | 35.3 | 6.8 | 35 | 14 | 63 | 128,806 | 3 | 28 | 42 | 27 |
| 1970–1979 | 39.1 | 7.1 | 38 | 20 | 72 | 142,637 | 2 | 26 | 41 | 31 |
| 1980–1989 | 41.1 | 7.2 | 41 | 20 | 81 | 150,221 | 1 | 20 | 40 | 39 |
| 1990–1999 | 42.2 | 7.4 | 42 | 22 | 75 (238)[a] | 154,181 | 1 | 16 | 34 | 48 |
| 2000–2009 | 42.4 | 7.1 | 42 | 20 | 70 (272)[b] | 154,993 | 0.7 | 16 | 27 | 57 |

[a]238 persons died on 28 September 1994 in the Estonia disaster.
[b]272 persons died on 26 December 2004 in the tsunami in Southeast Asia.

**TABLE 2.** Descriptive Statistics for Temperature Data

| Decade | Summer Mean[a] (Lag 01) | Max (Lag 01) | Winter Mean[b] (Lag 025) | Min (Lag 025) | Days with Heat Extremes[c] No. | Days with Cold Extremes[d] No. | Decadal 98th Percentile for Heat Extremes Temperature No. Days | Decadal 2nd Percentile for Cold Extremes Temperature No. Days |
|---|---|---|---|---|---|---|---|---|
| 1901–1909 | 15.1°C | 25.3°C | −2.2°C | −7.1°C | 55 | 11 | 20.1°C (66) | −4.9°C (66) |
| 1910–1919 | 15.5°C | 24.4°C | −2.3°C | −8.3°C | 66 | 55 | 20.2°C (74) | −6.2°C (74) |
| 1920–1929 | 15.1°C | 24.5°C | −2.3°C | −9.1°C | 44 | 64 | 19.5°C (74) | −6.4°C (74) |
| 1930–1939 | 16.7°C | 25.8°C | −0.8°C | −5.4°C | 79 | 0 | 20.7°C (74) | −3.7°C (74) |
| 1940–1949 | 16.6°C | 26.7°C | −3.5°C | −13.2°C | 91 | 216 | 21.1°C (74) | −10.3°C (74) |
| 1950–1959 | 16.1°C | 25.7°C | −2.2°C | −10.7°C | 55 | 53 | 20.3°C (74) | −5.6°C (74) |
| 1960–1969 | 16.3°C | 24.3°C | −2.9°C | −11.2°C | 51 | 119 | 20.4°C (74) | −7.2°C (74) |
| 1970–1979 | 16.6°C | 27.7°C | −1.6°C | −10.2°C | 66 | 89 | 20.9°C (74) | −6.6°C (74) |
| 1980–1989 | 16.2°C | 26.9°C | −2.6°C | −11.9°C | 58 | 158 | 20.7°C (74) | −7.7°C (74) |
| 1990–1999 | 17.0°C | 27.0°C | −0.3°C | −7.1°C | 113 | 22 | 21.8°C (74) | −4.8°C (74) |
| 2000–2009 | 17.5°C | 25.3°C | −0.6°C | −7.3°C | 126 | 10 | 22.0°C (74) | −3.6°C (74) |

[a]June, July, and August months comprise 99% of the heat extremes (five heat extremes occurred in September).
[b]January, February, and March months comprise 99% of the cold extremes (seven cold extremes occurred in December).
[c]Above 98th percentile = 20.8°C.
[d]Below 2nd percentile = −6.9°C.

(20.8°C) for the entire period (1901–2009). Cold extremes were defined as days for which the 26-day moving average of mean temperature ("lag025") was below the 2nd percentile (−6.9°C). These lags are sufficient to describe effects related to short-term variability in temperature.[22] Using the same temperature criteria throughout the study period will not take into account either the increasing temperature over time or acclimatization within decades. A single criterion could lead to bias in the earlier decades due to the fact that we might be estimating mortality for a more extreme relative temperature. To address this problem, we also investigated temperature extremes occurring within each decade, using the same percentiles and lags for heat and cold extremes as defined above.

## Statistical Methods

To analyze the relationship between extreme hot or cold temperatures and mortality, we used an approach that assumed the daily counts of mortality follow an overdispersed Poisson distribution. A generalized linear model was fit. Time trends in the daily number of deaths were described by a smooth function. This function was allowed 400 degrees of freedom (df) over the period, corresponding to around 4 df per year of data. The time-trend function allows baseline mortality to vary depending on demographic changes, changes in the data-collection system, and other slowly time-varying extraneous factors. However, the time-trend function cannot explain the short-term variability of daily deaths, which therefore must be explained by daily temperature fluctuations.

Day of the week was included in the model as a categorical explanatory variable. Binary variables indicated public Swedish holidays ("holiday") and the later period when all parishes are included in register data ("from 1947 onwards") ("complete"). Pandemic episodes of influence were included as binary variables (the Spanish flu, October 1918–November 1920; the Asian flu, October 1957–April 1958; and the Hong Kong flu, October 1969–March 1970).[23]

We established the model: $\text{Mortality}_t \sim \text{Poisson}(\mu_t)$

$$\begin{aligned}\log(\mu_t) = {} & \text{intercept} + \text{weekday} + \text{holiday} \\ & + S(\text{trend, df} = 400) + \text{pandemic} \\ & + \text{complete} + \text{heat extreme} + \text{heat} \\ & \text{extreme} \times \text{decade} + \text{cold extreme} \\ & + \text{cold extreme} \times \text{decade}\end{aligned}$$

Model 1 was computed using cutoff temperatures for temperature extremes defined for the entire period of investigation 1901–2009, whereas for model 2 the cutoff temperatures for temperature extremes were defined within each decade.

