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ORIGINAL PAPER

Temperature-induced excess mortality in Moscow, Russia

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Abstract After considering the observed long-term trends in average monthly temperatures distribution in Moscow, the authors evaluated how acute mortality responded to changes in daily average, minimum and maximum temperatures throughout the year, and identified vulnerable population groups, by age and causes of death. A plot of the basic mortality–temperature relationship indicated that this relationship was V-shaped with the minimum around 18°C. Each 1°C increment of average daily temperature above 18°C resulted in an increase in deaths from all non-accidental causes by 2.8%, from coronary heart disease by 2.7%, from cerebrovascular diseases by 4.7%, and from respiratory diseases by 8.7%, with a lag of 0 or 1 day. Each 1°C drop of average daily temperature from +18°C to −10°C resulted in an increase in deaths from all non-accidental causes by 0.49%, from coronary heart disease by 0.57%, from cerebrovascular diseases by 0.78%, and from respiratory diseases by 1.5%, with lags of maximum association varying from 3 days for non-accidental mortality to 6 days for cerebrovascular mortality. In the age group 75+ years, corresponding risks were consistently higher by 13–30%. The authors also estimated the increase in non-accidental deaths against the variation of daily temperatures. For each 1°C increase of variation of temperature throughout the day, mortality increased by 0.3–1.9%, depending on other assumptions of the model.

Keywords Mortality · Temperature · Cold · Heat · Moscow

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Introduction

In cold and temperate regions, the temperature–mortality curve has a minimum at about 18°C and rises as temperatures fall below or rise above this "point of maximum comfort" (Donaldson et al. 1998; Keatinge and Donaldson 2001; Hajat et al. 2002). Having established the profile of the daily average temperature versus the daily mortality curve, in this paper we study the effects of cold and heat separately. Numerous other studies confirmed that this curve is V-shaped. However, the point of minimum mortality varied from 16.5°C in the Netherlands (Huynen et al. 2001) to 24°C in Rome (Michelocci et al. 2000), since northern regions generally have lower temperatures of maximum comfort. Most studies of correlation between temperature and mortality focused on the effects of either low or high temperatures. The studies of the former category attempted to establish the range of linear increase in mortality that occurs with each 1°C drop of outdoor temperature and the effect of cold spells on mortality. The studies of the latter category estimated percentage increase in deaths for 1°C increase in temperature above the point of maximum comfort, and investigated the effect of heat waves on mortality. As usual in environmental epidemiology, original site-specific studies were followed by meta-analyses, which assessed cross-country variations of the observed effects, e.g., excess winter mortality in different countries (Heady 2003).

Cold exposure

The Eurowinter Group (1997) summarized the percentage increases in all-cause mortality per 1°C drop in temperature below 18°C and established that these increments were greater in warmer regions than in colder regions: 0.29% and

0.27% in North and South Finland, 0.60% in Baden-Wurttemberg, 0.59% in the Netherlands, 1.37% in London, 0.51% in North Italy, and 1.54% in Palermo, with the highest risk (2.15%) in Athens. Southern regions also have the highest rates of excess winter mortality: 28% in Portugal and 21% in Spain and Ireland, versus only 10% in Finland (Heady 2003). This is often thought to be due to the higher heat-conserving properties of houses built at higher latitudes. The linear range of (inverse) temperature–mortality correlation in London was found to stretch from +15°C to 0°C (Keatinge and Donaldson 2001). The "colder" end of this range is determined by the availability of data on extremely cold days, which, below a certain temperature, became too scanty to analyze. For instance, in Yekaterinburg, Russia, mortality linearly increased as the temperature dropped from 0°C to −29.6°C (Donaldson et al. 1998). In our study, we attempt to identify the subgroups in general population that are the most vulnerable to certain adverse weather conditions. Excess winter mortality is generally higher for aged people and for certain causes of death, including respiratory diseases (RD), ischemic (coronary) heart disease (IHD) and cerebrovascular diseases (CVD). For example, in Florence, for each 1°C decrease of mean daily air temperature, the increase of myocardial infarction was 1.9% for patients older than 65 years of age, and only 0.4% for the patients younger than 65 years of age (Morabito et al. 2005). In Yekaterinburg, relative risks of cold-related cause-specific mortality per 1°C decrease of temperature were: 1.15% for all causes, 3.7% for RD, 1.7% for IHD and 1.2% for CVD (Donaldson et al. 1998). Similarly, a 1.2% increase for IHD was reported in the USA (Danet et al. 1999). The time lags between cold days and cause-specific mortality response in eight European regions were found to be 3 days for all cause mortality, 12 days for RD, 2 days for IHD, and 5 days for CVD (The Eurowinter Group 1997).

