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Summer climate and mortality in Vienna – a human-biometeorological approach of heat-related mortality during the heat waves in 2003

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Sommer-Klima und Mortalität in Wien – Ein human-biometeorologischer Ansatz für den Vergleich der hitzebedingten Mortalität von 2003 mit anderen Jahren

Zusammenfassung. *Hintergrund*: Starke Hitzebelastung beeinträchtigt den menschlichen Organismus, die Mortalität steigt während Hitzeperioden. Der „Jahrhundertsommer 2003" mit mehreren langanhaltenden Hitzewellen führte besonders in West-Europa zu zahlreichen zusätzlichen Todesfällen; auch Wien war davon betroffen. In dieser Untersuchung betrachten wir den Sommer 2003 in einem größeren zeitlichen Kontext um zu beurteilen, ob wie sehr sich die hitzebedingte Mortalität 2003 von anderen Jahren unterscheidet.

Methode: Die Untersuchung basiert auf meteorologischen Daten und Mortalitätsdaten des Bundeslands Wien für den Zeitraum 1970–2007. Die thermische Belastung wurde über den human-meteorologischen Parameter *Physiologisch Äquivalente Temperatur* (PET) berechnet, kurzfristige Anpassungseffekte wurden über den HeRATE-Ansatz berücksichtigt. Basierend auf thermo-physiologischen Belastungsklassen wurde der Einfluss der Hitzebelastung auf die Mortalität bestimmt. Zwei verschiedene Ansätze berücksichtigen langfristige Veränderungen in der Sensitivität.

Ergebnisse: Die hitzebedingte Mortalität steigt mit zunehmender thermischer Belastung, im Laufe der Untersuchungsperiode verflachte sich jedoch dieser Anstieg. Eine über den Untersuchungszeitraum gemittelte Sensitivität, ergibt auch für Wien die höchsten Werte im Sommer 2003. Mit Berücksichtigung der abnehmenden Sensitivität wiesen jedoch die Sommer 1992, 1994 und 2000 eine höhere Zahl hitzebedingter Todesopfer auf.

Diskussion: Trotz oder vielleicht wegen der signifikanten Zunahme der Tage mit Hitzebelastung ist die Sensitivität gegenüber Hitzebelastung zurückgegangen. Dies könnte ein Hinweis auf langfristige Anpassungsprozesse an die veränderten klimatischen Bedingungen sein. Deswegen war das Jahr 2003 in Wien ein Jahr mit deutlich erhöhter Sterblichkeit durch Hitzestress, ohne jedoch außergewöhnlich gewesen zu sein.

Summary. *Background:* Strong heat load has negative impacts on the human health and results in higher mortality during heat waves. In Europe, the summer 2003 was responsible for a high number of heat-related deaths, especially in Western Europe. Vienna was only partially affected. The aim of this study is to compare the heat-related mortality of 2003 with other years and to analyze whether 2003 was exceptional in Vienna.

Methods: The analysis is based on both meteorological and mortality data for the federal state of Vienna (Austria) for 1970–2007. We used the human-biometeorological index *Physiologically Equivalent Temperature* (PET) in order to assess the heat load affecting the human body, and considered short-term adaptation by the HeRATE approach. Each day between April and October was classified according to its thermal stress level and the mean mortality for each class was analyzed. Two approaches, with and without long-term sensitivity trends were considered.

Results: Mortality increases significantly with thermal stress, but this increase attenuated in the last decades. Based on the sensitivity for the period of investigation, 2003 was the year with the highest heat-related mortality. Including the long-term sensitivity trend, other years (1992, 1994 and 2000) were characterised by higher values.

Discussion: In the last decades the number of days with heat stress increased, but the sensitivity to heat stress decreased. This could indicate long-term adaptation processes. Hence, heat-related mortality in 2003 was high, but not exceptionally high.

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Key words: Mortality, climate, heat wave 2003, Vienna, physiologically equivalent temperature, adaptation.

