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ORIGINAL ARTICLE

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Changes in the seasonality of mortality in Germany from 1946 to 1995: the role of temperature

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Abstract Based on records from the Federal Bureau for Statistics of Germany, the seasonality of mortality was investigated for the period 1946–1995. Lowest mortality rates were found during summer (August or September) while highest values were found in winter (January through March). Non-linear regression of all monthly mortality data with the average monthly temperatures in Germany revealed a significant negative relationship (r=–0.739; n=600; P<0.0001). The fact that the differences between the long-range monthly temperatures and the individual monthly temperatures also showed a distinct relationship to the mortality rates speaks against a mere coincidence of both parameters. The amplitude of this seasonal rhythm declined steadily within the observation period. It is concluded that low temperatures cause an increase in mortality rates and that this effect has become less important during recent decades due to the increased use of central heating and because of improvements in the public health system.

Key words Mortality · Human · Seasonality · Secular trend · Temperature

Introduction

In humans, a number of physiological, psychological, and endocrine parameters show distinct annual rhythms, e.g. fibrinogen content of blood (Stout and Crawford 1991), seasonal affective disorder (SAD, Dalgleish et al. 1996), and serum melatonin levels (Buresova et al. 1992; Vondrasova et al. 1997). Likewise, human reproduction shows seasonal components (for review see Roenneberg and Aschoff 1990a,b). Recently, a seasonal rhythm in human sex ratio at birth has been identified in Germany (Lerchl 1998).

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As at the beginning of life, there are also distinct seasonal rhythms at its end (McKee 1990; Laake and Sverre 1996; Motohashi et al. 1996). Seasonal mortality rates are believed to be caused by a number of physiological parameters, e.g. haemostatic factors (Stout and Crawford 1991; Stout et al. 1996), blood pressure (Woodhouse et al. 1993), malnutrition (Brewster and Greenwood 1993), and seasonal variations of the immune system (Nelson et al. 1995). It is suggested that these changes, in turn, are a consequence of seasonal fluctuations of temperature (Hare et al. 1981; McKee 1990; Enquselassie et al. 1993; Kalkstein and Greene 1997), rainfall (Motohashi et al. 1996), or photoperiod (Nelson et al. 1995). In addition, anthropogenic factors like air pollution also have some impact (Schwartz 1994).

Both seasonal rhythms of reproduction (Roenneberg and Aschoff 1990a; Lerchl et al. 1993) and mortality (Hare et al. 1981; Keatinge et al. 1989) show secular trends, e.g. a decrease in amplitude or a phase-shift over decades. These trends are probably caused by changes in the environment to which humans are actually exposed: this "microenvironment" has been progressively stabilized by air-conditioning and heating units, thus humans are less often exposed to the natural environment but are more and more shielded from it. The study presented here was conducted to evaluate the possible secular trends of mortality rates in a country in which the seasonality of birth rates has not only changed, but phase-shifted by 180° (6 months) during the 1970s (Lerchl et al. 1993). It was therefore interesting to investigate whether the mortality rhythms changed to a comparable extent.

Methods

Raw data were supplied by the Federal Bureau for Statistics (Wiesbaden, Germany) and covered the period from 1946 to 1995 for both parts of Germany, which were separated until 1990. The monthly data were corrected for different month lengths and linear trends and were related to the respective year's total mortality to yield a relative value (for details of the method see Roenneberg and Aschoff 1990a). The data are therefore expressed as per cent above or below the annual mean (0%). Monthly data were grouped at 5-year intervals to illustrate the secular trends.

Global temperature recordings and station identification codes were provided by the National Climatic Data Center (Asheville, N.C., USA) via internet download (http://www.ncdc.noaa.gov/pub/data/ghcn/v2). Data for Germany from 1946 to 1995 were extracted by a computer software package (SPSS Inc., Chicago, U.S.A.). Only recordings from weather stations below 800 m altitude were included for calculations of average monthly temperatures, since less than 1% of the German population lives at higher altitudes.

For regression analysis between the average monthly temperatures and the corresponding mortality rates, a quadratic equation was used ($y=a+bx+cx^2$). This model best described the relationship between the two parameters. Since the correlation of the monthly temperature data with the mortality rates may be a coincidence rather than a causal relationship, another statistical comparison was performed as outlined earlier (Jendritzky et al. 1997): for each month its long-ranging average was calculated for the entire observation period (50 years). Based on these 12 values (T_{month}), each individual month's (t_{month})deviation from its corresponding long-ranging value was computed: $\Delta t = T_{month} - t_{month}$. Finally, the mortality rates were grouped according to these deviations.