Effects of high temperatures

In London, every 1°C increase of average daily temperature above 19°C was found to be associated with a 3.34% increase in all non-accidental deaths, a 5.46% increase in RD deaths, and a 3.01% increase in CVD deaths (Hajat et al. 2002); the effect of summertime heat was immediate (the same day) rather than postponed, as it was with cold-related deaths. In Rome, a somewhat less significant (2.34%) increase in deaths from all causes among elderly people aged 65+ was reported, with a 1-day time lag (Michelocci et al. 2000). In the Netherlands, corresponding risks per 1°C of temperature increase above 16.5°C optimum were 2.72% for total mortality, 1.86% for CVD, and 12.82%(!) for RD (Huynen et al. 2001). But all these percentage increases should be viewed in light of possible forward displacement of deaths. For example, another study in London concluded that the heat-stress excess mortality persisted for only 2 days, and was followed by mortality deficits "that led to the sum of the two effects being zero by day eleven" (Hajat et al. 2005). Our work is original in looking at Russian data, because it utilizes daily mortality statistics collected in Moscow—the largest Russian city. This study is limited to linear models of the temperature–mortality relationship, and does not investigate such discrete events as heat waves and cold spells.

The purpose of this study was to investigate how daily mortality responded to changes in daily average, minimum and maximum temperatures, across the whole range of temperature variation throughout the year in Moscow, Russia, and to identify population groups vulnerable to temperature variations by age and cause of death.

Materials and methods

Data

The span of this time-series study covers 2,251 consecutive days from January 1, 2000 to February 27, 2006. Maximum and average daily temperatures were calculated by the authors on the basis of data obtained from the Moscow State University weather station, where ambient air temperature is being continuously monitored. The data was reported as 3-h minimum, maximum, and average temperatures.

Files of deaths were obtained from the Demography and Human Ecology Center of Economic Forecasting Institute, Russian Academy of Sciences. The causes of death were reported in ICD-10 format (the 10th revision of the International Classification of Diseases). Daily mortality counts for the study period were constructed for deaths from all non-accidental causes (total motality minus external causes, V00-Y98), ischemic heart disease and angina pectoris (IHD, codes I20–25), cerebral vascular diseases (CVD, codes I60–69), and chronic lower respiratory diseases (RD, codes J40–47). Mortality data was available for all ages, as well as for the age groups 60–74 and 75+ years. Although it is common in public health literature to study the age group 65+ (which corresponds to the retirement age in most Western countries), we could not stratify data for this age group. Therefore, along with the "all ages" group, we carried out all analyses for the age group 75+. The input of this age group in all-age mortality is still significant: this group contributes 42.7% to mortality from all non-accidental causes, 54.2% to IHD mortality, 59.8% to CVD mortality, and 40.9% to RD mortality. One should be aware that the share of males in this age group is only 28%, because the average age at death for males in Russia is much lower than that for females. However, in our analysis, no distinction was made by gender.