Sensitivity analyses of the estimated heat and cold coefficients were done using 300, 350, 450, and 500 degrees of freedom to investigate the importance of the smoothing parameter. The estimates of the RRs were quite similar for the various degrees of freedom used. See eTable 1 (http://links.lww.com/EDE/A724) for the estimates of the RRs and the corresponding 95% confidence intervals (CIs) using the various degrees of freedom.

We analyzed separately to investigate differences in vulnerability to extreme temperatures between sexes.[12,13] Since age has also been shown to modify susceptibility,[6,12,13] we analyzed data separately for various age groups. These age groups were 0–14, 14–64, and 65+ years. These age groups are characterized by different positions in society, as well as different rates and causes of death. Due to the considerable change in age of mortality over the 110 years under study, we further separated the elderly into two categories: 65–79 and 80+.

The relative effect modification index was used to investigate whether sex and age modified the mortality effects of exposure to extreme temperatures. This index is calculated as the ratio between the RR of the group of interest and the RR from the reference group.[24]

To investigate time trends in the RRs, bearing in mind the substantial difference in standard errors of the RR estimates


**FIGURE 1.** Number of periods of cold/heat extremes per decade, 1901–2009.

 

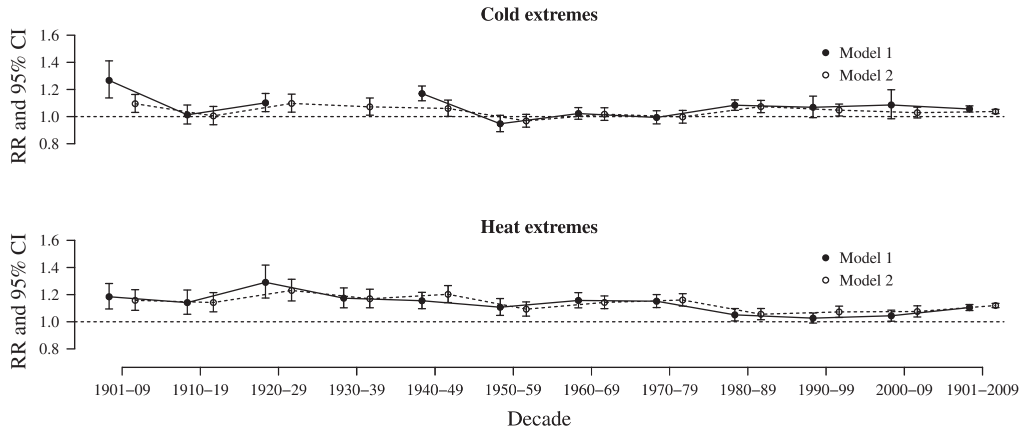


**FIGURE 2.** Mortality related to temperature extremes per decade, 1901–2009. See Methods section for description of Models 1 and 2.

over time, we performed a weighted least squares linear regression, with the RR estimates as the dependent variable and decade as the independent variable, using the weights inversely proportional to the variance of each RR. SAS version 9.2 software (SAS Institute, Cary, NC) was used to create datasets and variables. R version 2.13.1 was used for statistical models and creation of outputs.

## RESULTS

### Number of Temperature Extremes

Figure 1 presents the number of heat and cold extremes during 1901–2009, by decade, using cutoff temperatures for temperature extremes defined for the entire period of investigation 1901–2009.

Heat extremes increased over the 20th century, with the largest upsurge from 1990 onward. The last two decades had more than half-again as many extreme heat events as any other decade of the period. The number of cold extremes per decade was much more variable, and no trend is apparent. This number during the last two decades was low, as in the 1930s when no cold extremes occurred. During the 1940s and 1980s there were large numbers of cold extremes.

### RR of Mortality During Hot and Cold Weather

Figure 2 shows the RR (95% CI) of mortality associated with extreme heat (lag01) and extreme cold (lag025) compared with nonextreme days, by decade. Table 3 presents the results of the regression analyses stratified for sex and age. eTable 2 (http://links.lww.com/EDE/A724) presents the results of the regression analysis of trend over time for all investigated groups. Models 1 and 2 yielded similar risk and trend estimates; thus, if not specifically mentioned below, the results and conclusions apply to both models.

Mortality was increased with heat extremes in all decades, as well as for the entire period. The estimated RR of mortality during heat extremes over the entire period was 1.10 (95% CI = 1.08–1.13) and 1.12 (1.10–1.14) for models 1 and 2, respectively. There was a substantial decline of RR estimates for heat extremes during the period.

Although mortality with cold extremes was also increased overall (1.06 [1.03–1.08] and 1.04 [1.02–1.05] for models 1 and 2, respectively), the association was more variable across decades. During one period 1950–1959, the RR dropped below 1.00. There was little evidence of a declining trend in cold-related mortality over time.

The RRs associated with heat extremes were generally higher than those associated with cold extremes, with both sides risks stabilizing in the last three decades. Patterns and trends were similar for men and women separately (eFigures 1 and 2, http://links.lww.com/EDE/A724). Men had increased mortality during heat extremes in all but 1980–1989. Men's RR of mortality with heat declined over time. Risk with cold also declined over time, although the trend was less marked. Results were similar for women, with a decrease in morality RR with heat over time, but no apparent change in mortality risk with extreme cold. Sex was in general not a modifier of risk, for either heat or cold extremes.

RRs for the various age groups are presented in eFigures 3–7 (http://links.lww.com/EDE/A724). An increase in RR for those above age 65 years is present with both heat and cold extremes across the entire period. Not surprisingly, this pattern is similar to overall mortality in the last three decades, when over-65 mortality accounted for eight of ten deaths.

