MORTALITY AND SUMMER BIOCLIMATIC DISCOMFORT: AN EVALUATION OF SHORT AND MEDIUM TERM EFFECTS

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Titolo
Mortalità e disagio bioclimatico estivo: una valutazione degli effetti a breve e a medio termine

Key words:
Summer bioclimatic discomfort, short and medium term effects, attributable mortality, urban area

Parole chiave:
Disagio climatico estivo, effetti a breve e a medio termine, mortalità attribuibile, area urbana

Summary
Background: While short term effects of bioclimatic discomfort on mortality have been widely investigated, only few studies have been focused on medium term effects. We analysed the strength of the association between summer bioclimatic discomfort and mortality with respect to different temporal scales (same day, month and season). Final goal was to estimate heatattributable mortality. Methods: Mortality data of resident population in an Italian urban area were analyzed for summer periods in the years 19892003. Bioclimatic discomfort conditions were defined by using the Thom index. We assumed the existence of a threshold value of the Thom index after which mortality increases with a loglinear trend. Data after threshold were analyzed at daily, monthly and summer scale, using Poisson regressions. Analysis were conducted also by cause of death, gender and age. Attributable mortality was estimated by comparing mortality with baseline value. Results: All causes, natural, cardiovascular and respiratory mortality were significantly associated with bioclimatic discomfort. The percentage increase in mortality due to an unit increment of Thom index after threshold rises on enlarging the time window. For allcauses mortality, the percentage increases from 12 to 27%. The highest risk was for respi-

Background

Summer bioclimatic discomfort is a significant public health problem. Every year, a large number of deaths occur in association with stressful bioclimatic conditions (1, 2). Events like that experienced during summer 2003 in southern and central European regions could also give rise to emergency situations for the public health systems (3), and pointed out the need of setting up suitable warning and prevention systems. Furthermore, because of the projected consequences of global warming (4, 5), and the increased frequency and intensity of heat waves (6), heat-related mortality may assume greater public health significance during the coming decades (7, 8). Populations at middle latitudes are more vulnerable (9). Risks are even higher for people living in urban environments, where antropogenic emissions together with physical properties of materials used for buildings and streets give rise to the phenomenon known as the "urban heat island effect", i.e. higher heat inde-

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ratory mortality with a percentage increment at summer scale equal to 78%. Mediumterm allcauses mortality was the one most closely associated with bioclimatic discomfort, with pseudoR2 rising from 0.08 at daily scale to 0.51 at summer scale. At daily scale the >75 years old total mortality risk was about four times the <65 yearsold. Risk in men and women did not differ significantly. Heatattributable allcauses mortality estimated at summer scale for the period 19892003 was about 6% of the total deaths. Conclusions: The strong influence of bioclimatic discomfort on mortality we have found both for short and medium term highlights its role as primary risk factor and calls for appropriate prevention policies. he short term, so that the harvesting effect does not appear to have a primary role.

Riassunto

Introduzione: Mentre sono numerosi gli studi che hanno analizzato gli effetti a breve termine del disagio bioclimatico sulla mortalità, solo pochi hanno indagato gli effetti a medio termine. Si è voluto in questo lavoro studiare la forza dell'associazione tra disagio bioclimatico estivo e mortalità rispetto a diverse scale temporali (giornaliera, mensile e stagionale). Obiettivo finale è stato la stima della mortalià attribuibile. Metodi: Sono stati analizzati i dati di mortalità dei periodi estivi degli anni 1989-2003 della popolazione residente in un'area urbana italiana. Le condizioni di disagio bioclimatico sono state definite utilizzando l'indice di Thom. Si è verificata l'esistenza di un valore soglia del'indice di Thom oltre il quale la mortalità aumenta con un andamento log-lineare. I dati oltre la soglia sono stati analizzati alla scala temporale giornaliera, mensile e estiva usando regressioni di Poisson. Sono state condotte anche analisi per causa di morte, sesso ed età. La mortalità attribuibile è stata stimata confrontando la mortalità con il valore di baseline. Risultati: La mortalità per tutte le cause, per cause naturali, cardiovascolari e respiratorie è risultata significativamente associata al disagio bioclimatico. L'incremento percentuale della mortalità giornaliera dovuto ad un incremento unitario dell'indice di Thom dopo la soglia aumenta al con l'ampiezza della scala temporale. Rispetto alla mortalità per tutte le cause la percentuale aumenta dal 12 al 27%. La mortalità per cause respiratorie è risultata quella associata al rischio più elavato, pari, alla scala estiva, al 78%. Anche la forza dell'associazione aumenta con l'ampiezza della scala temporale. Gli pseudo-R^2 variano, per la mortalità totale, da 0.08 alla scala giornaliera a 0.51 alla scala estiva. Alla scala giornaliera il rischio di morte degli ultra-75enni è circa quattro volte maggiore di quello dei minori di 65 ani. I rischi negli uomini e nelle donne non sono risultati significativamente differenti. La mortalità nel periodo 1989-2003 attribuibile al disagio bioclimatico è stata stimata pari a circa il 6% della mortalità totale. Conclusioni: Il forte effetto, sia nel breve che nel medio termine, del disagio bioclimatico sulla mortalità evidenzia la sua rilevanza come importante fattore di rischio e richiama la necessità di adeguate politiche di prevenzione.