Quantification of weather warming in 2000–2006

The purpose of this section was to design a framework for direct estimation of the impact of weather warming on mortality in Moscow. Since the 6 years of temperature data (2000–2005) were not sufficient to identify trends in climate variation, we proved that, during the study period, the weather in Moscow was somewhat warmer in comparison with the baseline 1961–1990 weather patterns. To do so, a one-sample *t*-test was applied to the sample which consisted of the differences between the mean monthly temperatures during the study period and the respective mean monthly temperatures averaged for the period 1961–1990: $\Delta T^i = T^i_{2000-2005} - T^i_{1961-1990}$, where index i denotes month. The null hypothesis was formulated as follows: the mean of this sample is not significantly different from zero. At the concluding stage of this study, we combined the 12 monthly temperature increments ΔT^i with the corresponding mortality/temperature slope factors. Thus, for each month separately, we estimated the increments of non-accidental mortality attributed to the observed weather warming (see "Conclusions").

Seasonal variation in daily mortality

The amplitude of seasonal variation was defined as the ratio of the maximum of 30-day "moving window" average values to the minimum of 30-day average values of daily mortality. This ratio was calculated for each year separately and then averaged over the 6-year study period. This ratio should be somewhat greater than the January to August variation (as we established, mortality, averaged by month, had its minimum in August and maximum in January). We chose the above definition because it better describes the magnitude of seasonal oscillations of mortality rates.

Temperature/mortality curves

Simple plots of unprocessed mortality data against temperature with time lags of 0–12 days were used to obtain the characteristic V-shaped temperature/mortality curve. To fit in this curve, daily mortality data was first sorted by average daily temperature, and then averaged for each 1°C interval. We put average daily temperatures into 1°C bands to eliminate the characteristic "noise" of daily mortality, which has a rather large percentage relative error (see Table 2). For example, all days with a temperature between −0.9°C and 0°C were averaged to give the mortality count for 0°C, all days with a temperature between 0.1°C and 1°C were averaged to give the mortality count for 1°C, and so on. After this averaging procedure, the minimum of temperature/mortality curve cannot be established with accuracy less than 1°C, but this technique enabled us to uncover the basic temperature/mortality relationship at all temperatures except in temperature extremes where we did not have enough data to eliminate the mortality "noise".

Time series analyses

Having established the minimum of temperature/mortality curve (18°C), we ran simple linear regressions of daily mortality M against average daily temperature T *separately* for the "hot" and "cold" shoulders of temperature/mortality curve, to determine the corresponding slope factors β, or percentage changes of mortality per 1°C increase of daily temperature:

$$Ln(M) = Const + \beta T_{lag} + \varepsilon \quad (1)$$

"Hot" temperatures for Moscow were defined as $T>18°C$, while the "cold" range began at $T<18°C$. This procedure allowed us to avoid the deseasonalization of raw mortality data. Log-transformed daily deaths were used to produce a normal distribution of the dependent variable. In the above regression equation, the daily average temperature was entered with time lags varying from 0 to 12 days before the reference day when mortality was measured. The temperature intervals between −20°C and −10°C and above +25°C were studied separately, because there correlations between $Ln(M)$ and T became pronouncedly concave (the absolute value of β increased).

We also tested two modifications of the basic model (1). The first modification was regression of mortality on either minimum or maximum daily temperatures instead of daily average temperatures. The second modification involved adding a second regressor in the model (1), which was the variation of ambient temperatures throughout the day, or the difference between daily maximum temperature T_{max} and daily minimum temperature T_{min}. In other words, we tested the following regression model:

$$Ln(M) = Const + \beta T_{lag} + \alpha (T_{max} - T_{min})_{lag} + \varepsilon \quad (2)$$

The idea behind this model was that large variations of daily temperature could become a risk factor for mortality.