Results for the other age groups are more difficult to interpret, given the small number of deaths in these groups. Risks were elevated during heat extremes for both the age 0–14 and 15–64 years populations in the early 20th century, and then tended to decline. Toward the end of the study period, there was an upward risk trend in the 15–64 age group, similar to another study from this region, which indicated a recent increased risk of death among persons aged 45–64 years.[11]

The trends over time differ somewhat in the various age groups. Although RR of mortality from heat was consistently higher than for cold, there was a significant declining trend for

 

**TABLE 3.** Associations of Cold and Heat Extremes with Total Mortality, as well as Analyses Stratified by Sex and Age

| | | Effect of Short-Lasting Cold Extremes | | | | Effect of Short-Lasting Heat Extremes | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Model 1 | Model 2 | Model 1 | Model 2 | Model 1 | Model 2 | Model 1 | Model 2 |
| Decade | | RR (95% CI) | RR (95% CI) | REM Index (95% CI) | REM Index (95% CI) | RR (95% CI) | RR (95% CI) | REM Index (95% CI) | REM Index (95% CI) |
| 1901–1909 | Total | 1.27 (1.14–1.41) | 1.10 (1.03–1.16) | | | 1.18 (1.10–1.28) | 1.16 (1.08–1.24) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.19 (1.07–1.32) | 1.06 (0.97–1.15) | 1.00 | 1.00 | 1.16 (1.05–1.29) | 1.20 (1.10–1.31) | 1.00 | 1.00 |
| | Women | 1.34 (1.15–1.55) | 1.14 (1.04–1.24) | 1.12 (0.94–1.35) | 1.08 (0.95–1.21) | 1.24 (1.11–1.39) | 1.11 (1.01–1.22) | 1.07 (0.92–1.24) | 0.92 (0.81–1.05) |
| | Age; years | | | | | | | | |
| | 0–14 | 1.27 (1.04–1.54) | 1.10 (0.98–1.24) | 1.01 (0.63–1.64) | 1.00 (0.80–1.25) | 1.32 (1.17–1.50) | 1.26 (1.12–1.40) | 1.21 (0.98–1.50) | 1.16 (0.96–1.40) |
| | 15–64[a] | 1.25 (1.05–1.49) | 1.10 (1.00–1.22) | 1.00 | 1.00 | 1.09 (0.96–1.24) | 1.08 (0.97–1.21) | 1.00 | 1.00 |
| | 65+ | 1.25 (1.05–1.49) | 1.07 (0.96–1.19) | 1.00 (0.77–1.26) | 0.97 (0.84–1.12) | 1.19 (1.02–1.39) | 1.14 (1.00–1.30) | 1.09 (0.89–1.29) | 1.06 (0.89–1.23) |
| | 65–79 | 1.29 (1.04–1.61) | 1.06 (0.93–1.20) | 1.03 (0.78–1.37) | 0.96 (0.82–1.13) | 1.10 (0.91–1.32) | 1.11 (0.95–1.30) | 1.00 (0.80–1.26) | 1.03 (0.85–1.24) |
| | 80+ | 1.16 (0.80–1.67) | 1.11 (0.92–1.34) | 0.92 (0.62–1.39) | 1.01 (0.82–1.25) | 1.44 (1.09–1.88) | 1.21 (0.95–1.54) | 1.32 (0.97–1.78) | 1.12 (0.86–1.46) |