Introduction

Climate in general is closely related to human health and can have positive and negative effects on the human organism. The negative effects are usually caused by extreme climatic conditions, e.g. very cold or very hot conditions. The threshold for both very hot and very cold weather differs on regional and temporal scales. Additionally, various parameters or combination of parameters can be used to describe a heat load situation [1–3]. Therefore no globally valid definition of a heat wave exists till today [4, 5]. In contrast, the special relationship between thermal stress and human health needs to be analysed individually for each region [5, 6].

In many studies mortality is used as an indicator of human health in general, and in most cases a strong increase of mortality during heat waves was found. Usually heat waves and their effects have been expressed by simple climatological parameters, e.g. air temperature or a combination of air temperature and air humidity [7–10]. Most of them deal with daily maxima or minima values. However, modern human-biometeorology analyses the effects of the thermal environment on humans by modelling the energy exchange of the human body with its thermal environment. Based on these energy balance models, the thermal stress can be described in a "thermophysiological relevant way" [11]. One of these indexes is the Physiologically Equivalent Temperature (PET) [11, 12], which is based on the Munich energy balance model for individuals (MEMI) [13].

PET describes the complex thermal situation by a single thermal index (expressed in °C), which considers meteorological (air temperature, air humidity, wind speed, short- and long wave radiation) and thermo-physiological (clothing, activity of humans, age and others) elements of a standard person [11].

PET is defined as a distinct air temperature related to fixed standard indoor conditions, where the heat balance of the human body shows the same core and skin temperature equal to the outdoor conditions assessed [11]. Compared to other thermal indices PET has the advantage of using a commonly known unit (°C), which makes the result easily understandable, also for people who may be unfamiliar with the human-biometeorological terminology. Additionally, PET can be calculated for every day of the year in every climate [21]. Table 1 assigns PET ranges to different grades of thermal perception and physiological stress for the standard person used. The assignment is only valid for middle European countries like Austria.

In summer 2003, several heat waves covered large parts of Western Europe with serious impacts on human health in several European countries [14–17]. Two heat waves, one in June and another one in the first two weeks of August, were responsible for more than 45,000 additional deaths in Europe [17]. The highest intensities and also the highest health impact of the August 2003 heat wave were measured in the region of Paris. Austria and especially Vienna were only partially affected [15], although higher mortality values were also found for Vienna [18].

Table 1. Ranges of Physiologically Equivalent Temperature (PET in °C) for different grades of thermal perception by humans according to Ref. [22]

PET	Thermal perception	Grade of physiological stress
	very cold	extreme cold stress
4		
	cold	strong cold stress
8		
	cool	moderate cold stress
13		
	slightly cool	slight cold stress
18		
	comfortable	no thermal stress
23		
	slightly warm	slight heat stress
29		
	warm	moderate heat stress
35		
	hot	strong heat stress
41		
	very hot	extreme heat stress

In this study we compare the influence of the summer 2003 on mortality to other hot summers in the last decades, and analyse whether 2003 was a year with exceptional high heat-related mortality.

Materials and methods

Mortality data

We used daily mortality data for the federal state Vienna (size of the population about 1.6 million), obtained from the *Statistik Austria* for the period 1970–2007. The data are classified by gender and cause of death according to ICD–10 (*International Statistical Classification of Diseases*). Since the analysis focusses on the effect of heat waves, only the months of April to October were considered. The daily mortality is characterised by a clear seasonal cycle with higher values in winter and lower ones in summer. This seasonal cycle can be extracted by a Gaussian smooth, which results in a sinusoidal shape with peaks in the winter. Additionally the mortality shows a negative trend during the period of examination. The mean number of deaths per day reaches from 80 in the 1970th to around 50 in the first years of the 21th century; within this 38 years, mortality decreased significantly (p-value of the linear regression <0.001). During this time, only slight changes in the size of the population of Vienna occurred, hence the long-term trend is probably due to changes in the age-structure of the population and improvements in the medical system. In order to remove these effects and to identify the periods with higher mortality rates, a multi-fold approach was applied to calculate the expected mortality or baseline mortality for each day [19]. This approach calculates the expected mortality, based on a modified Gaussian smooth of the daily mortality rates (death per 100,000 inhabitants). Modified means, that the result of the Gaussian smooth is multiplied with a correction factor, to control for the fact, that the smoothing procedure flattens the minima and the maxima of the annual cycle. Additionally, extreme high or low values are removed before applying the Gaussian smooth [19]. Daily deviations (in percent) of the expected mortality were calculated, which are called *relative mortality* in the following. The Gaussian smooth is not defined at the beginning and at the end of the data, so the first six months in 1970 and the last six months in 2007 were removed by this procedure. Hence, in order to consider only complete years, the investigation period was limited to the period 1971–2006. In addition, running two day mean values of the general (causes of death) relative mortality were used to reduce the day-to-day variability.