Results

Long-term temperature trends

Table 1 shows the differences between mean monthly temperatures averaged over the study period and respective long-term average values. Weather warming in Moscow during

Table 1 Comparison of long-term monthly average temperatures for the periods 1961–1990[a] and 2000–2005, in °C

Months	1961–1990	2000–2005	ΔT, °C
Jan	−9.4	−5.2	4.2 (3.4)[b]
Feb	−7.7	−5.6	2.1 (1.0)[b]
Mar	−2.2	−1.1	1.1
Apr	5.8	8.1	2.3
May	13.3	13.3	0.0
Jun	16.8	15.9	−0.9
Jul	18.4	19.5	1.1
Aug	16.7	17.7	1.0
Sep	11.1	12.3	1.2
Oct	4.9	5.7	0.8
Nov	−1.4	−0.1	1.3
Dec	−6.2	−5.7	0.5
Year	5.0	6.3	1.3 (1.2)[b]

[a] Historical temperature data are taken from Isaev (2003).
[b] Numbers in parenthesis include the unusually cold January and February of 2006.

2000–2005 was statistically significant ($P < 0.001$). Moreover, the mean winter temperature increased more than summer temperature: ΔT_{winter}=2.2°C versus ΔT_{summer}=0.4°C.

Mortality: descriptive statistics and seasonal patterns

Table 2 presents some statistical parameters of the selected categories of mortality. Percent relative error ($PRE=\sigma/mean$, where σ is standard deviation, and *mean* is arithmetic mean) reflects the variability of daily mortality. The large dispersion of RD mortality is explained by the very small number of daily deaths in this category. Such large dispersion “blurs” the statistical dependencies of RD mortality from causal factors.

Seasonal variations of mortality profiles have been observed for all analyzed causes of death and both analyzed age groups. Figures 1 and 2 show seasonal variations of mortality from all non-accidental causes and respiratory mortality (as the most “stable” and the least “stable” categories of mortality). Seasonal profiles of IHD and CVD mortality look very similar to Fig. 1. As Fig. 2 shows, even respiratory mortality displays statistically significant seasonal variations, despite very large relative error in this category of mortality. As expected, a comparison of Figs. 1 and 2 shows that the relative amplitude of seasonal variations of RD mortality is much greater than that of mortality from all non-accidental causes. The relative amplitude of seasonal variations of RD mortality may reach almost three times (as in 2004).

Table 3 summarizes the relative amplitudes of seasonal variations of cause-specific mortalities in different age groups. As Table 3 shows, respiratory deaths are the most sensitive to season. In each category of mortality, excess winter mortality is greater for the elderly, which proves that they are more vulnerable to adverse weather conditions. By contrast, the age group 0–59 years (not shown in Table 3) is the least susceptible. The amplitude of seasonal variations of IHD deaths in the age group 0–59 is only 1.13, while CVD mortality in this group does not depend upon the seasons at all.

Mortality–temperature correlation

The graphs featuring the mortality data against daily average temperature at the time lags of 0 to 12 days showed characteristic V-shaped curve, with the minimum around 18°C (Fig. 3). To establish the time lag at which correlation between temperature and mortality is maximal, *t*-tests of power of linear correlation were performed separately for the “cold” temperature range (T<18°C) and the “hot” temperature range (T>18°C), at various time lags. It was established that, in the cold temperature range, the relationship between mortality and temperature was the steepest at the 3-day lag, and the power of association between temperature and mortality was the greatest. In the hot temperature range, the power of association between temperature and mortality was the greatest on the same day (i.e., with a lag of 0 days). Corresponding mortality risks, or percentage changes of daily mortality per each ΔT=1°C, calculated in the framework of log-linear regression model (1) with varying time lags, are summarized in Table 4. The cause- and age-specific temperature-induced mortality risks are summarized in Table 5.