| 1910–1919 | Total | 1.01 (0.94–1.09) | 1.01 (0.94–1.07) | | | 1.14 (1.06–1.23) | 1.14 (1.07–1.21) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.03 (0.96–1.10) | 1.03 (0.94–1.12) | 1.00 | 1.00 | 1.18 (1.07–1.31) | 1.17 (1.07–1.27) | 1.00 | 1.00 |
| | Women | 0.98 (0.89–1.08) | 0.98 (0.89–1.08) | 0.95 (0.85–1.08) | 0.96 (0.84–1.10) | 1.13 (1.02–1.26) | 1.11 (1.02–1.22) | 0.96 (0.83–1.11) | 0.95 (0.84–1.08) |
| | Age; years | | | | | | | | |
| | 0–14 | 0.98 (0.84–1.15) | 0.99 (0.85–1.16) | 1.07 (0.85–1.34) | 1.08 (0.86–1.37) | 1.30 (1.12–1.51) | 1.22 (1.07–1.38) | 1.20 (0.96–1.50) | 1.15 (0.96–1.36) |
| | 15–64[a] | 0.92 (0.82–1.03) | 0.91 (0.82–1.02) | 1.00 | 1.00 | 1.09 (0.96–1.24) | 1.06 (0.96–1.17) | 1.00 | 1.00 |
| | 65+ | 1.13 (1.02–1.26) | 1.13 (1.02–1.26) | 1.23 (1.05–1.38) | 1.24 (1.06–1.39) | 1.15 (1.00–1.31) | 1.20 (1.07–1.33) | 1.05 (0.88–1.23) | 1.13 (0.97–1.27) |
| | 65–79 | 1.20 (1.05–1.37) | 1.18 (1.04–1.34) | 1.30 (1.10–1.54) | 1.29 (1.09–1.52) | 1.11 (0.95–1.30) | 1.17 (1.02–1.33) | 1.02 (0.84–1.24) | 1.10 (0.93–1.29) |
| | 80+ | 1.01 (0.84–1.21) | 1.04 (0.87–1.25) | 1.10 (0.88–1.36) | 1.14 (0.92–1.41) | 1.22 (0.98–1.53) | 1.26 (1.05–1.52) | 1.12 (0.87–1.45) | 1.19 (0.96–1.46) |
| 1920–1929 | Total | 1.10 (1.04–1.17) | 1.10 (1.03–1.17) | | | 1.29 (1.17–1.42) | 1.23 (1.15–1.31) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.13 (1.07–1.20) | 1.13 (1.04–1.23) | 1.00 | 1.00 | 1.40 (1.24–1.59) | 1.25 (1.15–1.37) | 1.00 | 1.00 |
| | Women | 1.06 (0.98–1.15) | 1.07 (0.98–1.16) | 0.94 (0.85–1.04) | 0.95 (0.84–1.07) | 1.21 (1.06–1.38) | 1.21 (1.10–1.32) | 0.86 (0.72–1.03) | 0.96 (0.85–1.10) |
| | Age; years | | | | | | | | |
| | 0–14 | 1.16 (0.97–1.38) | 1.15 (0.96–1.37) | 1.04 (0.79–1.37) | 1.03 (0.78–1.36) | 1.34 (1.03–1.74) | 1.31 (1.09–1.58) | 1.00 (0.54–1.87) | 1.09 (0.72–1.64) |
| | 15–64[a] | 1.12 (1.01–1.23) | 1.12 (1.01–1.23) | 1.00 | 1.00 | 1.34 (1.16–1.53) | 1.20 (1.09–1.33) | 1.00 | 1.00 |
| | 65+ | 1.06 (0.97–1.16) | 1.07 (0.98–1.17) | 0.95 (0.84–1.08) | 0.96 (0.84–1.09) | 1.26 (1.09–1.45) | 1.23 (1.12–1.37) | 0.94 (0.77–1.14) | 1.03 (0.89–1.17) |
| | 65–79 | 1.04 (0.93–1.16) | 1.05 (0.94–1.17) | 0.93 (0.81–1.07) | 0.94 (0.82–1.09) | 1.33 (1.12–1.57) | 1.26 (1.12–1.42) | 0.99 (0.80–1.24) | 1.05 (0.90–1.22) |
| | 80+ | 1.10 (0.96–1.27) | 1.09 (0.95–1.26) | 0.99 (0.83–1.17) | 0.98 (0.82–1.16) | 1.13 (0.87–1.45) | 1.18 (0.99–1.41) | 0.84 (0.63–1.13) | 0.98 (0.80–1.20) |