Results

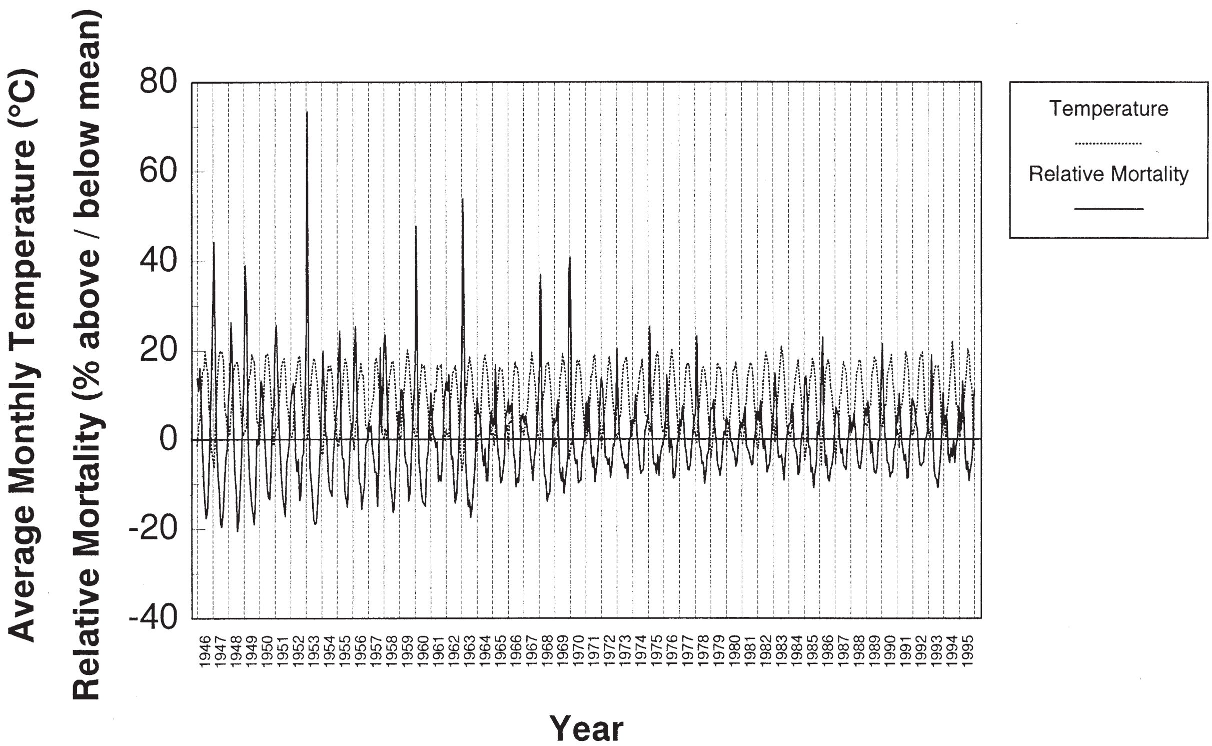
The consecutive mortality rates and the temperature recordings are shown in Fig. 1. One can see there is an inverse relationship between the temperatures and the mortality rates with no marked secular trend of the temperatures. The amplitude of the seasonal mortality rhythms, however, is much higher at the beginning of the observation period and becomes less pronounced at its end. This trend is more clearly visible when data are grouped at 5-year intervals (Fig. 2). While the highest deviations from the annual means reach 20–30% amplitude during the winter months (January or February) until 1956–1960, these values decline thereafter to less than 10% in the period 1991–1995. The relatively lowest mortality rates are observed in summer months either in July or August. Again, the derivations from the annual means decline from approximately 17% (1946–1950) to less than 10% after 1970. There was no secular phase shift seen, i.e. the months during which the highest and lowest mortality rates were observed remained almost unchanged.

The relationship between average monthly temperatures and the mortality rates is shown in Fig. 3. A highly significant, non-linear correlation is evident ($r=-0.739$; $P<0.0001$). The relation between deviations from the monthly mean temperatures and the mortality rates (Fig. 4) shows that the mortality is relatively low when the individual months' temperatures match the long-ranging ones, while they get higher at larger deviations from the long-ranging means, particularly at large negative deviations.

Discussion

The data presented here show a clear seasonal component of mortality which is in good accordance to former studies (Keatinge and Donaldson 1997; McKee 1990; Laake and Sverre 1996; Motohashi et al. 1996; Jendritzky et al. 1997). Interestingly, the amplitudes of the Norwegian seasonal mortality rates were less than half of the English ones (Laake and Sverre 1996). Likewise, the secular decline in seasonality of mortality rates as shown here matches the observations in England plus Wales (Hare et al. 1981; Keatinge et al. 1989), based on records covering the periods 1912–1978 and 1964–1984, respectively.