Effects of extreme temperatures

The relationship between $Ln(M)$ and T becomes non-linear (bends upward) in the range of extremely cold temperatures below −10°C, which corresponds to 7% centile of long-term distribution of daily average temperatures in Moscow. This may be proved by comparing slope factors β, calculated separately for temperature intervals (−10°C; +18°C)

Table 2 Descriptive statistics of daily mortality in Moscow, 2000–2005

	Age group	Min	Max	Mean	SD (PRE)[a]
All natural causes	All ages	255	586	331.2	30.41 (9%)
	75+	91	302	141.3	18.48 (13%)
RD	All ages	0	12	3.62	1.96 (54%)
	75+	0	7	1.48	1.29 (87%)
IHD	All ages	73	229	114.5	15.34 (13%)
	75+	29	147	62.11	10.45 (17%)
CVD	All ages	35	142	68.5	10.85 (16%)
	75+	16	85	40.99	8.07 (20%)

[a] Standard deviation and percentage relative error.

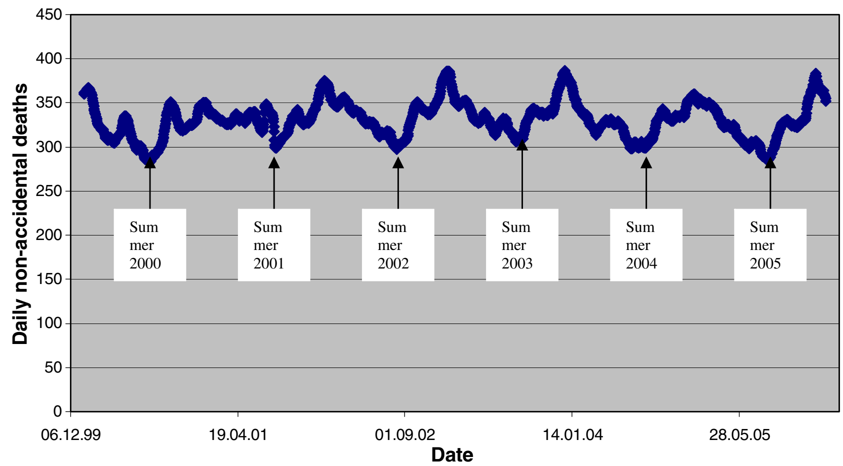

Fig. 1 Seasonal variations of mortality from all non-accidental causes. Daily mortality counts for the period January 2000–February 2006 are averaged with a 30-day moving window. *Arrows* point to summer minimums

and (−20°C; −10°C) in the framework of a log-linear regression model. For example, the relative increment of mortality from all non-accidental causes per each 1°C fall in daily average temperature *increases* from 0.49% ($P<$ 0.001) in the temperature interval (−10°C; +18°C) to 0.65% ($P=$ 0.007) in the temperature interval (−20°C; −10°C).

The same non-linear effect of mortality increase was observed at very high temperatures. If in the temperature interval 18°C$<T<$25°C, non-accidental mortality *on average* increased by 2.8% per each 1°C ($P<$0.001, see Table 5), then at temperatures above 25°C this increase was as high as 11.2% per each 1°C, P=0.001. This means that the V-shaped approximation of temperature–mortality relationship, in the framework of the two linear models, does not adequately describe the temperature–mortality relationship in the whole range of daily average temperature distribution. Nevertheless, an obvious advantage of linear models is straightforward interpretation of their results.

The fact that the relative increase of mortality is constant within a given temperature interval implies that the mortality–temperature relationship is *exponential* within this interval. If temperature interval is short enough, one may neglect the difference between exponential and linear mortality increases in this interval. This is the case with the interval of nearly linear increase of mortality between +18°C and +25°C.

However, the temperature interval between −20°C and +18°C is not small. This non-linearity may be described by a very rough *kinked* approximation of the mortality–temperature relationship with a kink at −10°C. Then, each 1°C drop in temperature between −10°C and +18°C is associated *on average* with 1.6 additional non-accidental deaths per day in Moscow, while each 1°C drop in temperature between −20°C and −10°C is associated *on average* with 3.2 additional non-accidental deaths per day (both $P<$ 0.001).