xes in urban than surrounding rural areas (10, 11).

Cardiovascular and respiratory effects are prominent (12-14), and most deaths have occurred in persons with pre-existing diseases, such as diabetes, ischemic hearth disease, stroke, or respiratory illnesses. However, heat could affect a vast array of health events, and also violent and accidental deaths (15). At individual level, several factors could influence the heat-related risk: demographic factors such as age (13, 16); behavioural factors such as living alone (17, 18), using air conditioning facilities (19, 20), living on the upper floors of multistory buildings and being alcoholic (19); health status factors such as being confined to bed (18), having a mental illness (20) and using tranquilizers (19). These individual factors, together with genetic and acclimatisation factors, are responsible for remarkable geographic heterogeneity in the effects of the bioclimatic discomfort (2, 21); this highlights the importance of local studies.

While a number of studies have explored the short term temporal pattern of the association between bioclimatic discomfort and mortality, only a few have analysed the medium term effects. The main objective of this paper was to examine the association between bioclimatic discomfort and mortality in the short (same day) and medium (monthly and seasonal) term in a middle-latitude urban area with recurrent stressful bioclimatic conditions (22) and exposed to heavy heat waves (23, 24). Attributable mortality at the three temporal scales was also estimated.

Methods

The study area was the urban district of Bologna, the chief city of the Emilia-Romagna region, in the north-east of Italy. We included in this definition the three municipalities of Bologna, Casalecchio and S. Lazzaro. This area is characterized by almost continuous building and, from a bioclimatic point of view, could be considered uniform. The city is in the Po Plain, a vast flat area surrounded by mountains (Alps and Apennines) in the north of Italy. The area is characterised by a continental climate with cold winters and hot summers (typical monthly mean temperatures ranging from 1,7 to 24,3°C), high humidity levels (typical monthly mean relative humidity ranging from 60 to 84%) and low typical wind intensities (annual mean wind intensities of about 2 m/sec). The urban population is about 420,000 persons (85% living in the municipality of Bologna). We analyzed the periods with highest frequency of heat waves (15 May – 31 August) in the 15 years from 1989 to 2003. Daily counts of residents who died within the city were calculated for all causes, natural causes (International Classification of Diseases – ICD-9 – codes < 800), cardiovascular causes (ICD-9 390-459) and respiratory causes (ICD-9 460-519). Daily deaths were categorized by gender and age (0-64, 65-74 and >75 years). The effect of bioclimatic discomfort was analyzed with respect to the same day (lag 0), temporal windows of 31-days (from now on referred as monthly window) and the whole "summer" periods (15 May-31 August). In the analyses of the short-term effects, lag 0 was preferred because most studies have shown that this approach is better, or not worse, than other more complex approaches (32). The monthly periods were 31 May-30 June, 1-31 July and 1-31 August. For seasonal analyses, in addition to the window 15 May-31 August we considered the wider window 15 May–30 September, in order to test an eventual decrease in mortality rates after the usual period of heat wave. We did not analyse the association of mortality and bioclimatic discomfort in the subsequent months because of the different risk factors typical of the autumnal period that might confound the results. To take into account the changes in age distribution of the population of the area, we calculated the five-year age-gender-specific standardized death rate. The reference population for the standardization is the population living in the study area in 2003. We controlled for long term trends in total, natural and cardiovascular mortality (no trend was found for respiratory mortality), probably due to slow changes in socio-economic status, medical practices, access to social and health care and home air conditioning prevalence. The trend was approximately linear.