(*Continued*)

**TABLE 3.** (Continued)

| | | Effect of Short-Lasting Cold Extremes | | | | Effect of Short-Lasting Heat Extremes | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Model 1 | Model 2 | Model 1 | Model 2 | Model 1 | Model 2 | Model 1 | Model 2 |
| Decade | | RR (95% CI) | RR (95% CI) | REM Index (95% CI) | REM Index (95% CI) | RR (95% CI) | RR (95% CI) | REM Index (95% CI) | REM Index (95% CI) |
| 1930–1939 | Total | NA | 1.07 (1.01–1.14) | | | 1.17 (1.10–1.25) | 1.17 (1.10–1.24) | | |
| | Sex | | | | | | | | |
| | Men[a] | NA | 1.04 (0.95–1.13) | NA | 1.00 | 1.12 (1.03–1.22) | 1.11 (1.02–1.21) | 1.00 | 1.00 |
| | Women | NA | 1.10 (1.02–1.19) | NA | 1.06 (0.94–1.19) | 1.25 (1.15–1.36) | 1.23 (1.13–1.33) | 1.12 (0.99–1.26) | 1.10 (0.98–1.24) |
| | Age; years | | | | | | | | |
| | 0–14 | NA | 1.06 (0.84–1.34) | NA | 1.03 (0.81–1.31) | 1.10 (0.87–1.4) | 1.09 (0.86–1.38) | 0.94 (0.62–1.40) | 0.95 (0.66–1.36) |
| | 15–64[a] | NA | 1.04 (0.94–1.14) | NA | 1.00 | 1.18 (1.07–1.30) | 1.15 (1.05–1.26) | 1.00 | 1.00 |
| | 65+ | NA | 1.10 (1.02–1.19) | NA | 1.06 (0.94–1.19) | 1.20 (1.10–1.31) | 1.20 (1.10–1.30) | 1.02 (0.90–1.14) | 1.04 (0.92–1.16) |
| | 65–79 | NA | 1.09 (0.99–1.20) | NA | 1.05 (0.91–1.20) | 1.17 (1.06–1.29) | 1.18 (1.07–1.30) | 0.99 (0.86–1.14) | 1.02 (0.89–1.17) |
| | 80+ | NA | 1.13 (0.98–1.29) | NA | 1.09 (0.92–1.29) | 1.28 (1.10–1.48) | 1.24 (1.08–1.43) | 1.08 (0.91–1.29) | 1.08 (0.91–1.28) |
| 1940–1949 | Total | 1.17 (1.12–1.23) | 1.06 (1.00–1.12) | | | 1.15 (1.10–1.22) | 1.20 (1.14–1.27) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.14 (1.10–1.19) | 1.02 (0.94–1.10) | 1.00 | 1.00 | 1.11 (1.04–1.19) | 1.13 (1.05–1.22) | 1.00 | 1.00 |
| | Women | 1.16 (1.10–1.23) | 1.10 (1.02–1.19) | 1.02 (0.95–1.09) | 1.08 (0.97–1.21) | 1.23 (1.15–1.31) | 1.27 (1.18–1.37) | 1.11 (1.00–1.22) | 1.12 (1.01–1.24) |
| | Age; years | | | | | | | | |
| | 0–14 | 0.92 (0.77–1.10) | 0.91 (0.70–1.18) | 0.82 (0.61–1.10) | 0.88 (0.68–1.15) | 1.27 (1.04–1.54) | 1.28 (1.04–1.58) | 1.09 (0.76–1.56) | 1.08 (0.74–1.60) |
| | 15–64[a] | 1.13 (1.05–1.20) | 1.03 (0.94–1.14) | 1.00 | 1.00 | 1.17 (1.08–1.27) | 1.18 (1.08–1.29) | 1.00 | 1.00 |
| | 65+ | 1.19 (1.14–1.25) | 1.09 (1.02–1.17) | 1.06 (0.97–1.14) | 1.06 (0.94–1.18) | 1.16 (1.08–1.24) | 1.21 (1.13–1.30) | 0.99 (0.89–1.10) | 1.02 (0.92–1.13) |
| | 65–79 | 1.16 (1.09–1.24) | 1.11 (1.01–1.21) | 1.03 (0.94–1.13) | 1.07 (0.94–1.23) | 1.15 (1.06–1.24) | 1.18 (1.08–1.29) | 0.98 (0.88–1.10) | 1.00 (0.88–1.13) |
| | 80+ | 1.25 (1.15–1.35) | 1.06 (0.94–1.20) | 1.11 (1.00–1.23) | 1.03 (0.88–1.20) | 1.18 (1.06–1.32) | 1.26 (1.12–1.41) | 1.01 (0.88–1.16) | 1.07 (0.92–1.23) |
| 1950–1959 | Total | 0.95 (0.89–1.01) | 0.97 (0.92–1.02) | | | 1.11 (1.05–1.17) | 1.09 (1.04–1.15) | | |
| | Sex | | | | | | | | |
| | Men[a] | 0.91 (0.86–0.97) | 0.93 (0.87–0.99) | 1.00 | 1.00 | 1.12 (1.04–1.21) | 1.11 (1.04–1.19) | 1.00 | 1.00 |
| | Women | 0.97 (0.89–1.06) | 1.01 (0.94–1.08) | 1.07 (0.96–1.19) | 1.09 (0.99–1.20) | 1.12 (1.03–1.21) | 1.07 (1.00–1.15) | 1.00 (0.90–1.11) | 0.97 (0.88–1.06) |
| | Age; years | | | | | | | | |
| | 0–14 | 0.93 (0.67–1.30) | 1.00 (0.77–1.30) | 1.04 (0.70–1.54) | 1.14 (0.79–1.65) | 1.58 (1.24–2.02) | 1.45 (1.16–1.82) | 1.40 (0.99–1.97) | 1.34 (1.02–1.76) |
| | 15–64[a] | 0.90 (0.80–1.01) | 0.88 (0.80–0.97) | 1.00 | 1.00 | 1.13 (1.02–1.25) | 1.08 (0.99–1.18) | 1.00 | 1.00 |
| | 65+ | 0.96 (0.89–1.03) | 1.01 (0.95–1.07) | 1.07 (0.93–1.21) | 1.15 (1.03–1.26) | 1.09 (1.02–1.16) | 1.08 (1.01–1.14) | 0.96 (0.85–1.08) | 0.99 (0.89–1.10) |
| | 65–79 | 0.94 (0.86–1.02) | 0.97 (0.90–1.04) | 1.04 (0.90–1.21) | 1.10 (0.98–1.24) | 1.14 (1.05–1.24) | 1.11 (1.03–1.19) | 1.01 (0.89–1.15) | 1.02 (0.91–1.15) |
| | 80+ | 1.00 (0.89–1.12) | 1.08 (0.99–1.19) | 1.11 (0.94–1.32) | 1.23 (1.08–1.41) | 0.99 (0.88–1.11) | 1.02 (0.92–1.13) | 0.87 (0.75–1.02) | 0.94 (0.82–1.08) |