Now, let us briefly describe the effects of daily minimum and maximum temperatures on total non-accidental mortality. In the cold temperature range (daily average temperatures between −10°C and +18°C), the correlation was the strongest with daily minimum temperature: β_{min_T}=−0.57%, t=−26.1 versus β_{avg_T}=−0.49%, t=−23.3, while the correlation with maximum daily temperature was the weakest. We also established that inclusion of temperature variation term in the regression Eq. (2) increased the explanatory power of the model, in terms of R_{adj}^2. The regression coefficient α was positive and statistically significant: $P_\alpha<$ 0.001. All-cause

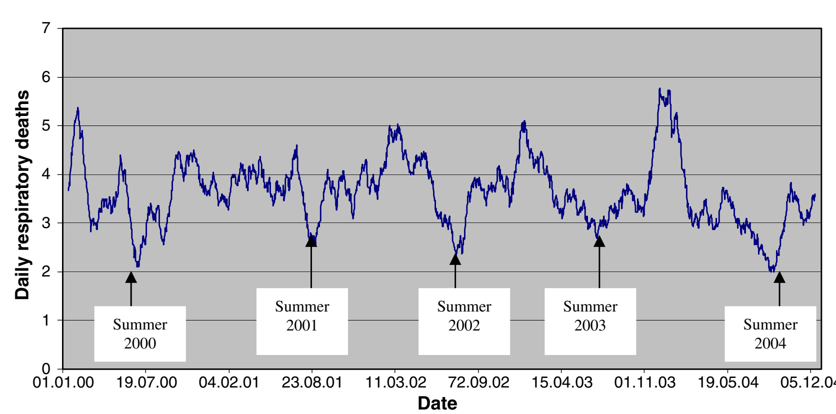

Fig. 2 Seasonal variations of daily RD mortality for all ages in 2000–2004. Daily mortality counts are averaged with a 30-day moving window. *Arrows* point to summer minimums

Table 3 Relative amplitude of seasonal variations of mortality by cause and age group in 2000–2005

Cause of death	Age group	Amplitude of seasonal variation
All non-accidental deaths	All ages	1.26
	75+	1.35
IHD	All ages	1.31
	75+	1.36
CVD	All ages	1.28
	75+	1.35
RD	All ages	2.16
	75+	2.80

non-accidental mortality increased on average by 0.30% per each 1°C of temperature variation throughout the day (at *lag*=3 days).

In the hot temperature region (average daily temperatures in the range 18°C$<T<$25°C), the model with minimum daily temperature and temperature variation term had the greatest explanatory power (at *lag*=0 days). The regression coefficients in this case were: β_{min_T}=5.1%, P_β< 0.001 and α=1.9%, P_α= 0.01. This means that non-accidental mortality increased by 5.1% per each 1°C of increase of minimum daily temperatures (vs 2.8% per 1°C increase of daily average temperature, see Table 5), and mortality increased by 1.9% per each 1°C of *variation* of daily temperature. This result emphasizes the importance of the harmful effects of high night time temperatures during heat waves, previously reported in the literature.

Discussion

To compare excess winter mortality in Moscow with that in European countries, one must calculate excess winter mortality as the ratio of surplus daily deaths occurring in the winter season (December–March inclusive) to the average of non-winter months. This formula would produce much lower estimates than in our Table 3. For example, thus defined excess winter mortality from all non-accidental causes in Moscow will be only 8%, which is even lower than in Finland, where it is 10%, with 95% CI (7%, 13%)—the lowest estimate among all European countries studied by Heady (2003), who inferred that excess winter mortality in Europe *increased* as the winter climates became milder. Therefore, excess winter mortality in Moscow should be *smaller* than in Finland, because the winter in South Finland (where most Finns live) is milder than in Moscow. This result agrees with the result of earlier study of seasonal variation of mortality in Moscow (McKee et al. 1998), which established that "a winter excess of deaths [in Moscow] is much smaller than in many western countries". McKee and co-authors linked the low levels of excess winter mortality to warmer indoor environments than in the west. This observation revisits the longstanding debate about the comparative importance of exposure to temperature inside the house and outside it, which was also addressed in the Ekaterinburg study (Donaldson et al. 1998), where the authors estimated the amount of time spent outdoors. No matter how important this discussion might be, it is out of scope of our study, which links health effects to ambient temperatures.