Bioclimatic discomfort conditions were defined by using Thom index (25), already used in several epidemiologic studies (22, 26-28), and chosen since the 1980s by the Emilia-Romagna Regional Meteorological Service as reference bioclimatic index. This index combines temperature and humidity trough a linear combination of air temperatures measured by dry (T_d) and wet (T_w) thermometers. On the basis of experiments, literature proposed that a value over 24 may outlook health problems for several members of a population. We used the mean daily value of the index in order to take into account both the diurnal, more unfavourable conditions and the nocturnal ones, important for physical recovery. Dry (T_d) and wet (T_w) thermometer temperatures were calculated using temperature and humidity data of the airport station ("Borgo Panigale"), located very close to the city. In order to better capture the "heat island effect" (the airport station is very close to the city but obviously not in the city center), we corrected the airport data using a linear function estimated by relating the airport data with the data of a station located within the city center operating only from 2001 (R^2 temperature = 0.96 and R^2 humidity = 0.79); the correction was applied to the whole historical data set of the airport station. We did not include in the analysis the effects of ozone and particulate matter since ozone and PM10 data were not available for the entire period (monitoring activity started in 1994 for ozone and in 1999 for PM10) and we chose to privilege the length of the bioclimatic discomfort time series. Air conditioning use in the study area was also not available.

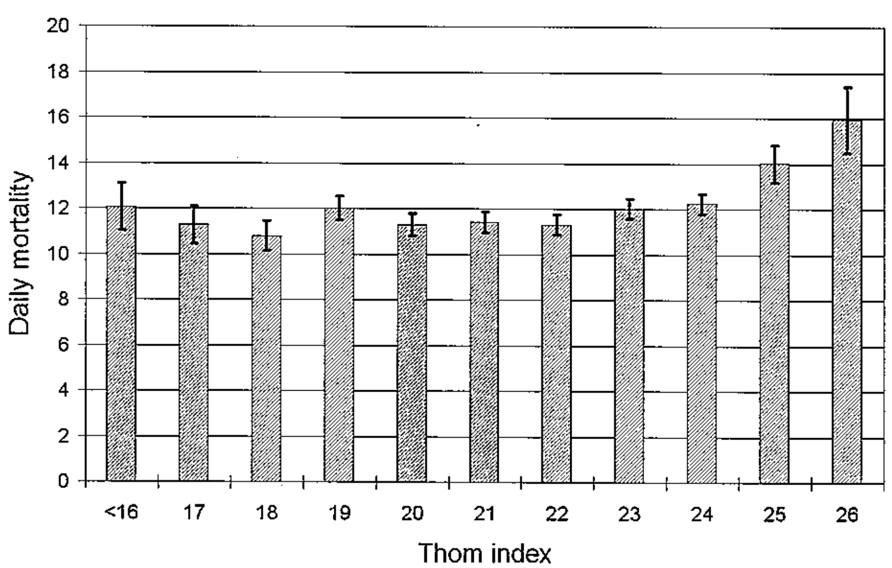

Fig. 1 - All causes average mortality against mean daily integer Thom index (mean value and CI95%)

In agreement with literature, we found in a preliminary analysis (Fig. 1) a threshold value of Thom index (24) before which mortality was constant and after which it increases with a trend that could be assumed as log-linear. In order to estimate daily risks, we analyzed the data after the threshold using a Poisson regression. At the monthly and summer level, consistently with this approach, we defined a medium term discomfort index as the (monthly or summer) sum of daily Thom index values over the threshold (from now on called for the sake of brevity Over-Threshold Thom Index Sum – OTTIS value). The method used to estimate the heat-attributable mortality was also based on the assumption of constant mortality before threshold. The regression analyses results were used to estimate the attributable deaths (M) by using the following expression:

$$M = \Sigma_i ((Y^*|X_i)-Y_b)$$

where X_i are the OTTIS values of Thom index, $(Y^*|X_i)$ are the estimated values with the regression functions at each temporal scale, Yb is the baseline value of mortality (assumed to be equal to the intercepts of the regressions) and the sum operator must be applied to all the over-threshold days and to all the monthly and summer values. We assigned to this estimate a confidence interval by using the uncertainties associated with the fits of the regressions. Hence, the formula for the low confidence limits was:

$$LCL_N = \Sigma_i ((LCL_{Y^*|Xi)}- Y_b)$$

and symmetrically for the upper ones.