*(Continued)*

**TABLE 3.** (Continued)

| Decade | | Cold Extremes Model 1 RR (95% CI) | Cold Extremes Model 2 RR (95% CI) | Cold Extremes Model 1 REM Index (95% CI) | Cold Extremes Model 2 REM Index (95% CI) | Heat Extremes Model 1 RR (95% CI) | Heat Extremes Model 2 RR (95% CI) | Heat Extremes Model 1 REM Index (95% CI) | Heat Extremes Model 2 REM Index (95% CI) |
|---|---|---|---|---|---|---|---|---|---|
| | | Effect of Short-Lasting Cold Extremes | | | | Effect of Short-Lasting Heat Extremes | | | |
| | | Model 1 | Model 2 | Model 1 | Model 2 | Model 1 | Model 2 | Model 1 | Model 2 |
| 1960–1969 | Total | 1.02 (0.98–1.07) | 1.02 (0.97–1.07) | | | 1.16 (1.10–1.21) | 1.14 (1.10–1.19) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.00 (0.96–1.05) | 1.02 (0.96–1.09) | 1.00 | 1.00 | 1.16 (1.09–1.23) | 1.16 (1.10–1.23) | 1.00 | 1.00 |
| | Women | 1.03 (0.97–1.09) | 1.02 (0.95–1.09) | 1.02 (0.95–1.10) | 1.00 (0.91–1.09) | 1.18 (1.10–1.26) | 1.12 (1.06–1.19) | 1.02 (0.93–1.12) | 0.96 (0.89–1.05) |
| | Age; years | | | | | | | | |
| | 0–14 | 1.08 (0.84–1.38) | 0.94 (0.71–1.25) | 1.00 (0.75–1.33) | 0.86 (0.62–1.20) | 1.02 (0.76–1.38) | 1.02 (0.78–1.32) | 0.91 (0.62–1.32) | 0.90 (0.64–1.28) |
| | 15–64[a] | 1.08 (1.00–1.17) | 1.10 (1.00–1.20) | 1.00 | 1.00 | 1.13 (1.03–1.23) | 1.13 (1.04–1.22) | 1.00 | 1.00 |
| | 65+ | 0.99 (0.94–1.03) | 0.99 (0.94–1.05) | 0.91 (0.83–1.01) | 0.90 (0.81–1.01) | 1.19 (1.13–1.26) | 1.15 (1.10–1.21) | 1.06 (0.95–1.16) | 1.02 (0.93–1.12) |
| | 65–79 | 0.96 (0.90–1.02) | 0.96 (0.90–1.03) | 0.89 (0.80–0.98) | 0.88 (0.78–0.98) | 1.16 (1.08–1.25) | 1.12 (1.05–1.19) | 1.03 (0.92–1.16) | 0.99 (0.90–1.10) |
| | 80+ | 1.02 (0.95–1.10) | 1.04 (0.95–1.12) | 0.95 (0.85–1.06) | 0.95 (0.84–1.07) | 1.23 (1.13–1.34) | 1.21 (1.12–1.30) | 1.10 (0.97–1.24) | 1.07 (0.96–1.19) |
| 1970–1979 | Total | 0.99 (0.95–1.04) | 1.00 (0.95–1.05) | | | 1.15 (1.10–1.20) | 1.16 (1.12–1.21) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.00 (0.95–1.05) | 1.01 (0.95–1.08) | 1.00 | 1.00 | 1.13 (1.07–1.19) | 1.13 (1.07–1.19) | 1.00 | 1.00 |
| | Women | 0.97 (0.91–1.04) | 0.98 (0.92–1.05) | 0.97 (0.90–1.06) | 0.97 (0.88–1.06) | 1.20 (1.14–1.27) | 1.20 (1.13–1.27) | 1.06 (0.98–1.15) | 1.07 (0.99–1.15) |
| | Age; years | | | | | | | | |
| | 0–14 | 1.10 (0.78–1.56) | 1.11 (0.78–1.58) | 1.02 (0.70–1.49) | 1.03 (0.71–1.51) | 1.26 (0.96–1.65) | 1.22 (0.93–1.61) | 1.11 (0.77–1.60) | 1.07 (0.74–1.56) |
| | 15–64[a] | 1.08 (0.98–1.19) | 1.07 (0.97–1.18) | 1.00 | 1.00 | 1.14 (1.05–1.23) | 1.14 (1.05–1.23) | 1.00 | 1.00 |
| | 65+ | 0.95 (0.91–1.01) | 0.97 (0.92–1.03) | 0.88 (0.79–0.99) | 0.91 (0.81–1.02) | 1.17 (1.12–1.23) | 1.17 (1.12–1.22) | 1.03 (0.94–1.12) | 1.03 (0.94–1.12) |
| | 65–79 | 0.94 (0.87–1.01) | 0.96 (0.89–1.03) | 0.87 (0.77–0.98) | 0.90 (0.79–1.01) | 1.15 (1.09–1.23) | 1.15 (1.09–1.23) | 1.02 (0.92–1.12) | 1.02 (0.92–1.12) |
| | 80+ | 0.97 (0.90–1.05) | 0.99 (0.91–1.07) | 0.90 (0.80–1.02) | 0.92 (0.81–1.04) | 1.19 (1.12–1.28) | 1.19 (1.11–1.27) | 1.05 (0.95–1.17) | 1.04 (0.94–1.16) |
| 1980–1989 | Total | 1.07 (0.99–1.15) | 1.07 (1.03–1.12) | | | 1.05 (1.01–1.10) | 1.06 (1.02–1.10) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.11 (1.07–1.14) | 1.09 (1.03–1.16) | 1.00 | 1.00 | 1.00 (0.95–1.06) | 1.00 (0.95–1.06) | 1.00 | 1.00 |
| | Women | 1.04 (1.00–1.09) | 1.05 (0.99–1.12) | 0.94 (0.89–0.99) | 0.96 (0.89–1.05) | 1.12 (1.06–1.19) | 1.11 (1.05–1.17) | 1.12 (1.03–1.21) | 1.11 (1.03–1.20) |
| | Age; years | | | | | | | | |
| | 0–14 | 0.75 (0.55–1.03) | 0.73 (0.46–1.13) | 0.69 (0.49–0.98) | 0.69 (0.44–1.09) | 0.87 (0.58–1.32) | 0.78 (0.52–1.18) | 0.81 (0.53–1.26) | 0.73 (0.47–1.12) |
| | 15–64[a] | 1.08 (1.01–1.17) | 1.05 (0.95–1.17) | 1.00 | 1.00 | 1.07 (0.98–1.17) | 1.07 (0.99–1.17) | 1.00 | 1.00 |
| | 65+ | 1.08 (1.04–1.11) | 1.08 (1.03–1.13) | 0.99 (0.92–1.07) | 1.03 (0.92–1.14) | 1.06 (1.01–1.11) | 1.05 (1.01–1.10) | 0.99 (0.89–1.09) | 0.98 (0.89–1.08) |
| | 65–79 | 1.08 (1.04–1.13) | 1.05 (0.98–1.12) | 1.00 (0.91–1.09) | 1.00 (0.88–1.12) | 0.99 (0.93–1.06) | 1.00 (0.94–1.06) | 0.93 (0.83–1.03) | 0.93 (0.83–1.03) |
| | 80+ | 1.08 (1.02–1.13) | 1.12 (1.05–1.19) | 0.99 (0.91–1.08) | 1.06 (0.94–1.20) | 1.13 (1.06–1.21) | 1.12 (1.05–1.19) | 1.05 (0.94–1.18) | 1.04 (0.94–1.16) |

(*Continued*)