Climate data

The *Central Institute for Meteorology and Geodynamics* (ZAMG) in Vienna provided the climate data. For the present study the 14 CET (Central European Time) measurements of air temperature, air humidity, wind speed and cloud cover from the main station (Hohe Warte, Vienna) of the ZAMG were used. From this data the PET for a standard person (male, age: 35 years, height: 1.75 m, weight: 75 kg, light activity, thermal resistance of clothing: 0.9 clo) was calculated using the RayMan model [20].

Previous studies found a different effect of heat waves in early summer compared to late summer [1, 23]. The impact of early heat waves on mortality is higher than the impact of heat waves of the same magnitude in late summer, a fact that can be explained by short-term adaptation processes. We used the HeRATE [19] approach to allow for this effect. HeRATE modifies the thresholds of thermal perception (Table 1), in regard of thermal conditions of the previous 30 days using a semi-fold Gaussian smooth [19, 24]. This intensifies earlier heat waves and reduces later ones.

In this study, we focus on single days with high values of thermal stress. Following the modified thresholds of Table 1, the days of the investigation period 1971–2006 were assigned to four thermal stress classes. We defined a large class of days with thermal acceptability (PET < 29°C) and three heat stress classes for days with moderate (PET 29–35°C), strong (PET 35–41°C) and extreme (PET ≥ 41°C) heat stress. For each class the mean relative mortality per class was calculated based on different time periods. Afterwards the mean relative mortality per class was combined with the number of days per class and year to calculate the accumulated effect of heat stress of single years.

Results

In the first step, the heat stress conditions of the summer 2003 are described and compared to other years of the period 1971–2006. Afterwards we investigate the relation between heat stress and mortality in Vienna and we present two different approaches to assess the health impact of summer 2003.

Heat stress in Vienna

Figure 1 shows the number of days of the four heat stress classes for each year from 1971 to 2006. Each year contains 214 days, due to the restriction to the months April to October. The hot conditions of summer 2003 are obvious, the years 1992, 1994 and 2000 show similar patterns though. The number of days with extreme heat stress was highest in 1994, with 17 days compared to 15 in 2003. Furthermore, days with moderate or strong heat stress were more frequent in 2003 (50 and 35 days, compared to 36 and 24, respectively).

For the modified climate data, which includes short-term adaptation (HeRATE), the days with extreme heat stress become more frequent (figure not shown). The highest number of days with PET ≥ 41°C occurs in 2003, with 22 days compared to 20 in 1992 and 1994.

Since 1956, the temperature increased globally by 0.13°C per decade [25]. In Vienna the increase of annual mean air temperature between 1971 and 2006 was notably higher, reaching 0.31°C [95% confidence interval (CI): 0.21°C to 0.41°C] per decade for annual mean, and 0.52°C [CI: 0.43°C to 0.61°C] per decade for the mean value of the months April to October. This trend is reflected in the number of days with heat stress. In the investigation period a significant decrease in the number of days with thermal acceptability and an increase in the number of days for the three heat stress classes was found. This increase was significant in the classes of strong (+0.26 days per year, CI: 0.17, 0.35) and extreme (+0.20 days per year, CI: 0.13, 0.26) heat stress.