Fig. 1 Consecutive data for average monthly temperatures and mortality rates, related to the total number of each year's deaths



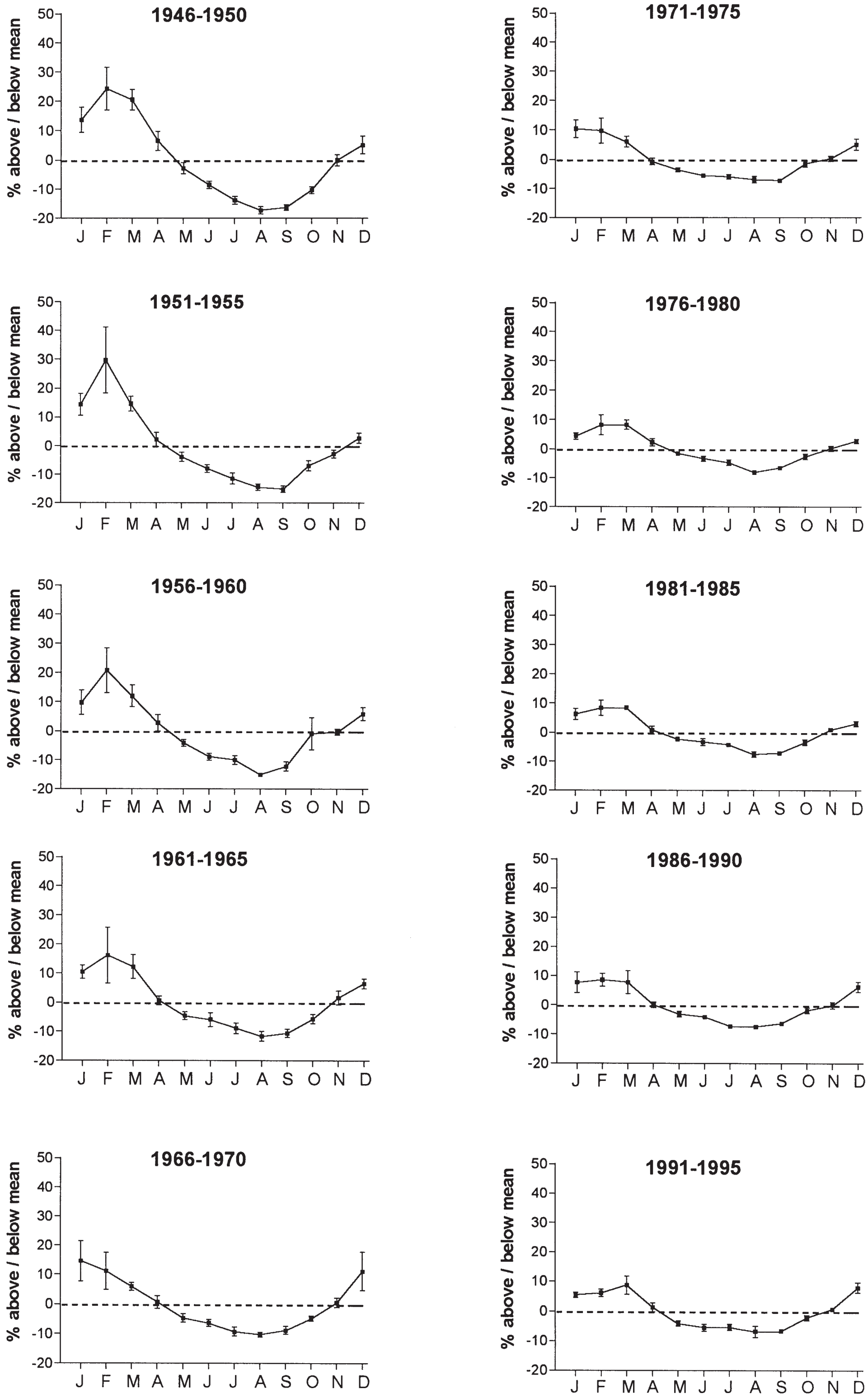


Fig. 2 Secular trend of mortality rates in Germany from 1946 to 1995. Means ± SEM are shown

As discussed by Keatinge et al. (1989), the decreased seasonal component in recent years is probably a consequence of the increased use of central heating, from some 13% in 1964 to 69% in 1984. Nevertheless, the persistent excess in mortality during cold months is believed to be mainly due to brief excursions outdoors. The fact that in the present study there is virtually no further decline in seasonality of mortality after 1971 is in good accordance with the stabilizing proportion of households with central heating.