Results

Table 1 shows the percentage increase in mortality due to a unit increment of

		M+F	M	F
All causes	Day	13* (9 to 17)	13* (7 to 20)	12* (7 to 18)
	Month	15* (10 to 21)	13* (5 to 20)	23* (16 to 31)
	Summer	27* (18 to 36)	25* (12 to 39)	29* (16 to 41)
Natural	Day	12* (8 to 16)	12* (6 to 19)	12* (6 to 17)
	Month	15* (10 to 20)	12* (4 to 20)	23* (16 to 30)
	Summer	25* (16 to 35)	22* (8 to 36)	28* (15 to 41)
Cardio	Day	15* (8 to 23)	17* (6 to 30)	14* (5 to 23)
	Month	18* (9 to 27)	6 (-8 to 20)	31* (20 to 43)
	Summer	27* (11 to 43)	4 (-20 to 29)	44* (23 to 65)
Resp	Day	27* (13 to 43)	21* (1 to 45)	32* (12 to 54)
	Month	50* (32 to 68)	35* (10 to 60)	72* (48 to 97)
	Summer	78* (46 to 111)	94* (49 to 139)	61* (14 to 108)

Tab. 1 - Percentage increases and CI95% in daily mortality risk by temporal scale, time window, cause of death and gender due to a unit increment of Thom or OTTIS (monthly or seasonal sum of Thom index values over the threshold).

	Day	Month	Summer
All causes	0.08	0.21	0.51
Natural	0.07	0.20	0.50
Cardiovascular	0.04	0.11	0.25
Respiratory	0.02	0.23	0.43

Tab. 2 - Pseudo-R2 of the Poisson regressions between mortality and Thom or OTTIS (monthly or seasonal sum of Thom index values over the threshold) values by temporal scale and cause of death.

Thom index (or of OTTIS) at the daily, monthly and summer scales. The percentage reported in the table may be interpreted as the mortality increment with respect to the daily baseline mortality for a single day in a daily, monthly or summer time window with a discomfort index a unit higher than the threshold value (monthly and summer percentage were "normalized" to daily scale).

The summer percentage increment in mortality was the highest, followed by the monthly and the daily ones. In particular, the risk derived at summer scale with respect to total mortality was more than twice the daily one; with respect to respiratory mortality the risk became nearly three times higher.

Table 2 shows the results of the Poisson regression analyses in terms of pseudo-R^2 (29). The highest pseudo-R^2 coefficients were found for total and natural mortality. The coefficients became higher broadening the time windows (Figure 2 shows scatter plots at the three temporal scales of all-causes mortality against bioclimatic index).

In order to evaluate a possible distortion in the estimates produced by the exceptional heat waves of 1998 and 2003, we re-analysed the risks without 1998 and 2003 data. The results were very similar: taking into account total mortality, the risks became 13% (8, 18) using daily data, 12% (6, 18) using monthly data and 21% (9, 33) using summer data.

The associations between bioclimatic discomfort and mortality in the period May-September were very similar to the associations in the May-August period: 0.45, 0.46, 0.37, and 0.39 respectively for all causes, natural, cardiovascular and respiratory mortality. Therefore, September did not show lower than average mortality after summer periods with heat-related excess deaths.

Respiratory mortality risks were the highest at all the temporal scales. Risk in men and women did not differ significantly. The largest difference, even if not significant, was found for cardiovascular mortality at the monthly and summer scales. We explored the association between mortality and bioclimatic discomfort respect to age only for total and natural mortality, because of the small number of respiratory and cardiovascular deaths. There was a positive association between bioclimatic discomfort and both total and natural mortality in each age group, even if only >75 years-old risks were significant (Table 3). At daily scale, the >75 years total and natural mortality risks were respectively about four and five times the <65 years-old. Similarly, the risk increased with age at the monthly scale, whereas small differences among the age groups were found at the summer scale.