As Table 4 shows, the effect of hot temperatures is immediate, while the effect of cold temperatures is delayed. This result agrees with the results of foreign studies (Keatinge and Donaldson 2001; Hajat et al. 2002). Relative risks of mortality disaggregated by cause and age have basically similar distributed lag profiles, and temperature influence on mortality in age group 75+ is always more pronounced than for all ages (see Table 5). The results of Table 5 are quite informative. Relative risks of temperature-induced mortality have been established for all causes of death and age groups analyzed, with the exception of heat-induced mortality from respiratory diseases in age group 75+, for which there was not enough statistical material to establish significant trends, but the effect should exist. The results of the Moscow study largely agree with previously reported results, obtained both in foreign and Russian studies. For example, our results, obtained for heat-related

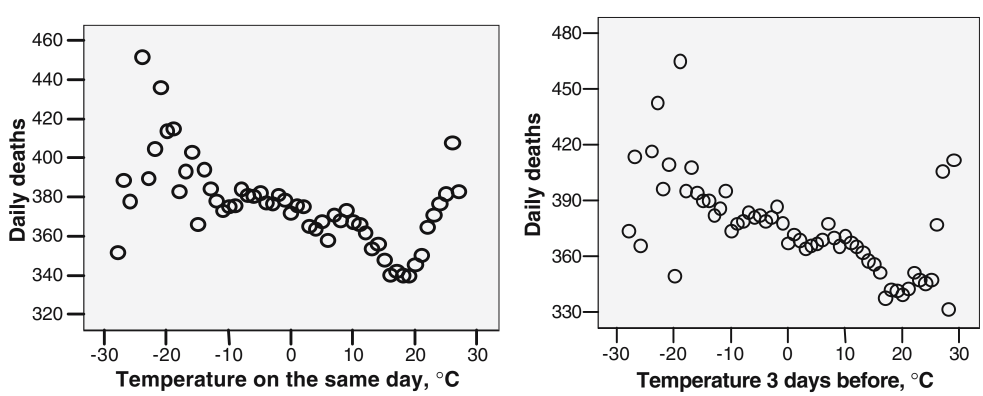

Fig. 3 Mortality–temperature relationship at 0- and 3-day lags

Table 4 Variation in lag and relative increment of non-accidental mortality per ΔT=1°C

	Effects of cold (−10°C<T<18°C)				Effects of heat (18°C<T<25°C)		
Temperature lag, days before death	0	3	6	12	0	3	6
Relative increase of mortality, % (95% Confidence Interval, %)	−0.42 (−0.46; −0.38)	−0.49 (−0.53; −0.45)	−0.41 (−0.45; −0.37)	−0.38 (−0.42; −0.34)	2.8 (2.0; 3.6)	1.7 (0.9; 2.5)	1.1 (0.1; 2.1)
t-statistics	−19.3	−23.3	−20.5	−18.0	7.7	3.9	2.5
P-statistics	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.028

mortality, are in very good agreement with Huynen et al. (2001), who reported a 2.72% increase of total mortality and a 12.82% increase of mortality from respiratory diseases in the Dutch population for each 1°C increase of daily average temperature above the optimum. Several conclusions may be drawn from the analysis of relative magnitudes of risks in Table 5.