**TABLE 3.** (Continued)

| | | Effect of Short-Lasting Cold Extremes | | | | Effect of Short-Lasting Heat Extremes | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Model 1 | Model 2 | Model 1 | Model 2 | Model 1 | Model 2 | Model 1 | Model 2 |
| Decade | | RR (95% CI) | RR (95% CI) | REM Index (95% CI) | REM Index (95% CI) | RR (95% CI) | RR (95% CI) | REM Index (95% CI) | REM Index (95% CI) |
| 1990–1999 | Total | 1.07 (0.99–1.15) | 1.05 (1.00–1.09) | | | 1.03 (0.99–1.06) | 1.07 (1.03–1.12) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.03 (0.96–1.11) | 1.05 (0.99–1.11) | 1.00 | 1.00 | 1.04 (0.99–1.09) | 1.06 (1.00–1.12) | 1.00 | 1.00 |
| | Women | 1.09 (0.99–1.21) | 1.04 (0.99–1.11) | 1.06 (0.94–1.20) | 1.00 (0.92–1.08) | 1.04 (0.99–1.09) | 1.08 (1.02–1.14) | 1.00 (0.93–1.06) | 1.02 (0.94–1.10) |
| | Age; years | | | | | | | | |
| | 0–14 | 0.90 (0.27–2.18) | 0.81 (0.49–1.33) | 1.09 (0.42–2.83) | 0.90 (0.52–1.54) | 0.81 (0.55–1.19) | 1.09 (0.73–1.65) | 0.84 (0.57–1.23) | 1.14 (0.75–1.74) |
| | 15–64[a] | 0.83 (0.66–1.03) | 0.90 (0.80–1.01) | 1.00 | 1.00 | 0.97 (0.89–1.05) | 0.96 (0.87–1.06) | 1.00 | 1.00 |
| | 65+ | 1.11 (1.03–1.20) | 1.08 (1.03–1.13) | 1.34 (1.06–1.57) | 1.20 (1.06–1.32) | 1.06 (1.02–1.09) | 1.09 (1.05–1.14) | 1.09 (1.00–1.18) | 1.14 (1.02–1.25) |
| | 65–79 | 1.10 (0.97–1.25) | 1.03 (0.96–1.11) | 1.33 (1.03–1.72) | 1.15 (1.00–1.32) | 1.02 (0.97–1.08) | 1.08 (1.01–1.15) | 1.06 (0.96–1.17) | 1.12 (1.00–1.27) |
| | 80+ | 1.11 (1.01–1.23) | 1.10 (1.04–1.17) | 1.35 (1.06–1.71) | 1.23 (1.08–1.40) | 1.08 (1.03–1.13) | 1.10 (1.04–1.16) | 1.12 (1.01–1.23) | 1.15 (1.03–1.29) |
| 2000–2009 | Total | 1.09 (0.98–1.20) | 1.03 (0.99–1.07) | | | 1.04 (1.00–1.09) | 1.08 (1.04–1.12) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.04 (0.95–1.15) | 1.01 (0.95–1.06) | 1.00 | 1.00 | 1.06 (1.02–1.11) | 1.09 (1.03–1.15) | 1.00 | 1.00 |
| | Women | 1.12 (0.98–1.27) | 1.04 (0.98–1.09) | 1.07 (0.91–1.26) | 1.03 (0.96–1.11 | 1.07 (1.02–1.11) | 1.07 (1.01–1.12) | 1.01 (0.95–1.07) | 0.98 (0.91–1.06) |
| | Age; years | | | | | | | | |
| | 0–14 | 0.47 (0.05–4.16) | 0.53 (0.28–0.99) | 0.43 (0.05–3.84) | 0.54 (0.29–1.00) | 1.08 (0.74–1.57) | 0.86 (0.51–1.45) | 1.06 (0.73–1.55) | 0.81 (0.47–1.39) |
| | 15–64[a] | 1.09 (0.83–1.43) | 0.99 (0.89–1.10) | 1.00 | 1.00 | 1.02 (0.94–1.10) | 1.05 (0.96–1.16) | 1.00 | 1.00 |
| | 65+ | 1.08 (0.98–1.20) | 1.03 (0.99–1.08) | 0.99 (0.75–1.28) | 1.04 (0.93–1.16) | 1.07 (1.04–1.11) | 1.08 (1.04–1.13) | 1.06 (0.97–1.14) | 1.03 (0.92–1.13) |
| | 65–79 | 1.04 (0.86–1.25) | 1.01 (0.94–1.09) | 0.95 (0.69–1.32) | 1.02 (0.90–1.16) | 1.07 (1.02–1.13) | 1.06 (0.98–1.13) | 1.06 (0.96–1.16) | 1.00 (0.89–1.13) |
| | 80+ | 1.10 (0.98–1.25) | 1.04 (0.99–1.10) | 1.01 (0.75–1.36) | 1.05 (0.94–1.18) | 1.07 (1.03–1.12) | 1.10 (1.04–1.15) | 1.06 (0.97–1.15) | 1.04 (0.93–1.16) |
| 1901–2009[b] | Total | 1.06 (1.03–1.08) | 1.04 (1.02–1.05) | | | 1.10 (1.08–1.13) | 1.12 (1.10–1.14) | | |
| | Sex | | | | | | | | |
| | Men[a] | 1.06 (1.04–1.08) | 1.03 (1.01–1.05) | 1.00 | 1.00 | 1.09 (1.07–1.11) | 1.11 (1.09–1.13) | 1.00 | 1.00 |
| | Women | 1.05 (1.03–1.08) | 1.04 (1.02–1.06) | 0.99 (0.96–1.03) | 1.01 (0.98–1.04) | 1.13 (1.10–1.15) | 1.13 (1.11–1.15) | 1.03 (1.00–1.06) | 1.02 (0.99–1.05) |
| | Age; years | | | | | | | | |
| | 0–14 | 1.03 (0.95–1.11) | 1.03 (0.96–1.09) | 0.97 (0.84–1.12) | 1.01 (0.94–1.09) | 1.24 (1.16–1.33) | 1.21 (1.15–1.27) | 1.13 (0.93–1.38) | 1.10 (0.90–1.34) |
| | 15–64[a] | 1.06 (1.03–1.10) | 1.02 (0.99–1.05) | 1.00 | 1.00 | 1.10 (1.07–1.13) | 1.10 (1.08–1.13) | 1.00 | 1.00 |
| | 65+ | 1.06 (1.04–1.08) | 1.04 (1.03–1.06) | 0.99 (0.96–1.03) | 1.03 (0.99–1.06) | 1.10 (1.09–1.12) | 1.12 (1.10–1.14) | 1.00 (0.97–1.04) | 1.01 (0.98–1.05) |
| | 65–79 | 1.04 (1.02–1.07) | 1.02 (1.00–1.05) | 0.98 (0.94–1.02) | 1.00 (0.97–1.04) | 1.09 (1.07–1.12) | 1.10 (1.08–1.13) | 0.99 (0.96–1.03) | 1.00 (0.97–1.04) |
| | 80+ | 1.07 (1.04–1.10) | 1.07 (1.04–1.09) | 1.01 (0.97–1.05) | 1.05 (1.01–1.09) | 1.11 (1.09–1.14) | 1.13 (1.11–1.16) | 1.01 (0.98–1.05) | 1.03 (0.99–1.07) |