The results of the 1989-2003 heat-attributable mortality analysis are shown in table 4. At summer scale, all causes, natural and cardiovascular-attributable mortality were about 6% of the corre-

		All causes			Natural		
		Day	Month	Summer	Day	Month	Summer
0-64	M+F	5 (-7 to 18)	5 (-11 to 21)	26 (-2 to 54)	3 (-9 to 16)	4 (-13 to 21)	22 (-7 to 51)
	M	5 (-10 to 22)	-3 (-24 to 17)	9 (-26 to 45)	4 (-11 to 22)	-4 (-25 to 17)	-1 (-38 to 36)
	F	4 (-14 to 26)	18 (-8 to 44)	54* (8 to 100)	1 (-17 to 23)	17 (-10 to 44)	60* (13 to 108)
65-74	M+F	6 (-3 to 17)	2 (-11 to 15)	19 (-5 to 42)	6 (-4 to 17)	2 (-11 to 16)	19 (-5 to 43)
	M	6 (-7 to 20)	2 (-16 to 19)	24 (-6 to 55)	6 (-7 to 20)	2 (-15 to 20)	26 (-5 to 57)
	F	7 (-7 to 24)	2 (-19 to 23)	10 (-26 to 47)	7 (-8 to 23)	2 (-19 to 23)	9 (-29 to 46)
>75	M+F	16* (11 to 21)	21* (15 to 28)	29* (18 to 40)	15* (10 to 20)	22* (15 to 28)	27* (16 to 38)
	M	18* (10 to 27)	17* (7 to 27)	29* (12 to 46)	18* (10 to 26)	17* (7 to 27)	26* (9 to 43)
	F	14* (8 to 21)	24* (16 to 32)	29* (14 to 43)	14* (8 to 20)	25* (17 to 33)	28* (13 to 43)

*P<0.05

Tab. 3 - Percentage increases and CI95% in daily mortality risk by temporal scale, time window, cause of death and gender due to a unit increment of Thom or OTTIS (monthly or seasonal sum of Thom index values over the threshold).