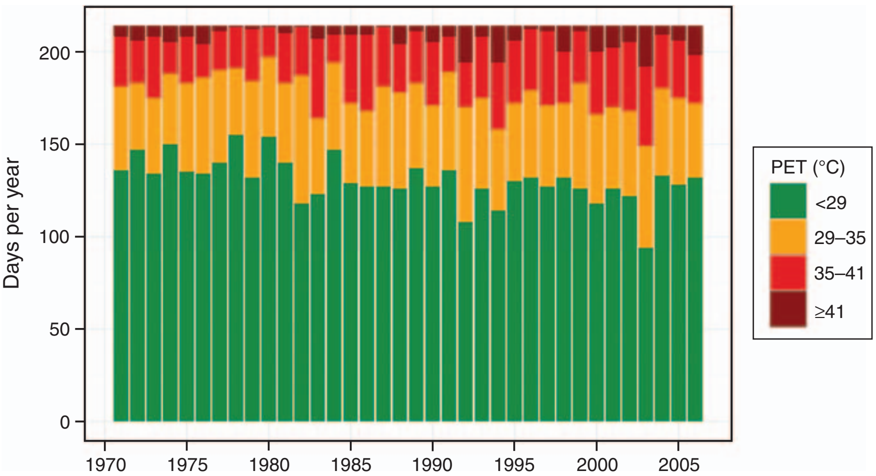

Fig. 1. Long-term annual amount of days in the PET classes (<29°C, 29–35°C, 35–41°C, ≥41°C) for the months April to October in Vienna

Relationship between thermal stress and mortality

The population of Vienna shows a significant sensibility to thermal stress (Fig. 2). Summer days with a midday PET below 29°C show a mean relative mortality slightly below the expected value (–1.8% CI: 2.1%, 1.5%). Above 29°C PET relative mortality rises significantly, on days with moderate heat stress by 0.9% (CI: 0.4%, 1.4%), on days with strong heat stress by 5.8% (CI: 5.0%, 6.5%), and on days with extreme heat stress by 13.0% (CI: 11.1%, 14.7%). The differences between the classes are significant in all classes.

A gender-specific evaluation (not shown) reveals a significantly higher sensitivity for women compared to men. In addition, the mortality due to respiratory diseases and diseases of the cardiovascular system is more sensitive to thermal stress, with significant differences compared to the relative mortality for all causes of death on days with extreme heat stress.

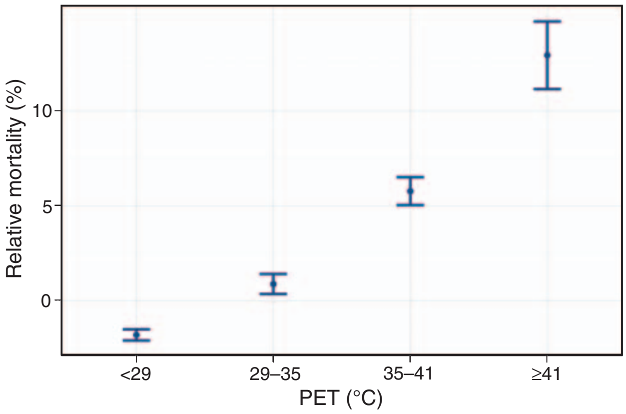

Fig. 2. Mean relative mortality (with 95% confidence interval) per PET class (<29°C, 29–35°C, 35–41°C, ≥41°C) for the period 1971–2006 in Vienna

Impact of 2003 – first approach

To assess the impact of the different heat stress classes, the number of occurrences for each class is combined with its impact. This is done by a multiplication of the mean relative mortality (including CI) with the mean number of days per year. The product is called *accumulated heat-related relative mortality* (Fig. 3) and describes the accumulated daily deviations of the mortality from the expected value for every year.

Days with thermal acceptability show an accumulated heat-related relative mortality that is notable negative, and days with moderate heat stress show only slightly elevated values. Since we focus on heat stress, the following results are limited to days with strong or extreme heat stress (PET ≥ 35°C).

The upper panel of Fig. 3 describes the accumulated heat-related relative mortality for days with strong and extreme heat stress, the lower two panels contain the values for strong or extreme heat stress, respectively. Using the mean relative mortality for the period 1971–2006, the year 2003 is characterised by the highest accumulated heat-related mortality. This is a combined effect of the high number of days with strong and extreme heat stress, whereas other years are characterised by a high number of days with strong or extreme heat stress either. However, the differences to other years with high-accumulated mortality (e.g. 1994) are not significant.