[a]Reference category.
[b]Entire study period.
REM indicates relative effect modification; NA, data not available.

heat and cold extremes in the 0–14 age group but not the 15–64 age group. Time trends among the elderly followed that of total mortality, with a significant declining trend over time for heat extremes but not for cold extremes. We found no strong evidence of age being an effect modifier for changes over time.

## DISCUSSION

Mortality data for the past century in Stockholm, Sweden, show a consistent elevation in RR of death after extremes of temperature, with greater risks for extremes of heat than of cold. Over time there has been a generally declining trend of mortality RR with temperature extremes, although risks remain elevated for the elderly. Age and sex are not consistent effect modifiers. Because women tend to live longer than men, the modifying effect in older age groups is hard to disentangle from the effect of sex. There are even indications that, beginning one to three decades ago, the population of Stockholm County may be becoming more susceptible to heat extremes. In particular, men and the middle-aged appear to contribute to this recent upward trend.

Recent changes are occurring at a time when the number of cold extremes is decreasing and heat extremes are becoming more frequent and intense. A decrease in cold extremes may be contributing to a shift in susceptible populations, such that mortality formerly caused by cold is more likely to occur with heat.[25] A doubling of susceptibility to heat-related mortality in the last two decades has been reported in this region.[25]

Patterns of temperature-related mortality over a longer period may shed light on results from studies focused on shorter periods. We found reduced vulnerability to heat- and cold-related mortality over time. This decline may be attributable to better housing and health systems, behavioral and physiologic adaptation, and heightened public awareness of dangers associated with extreme temperatures. Given that Stockholm is situated in a cold climate, it is likely that many of the adaptive measures over time have aimed at reducing the adverse effects of cold temperatures.

The past 100 years has been a time of fundamental changes in both public health and mortality. Life expectancy at the national level increased from about 56 years during the first decade of the 20th century to more than 81 years in 2009.[26] The epidemiologic transition[20] changed mortality patterns from death primarily in childhood to death in old age. This development is connected to changes in the causes of death. The dominant cause of mortality in early industrial periods was infectious disease, often of epidemic character, whereas chronic diseases are presently responsible for most deaths.

Our results are similar to those of Carson et al[17] and Ekamper et al[19] who reported declining vulnerability to temperature-related mortality in England and the Netherlands over the 20th century. Davis et al[18] investigated whether annual heat-related mortality rates had changed in the United States during 1964–1998. They detected a decline in heat-related vulnerability, which they attributed mainly to improvements in the health sector, population adaptation, improvements in urban design, and increased use of air conditioning. Lerchl[27] found declining seasonality of mortality in Germany during 1946–1995 and concluded that this was mainly due to increased use of central heating and improvements in the public health sector.

We report results from two models—model 1 producing estimates with fixed criteria for extreme temperatures over time, and model 2 using decade-specific criteria. The results of these models should be interpreted somewhat differently. Model 2 defines temperature extremes relative to the prevailing climate, thus assuming adaptation to potentially increasing temperatures and accounting for changes in temperature extremes over time. Even though both models show increased risk of mortality during heat extremes, model 1 generally reports higher estimates than model 2 in the earlier part of the century whereas model 2 shows higher estimates in the later part of the century. This contrast is presumably due to increasing temperatures over time.

One limitation to the study is that neither intensity nor duration of the temperature extremes were taken into account when estimating the RRs of mortality. Barnett et al[28]found that more intense heat waves increased the risk of mortality, whereas the same was not true for cold spells. Gasparrini and Armstrong[29] found heat waves lasting more than 4 days had a small effect on mortality (compared with the effect of temperature itself). Due to data availability, we report only results for all-cause mortality. Given the substantial changes in causes of mortality over the study period, and given that temperature–mortality relationships differ among vulnerable groups, it would be of interest to be able to present results for cause-specific mortality.

Previous studies have suggested that adaptation to weather has occurred over the 20th century. However, the changes observed in this and previous studies cannot be attributed to adaptation alone. None of these investigations has controlled for variables independent of adaptation, which potentially modify temperature effects and their change over time (eg, causes of death, demographic factors, and prevalence of medical conditions). Unexpectedly, we observed a recent leveling of the decreasing trend of heat susceptibility, with some groups experiencing an upward trend in temperature susceptibility in recent decades.

In conclusion, we found that susceptibility to heat extremes has decreased substantially over the last 110 years in Stockholm, Sweden. A decreasing susceptibility to cold extremes was also found, although with more variability. This apparent progress over time may indicate improvements in adaptation and general conditions, although recent increases in risk indicate possible increasing susceptibility to temperature extremes, particularly heat. To the extent that climate change brings increased episodes of extreme heat, this poses a challenge to societies and to the health sector, especially in protecting susceptible populations.

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