It appears safe to state that the primary meteorological correlate for the seasonality of mortality is the seasonality

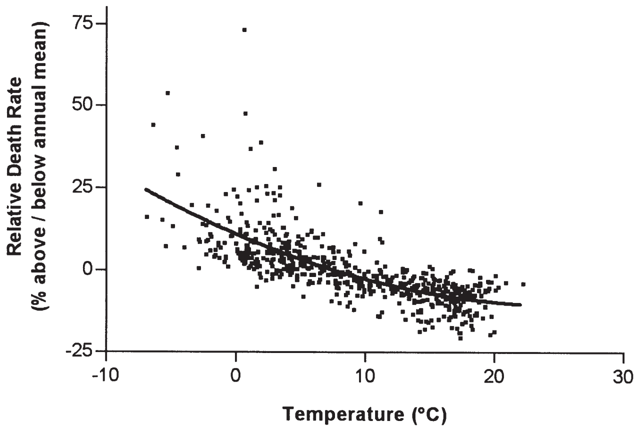


Fig. 3 Relation between average monthly temperatures and mortality rates in Germany for the period 1946–1995; n=600, P<0.0001 (non-linear regresion)

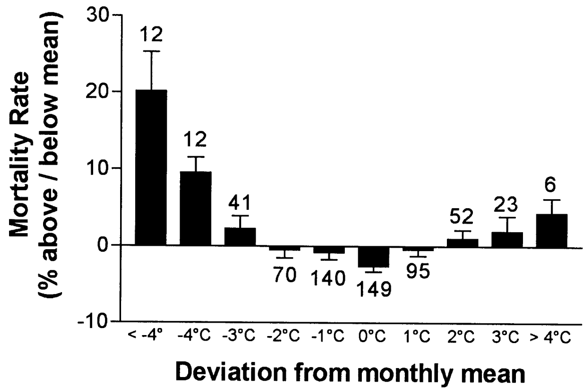


Fig. 4 Effects of deviations of the mean monthly temperatures on the mortality rates. Means ± SEM are shown. The numbers above the *bars* give the observations per mean

of outdoor temperatures: first, a highly significant non-linear correlation was found between the mean monthly temperatures and the mortality rates (Fig. 3); second, the mortality rates are further affected by the individual months' temperature deviations from their respective long-ranging mean (Fig. 4). Another study from southwest Germany found a comparable relationship within a shorter observation period (Jendritzky et al. 1997), thus corroborating the data given here. Since low temperatures cause a variety of physiological changes, e.g. of the blood composition and blood pressure (Stout and Crawford 1991), which in turn are believed to contribute to an increased incidence of stroke and heart infarcts (Enquselassie et al. 1993; Woodhouse et al. 1993), it appears clear why low temperatures are associated with higher mortality rates.

When looking at Fig. 3 one could draw the conclusion that the higher the environmental temperatures become, the lower the mortality rates become. However, the temperatures in Germany are considered to be moderate with average monthly temperatures very rarely exceeding 20°C (Fig. 3). In other countries, the situation is quite different. Kalkstein and Greene (1997), for example, have analysed the mortality data for large cities in the United States and found increased mortality rates during winter, but also at high temperatures during the summer months, the latter being a consequence of circulatory distortions (heat load). In Shanghai, a city with comparably high temperatures, maximum daily temperatures of more than 35°C can cause an increase in mortality of more than 200%, as compared to temperatures below 25°C (Hsia and Lu 1988). Thus, the lowest mortalities are to be expected at temperatures around 20–25°C.

In contrast to the aforementioned studies and our data, a comparison of mortality rates and outdoor temperatures in Norway did not show a distinct relationship. Rather, the main cause for the winter excess of deaths was found to be associated with a higher influenza infection rate (Laake and Sverre 1996). Thus, different causes for the winter excess of mortality may exist in some countries (see also Keatinge and Donaldson 1997).

The secular trend of mortality rates (Fig. 2) indicates that the influence of environmental temperatures is becoming less pronounced since the temperatures per se are more or less unchanged (see also Fig. 1). Thus, either the outdoor temperatures influence humans to a lesser degree, or they cause less damage. There is evidence for both possibilities: On the one hand, the increased use of central heating (Keatinge et al. 1989; Keatinge and Donaldson 1997) has certainly led to a diminished exposure to low outdoor temperatures, while the availability and higher quality of clothes has led to improved insulation. On the other hand, the health care system has changed over the years, leading to a better diagnosis and treatment of many diseases such as hypertension, which is probably the indirect cause of seasonal mortality, especially in the elderly (Woodhouse et al. 1993).

There are strong indications for a secular trend in environmental temperatures due to increased pollution of the atmosphere. That these trends may drastically increase the already high mortality rates during summer months and slightly decrease the mortality in winter months has been calculated recently for cities in the United States by Kalkstein and Greene (1997). If comparable temperature increases are to be expected in Germany, it is speculated that the overall mortality rates in winter months will be decreased while the excess of mortality in summer months will increase (Fig. 4).

Although the data presented here show a clear decrease in the seasonality of mortality rates, there is no sign of a phase reversal as seen in the birth rates from 1946 to 1990 (Lerchl et al. 1993). This difference corroborates the theory that seasonality of birth rates is a consequence of both social and environmental influences while the seasonality of mortality rates is likely to be due to influences of climatic factors only.

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