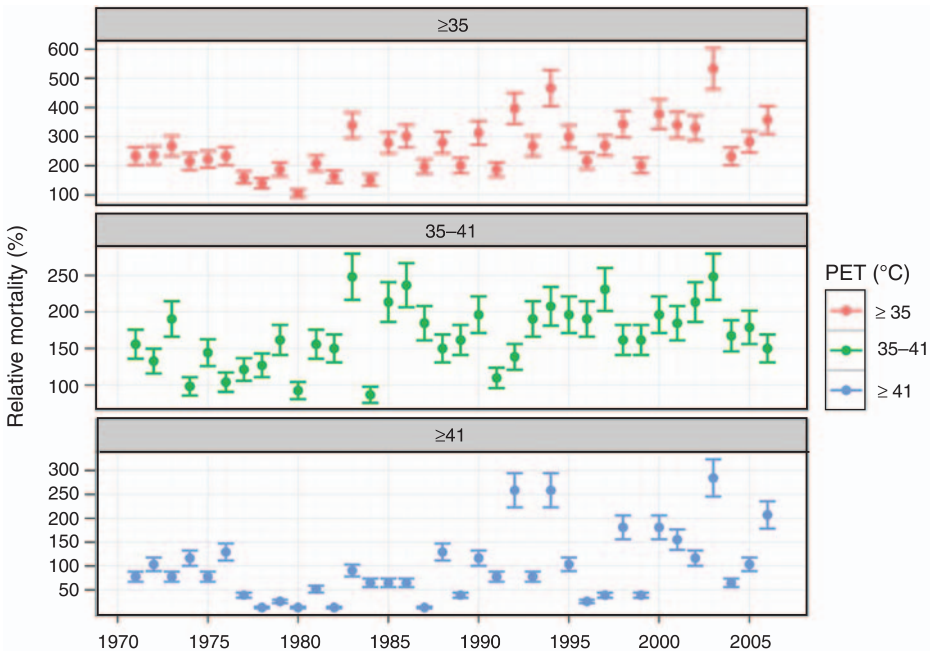

Fig. 3. Annual accumulated heat-related relative mortality for the period 1971–2006 in Vienna based on the mean mortality over the complete period 1971–2006

Impact of 2003 – second approach

The mean mortality per class based on the 36 years period is not the optimal way to describe the additional heat-related mortality in 2003. Since 1971, the PET-mortality relationship shows a decline in all heat stress classes, with significant trends in the classes of moderate and strong heat stress (Fig. 4). For this reason, the use of the decadal mean relative mortality could be more appropriate.

The mean relative mortality per class and decade is presented in Fig. 5, where the last decade 2001–2006 contains only 6 years, resulting in a slightly larger confidence interval, but lower mean values compared to the mean values of the period 1971–2006.

A combination of the decadal mean values per class, combined with the number of days per class for each year reveals a new assessment of the heat-related mortality in 2003. As seen in Fig. 6, 2003 is now characterised by an accumulated heat-related mortality, which is still above the mean of the investigation period, but no longer the highest. In contrast, there are some years in the early 1990th with higher, but not significant higher values than 2003.