The slope of the right wing of each mortality–temperature curve is always steeper than the slope of its left wing. However, the left wing is longer: it corresponds to the temperature interval between −20°C and +18°C, while the right wing corresponds to temperature interval between +18°C and +25°C. Thus, the relative amplitudes of heat-related and cold-related mortality increments above the point of maximum comfort become *comparable*. As our model suggests, the amplitude of cold-related variation of mortality from all non-accidental causes, which corresponds to a temperature fall from the point of maximum comfort (+18°C) to −19.3°C (1% centile of temperature distribution), will be approximately 24%, or 72 additional daily deaths in Moscow. This theoretical estimate agrees with the observed amplitude of winter-to-summer variations in Table 3. On the other hand, the heat-related variation of mortality, which corresponds to a rise of daily average temperatures from +18°C to +25°C (99% centile of temperature distribution), may reach 20%, or 60 additional non-accidental deaths per day.

The causes of mortality in Table 5 are ordered so that the absolute values of temperature-related risks *increase* within a given age group. The ordering remains the same both for cold-induced and heat-induced mortality, with one exception: heat-induced mortality from IHD is slightly *lower* than heat-induced mortality from all non-accidental causes. The greatest risks are observed for respiratory mortality. The amplitude of temperature-related variation of RD mortality, defined as the excess of daily mortality over its minimum value, which corresponds to the point of maximum comfort (+18°C), may reach as much as 60% on extremely cold days and 80% on extremely hot days.

Concerning the time lags of temperature effects on mortality, our results agree with the results of The Eurowinter Group (1997). Indeed, we obtained the same time lags for non-accidental, IHD and CVD mortality. For respiratory mortality, The Eurowinter Group reported a 12-day lag. In Moscow, the strongest correlation between cold and respiratory mortality was obtained with the lag of 5 days, but it should be taken into account that the power of association diminished very slowly and on the 12th day it was almost as strong as on the 5th day (t_{12}=5.2 vs t_5=5.9).

Conclusions

This paper uses standard methods to look at the association between temperature and mortality in Moscow, which is a matter of growing importance given climate change. Combining the increments of monthly average temperatures observed during 2000–2006 over their long-term expected values (Table 1) with mortality–temperature slope factors

Table 5 Relative change of daily mortality (%) per 1°C increase of daily average temperature, and lags of maximal effects

Cause of death	Age group	Effects of cold (−10°C<T<18°C)		Effects of heat (18°C<T<25°C)	
		ΔM, % (95% CI, %); *P*-value	Lag of max. effect (days)	ΔM, % (95% CI, %); *P*-value	Lag of max. effect (days)
All non-accidental deaths	All ages	−0.49 (−0.53, −0.45); < 0.001	3	2.8 (2.0, 3.6); < 0.001	0
	75+	−0.65 (−0.71, −0.59); < 0.001	3	3.3 (2.1, 4.5); < 0.001	1
IHD	All ages	−0.57 (−0.63, −0.51); < 0.001	3	2.7 (1.7, 3.7); < 0.001	0
	75+	−0.69 (−0.77, −0.61); < 0.001	3	3.1 (1.7, 4.5); < 0.001	0
CVD	All ages	−0.78 (−0.86, −0.70); < 0.001	6	4.7 (3.5, 5.9); < 0.001	1
	75+	−0.92 (−1.02, −0.82); < 0.001	6	5.3 (3.7, 6.9); < 0.001	1
RD	All ages	−1.5 (−2.1, −0.9); < 0.001	5	8.7 (0.7, 16.7); 0.033	0
	75+	−1.7 (−2.5, −0.9); < 0.001	5	–	

from Table 5 allows us to directly estimate the impact of climate warming on mortality in Moscow. However, the net mortality change, calculated in the framework of linear model (1), appears to be insignificant, because the mortality increment in summer is nearly balanced out by mortality decrement during spring, winter and autumn. Nevertheless, there are strong reasons to believe that climate warming has already affected some indicators of human health due to growing amplitudes and frequencies of unusual weather events—heat waves and cold spells. In another study, we observed a *non-linear* increase of mortality in Moscow during the heat wave of 2001 (Revich and Shaposhnikov 2006).

Despite the inherent limitations of the methods and data that we used, our research may provide policy makers with convincing evidence of the need to minimize the established health risks.

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