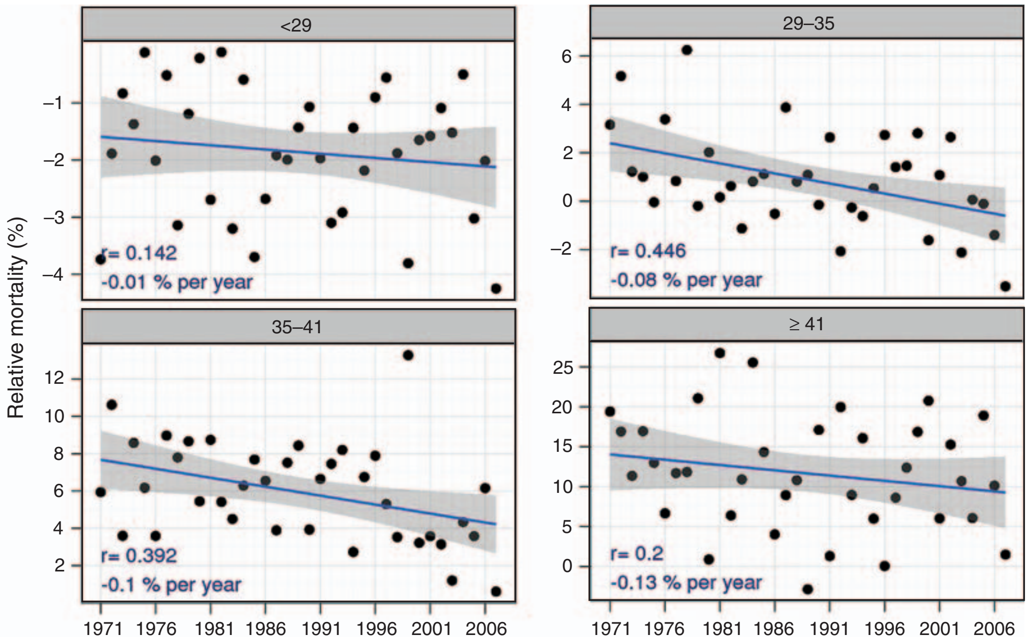

Fig. 4. Mean relative mortality per PET-class (°C) and year including a linear regression line (with 95% confidence interval)

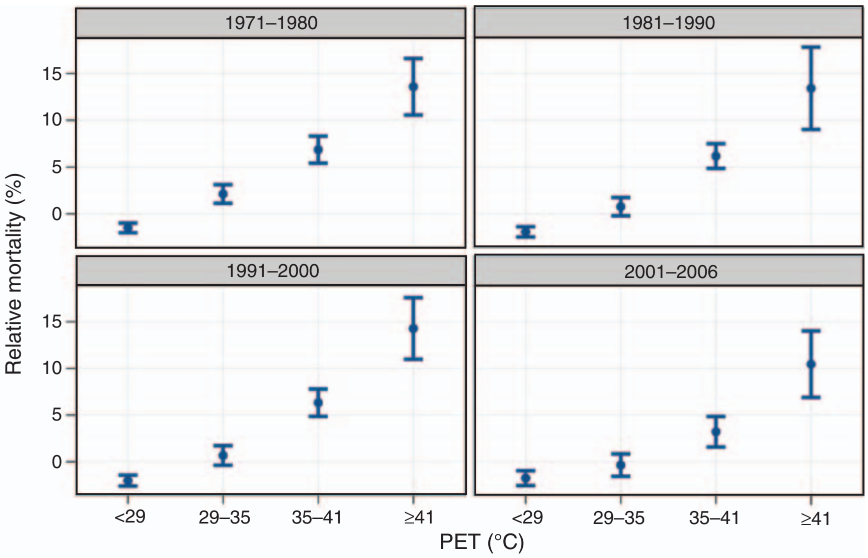

Fig. 5. Mean relative mortality (with 95% confidence interval) per PET-class (<29°C, 29–35°C, 35–41°C, ≥41°C) per decade in Vienna

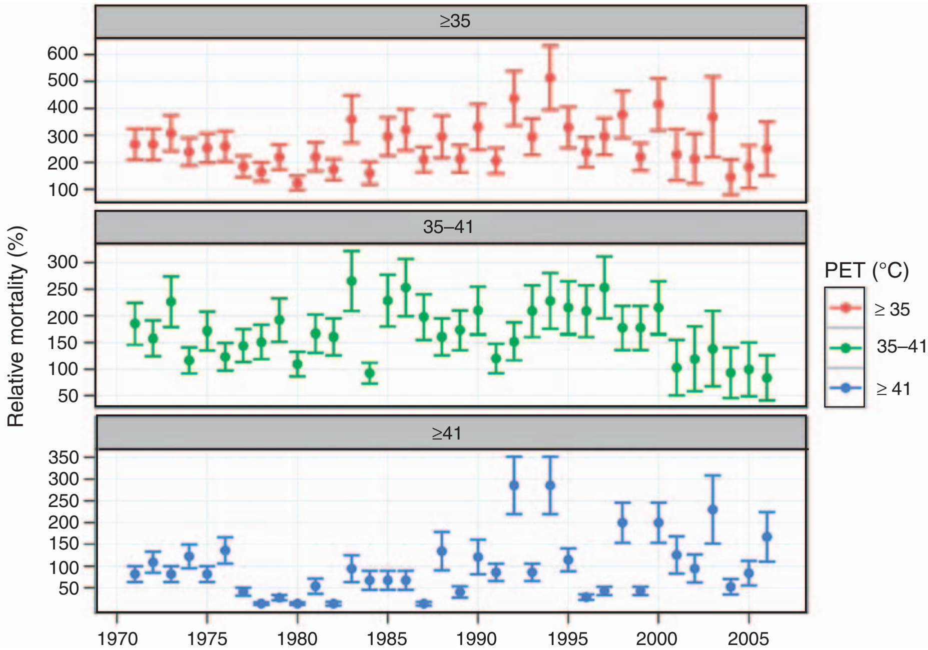

Fig. 6. Annual accumulated heat-related relative mortality in Vienna based on decadal mean mortality

Discussion

We found a significant increase of mortality on days with heat stress; similar results were found by Hutter et al. [18]. In Vienna the threshold between thermal acceptability, with a relative mortality below the expected mortality and heat stress is situated at about 29°C (PET at 14 CET).

In summer 2003 the amount of days with heat stress (PET ≥ 29°C) was the highest in the investigation period. Hence, 2003 can be classified as an exceptional year with strong (PET 35–41°C) and extreme (PET ≥ 41°C) heat stress. This can be seen also from Fig. 3, where the accumulated heat-related relative mortality of both classes is high, whereas other years show only high values on days with strong (1983, 1986) or extreme (1992, 1994) heat stress. The combined effect of both classes leads to the highest accumulated relative-heat-related mortality in 2003 without differing significantly from 1994.

The number of days with strong or extreme heat stress increased significantly during the investigation period. This trend is probably intensified through the particularly cold decade of the 1970th. Contrary to the PET trend, the mean relative mortality per heat stress class decreased in the same period. The trend is significant in the moderate (0.08% per year, CI: 0.03, 0.11) and strong heat stress class (0.10% per year, CI: 0.06, 0.13), but not in the class of extreme heat stress. Since the approach to calculate the expected mortality adapts to long-term changes in the daily mortality data (e.g. through changes in the size or structure of the population), this may indicate that the population of Vienna was able to adapt to the increasing heat stress. Components of this long-term adaptation process can be technical measures, like fans or air conditioners [9] as well as behavioural changes [26]. On days with extreme heat stress, these measures are obviously not sufficient to keep the thermal stress on a moderate level, and the relative mortality remains at high values. Additionally, the absolute heat load has increased in this class, since this stress level is not limited by an upper threshold.

This long-term trend results in lower mean relative mortality values on days with strong heat stress in the last years (2001–2006), compared to the mean of 1971–2006, which leads to an average accumulated heat-related mortality in 2003 (Fig. 5).

Hutter et al. [18] found that the 2003 heat waves were responsible for about 180 additional deaths in Vienna, based on data for the periods 1998–2004. Our analysis based on long-term data and human-biometeorological methods shows that the heat-related mortality in 2003 was not extraordinary higher compared to other years in the early 90th of the 20th century. Furthermore, this indicates that long data periods (usually more than 20–30 years) are necessary to evaluate the singularity of individual years.

For a more detailed analysis, the influence of the persistence of the different heat waves should be considered more in detail. Additionally, nighttime conditions, where the human body recovers from the daily heat stress, are of importance. Both were not the aim of this study. Here we showed by two different approaches (in accordance with [18]) that the summer 2003 had less serious impacts in Vienna compared to other years and also compared to the results of other European countries.

Nevertheless, climate scenarios indicate an increase in heat stress concerning intensity and persistence [25, 27, 28], which could lead to a further increase of heat-related mortality. In contrast, the cold-related mortality, which is responsible for the majority of thermal-related deaths during the year, could decline [2, 29]. Further research is required to assess the impacts of climate change on human health and the special relationship in Vienna. The use of human-biometeorological parameters as well as the inclusion of short-term adaptation is recommended to achieve a realistic characterisation of the thermal environment affecting the human body.

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Conflict of interest

The authors declare that there is no conflict of interest.

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