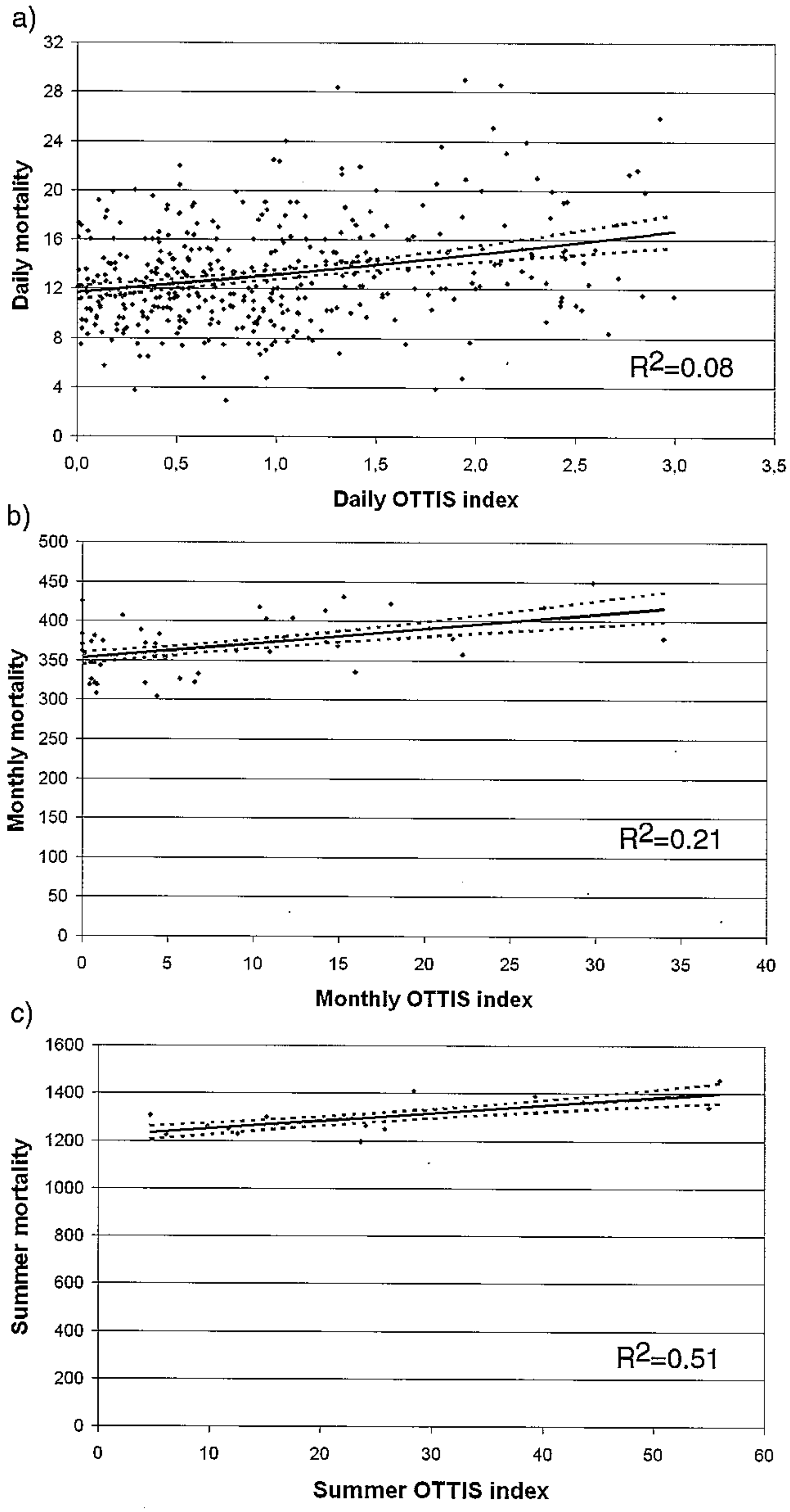

Fig. 3 - Poisson linear regressions of daily, monthly and summer mortality against sum of Thom index values over the threshold (OTTIS value). Daily OTTIS Index is Thom index value minus the index threshold 24. Dashed lines are 95% confidence intervals.

sponding deaths of the period; the percentage rose to about 17% for respiratory mortality.

Discussion

The study showed a strong influence of bioclimatic discomfort on mortality in both short and medium term.

High risks were found on the same day. Critical, but not exceptional, bioclimatic conditions (Thom index equal to 26) have been linked to increments of about 30% in total mortality. The strongest effects were found for respiratory mortality and in the 75-years old. The results are qualitatively consistent with many other studies even if a quantitative comparison is difficult because of the different bioclimatic indexes (simply temperature, Apparent Temperature, Humidex, etc) and daily indicators (mean, maximum or minimum daily values) used in literature. Analogies were found especially with areas with continental climates (21).

An even stronger effect on mortality of bioclimatic discomfort was found in medium term (monthly and seasonal temporal scales). The risks increase broadening the time window. This could be explained both by a cumulative effect of the risk in days after heat peaks and by the effects of persistence of the discomfort conditions that could enhance the heat waves effect on mortality.

Previous studies on medium term effects are only a few and results quite controversial. Ballester et al. (30) highlighted effects at weekly scale. A recent work of Hajat et al. (31) showed medium term effects on mortality up to four weeks in Dehli and São Paulo (but not in London). However, more studies (9, 32-34) found periods of lower-than-average deaths some days or weeks after exposure to discomfort conditions. This pattern is sometimes referred to as the harvesting effect.

Our study did not analyze the behaviour of mortality in the single days after discomfort conditions. However, our results showed that, at monthly and summer scale, a possible decrease in mortality attributable to the harvesting effect in the

	Day	Month	Summer
All causes	572 (385 to 768)	688 (351 to 1034)	1184 (813 to 1562)
Natural	522 (338 to 713)	638 (308 to 977)	1061 (698 to 1432)
Cardiovascular	235 (126 to 352)	279 (82 to 484)	415 (198 to 640)
Respiratory	101 (47 to 163)	183 (88 to 286)	270 (166 to 381)

Tab. 4 - 1989-2003 heat related mortality and CI by temporal scale and cause of death.

days after heat peaks was however lower than the mortality increase due to cumulative or delayed effects. In fact, by considering the monthly and the summer scale with respect to the daily one, we observe an increasing both of the mortality risk and of the Pseudo-R2. The analysis of the May-September period was a further check that the relationship between mortality and bioclimatic discomfort was not only due to mortality displacement.

Some limitations are present in the study. For example, other potentially important environmental risks factors such as PM10 and ozone were not taken into account in this study because of the lack of data for many years of the study period. However, the Italian meta-analysis on short term effects of air pollution MISA II (35) (consistently with the other main international meta-analyses NMMAPS and APHEAII) together with other studies considering also effects on medium term (36,37), found risks much lower in magnitude with respect to those found in this work and hardly could account both single day effects and the increase in risk found broadening the time window. Furthermore, a recent work of Keatinge and Donaldson (38) concluded that pollutants played a little part in excess mortality associated with hot weather.

Indicators of time evolutions of socio-economic status and air conditioning prevalence were also not included in the study. Even if, generally speaking, these confounders could be important, they are belived to have not a primary influence on the results of this study. In fact, the trend in these indicators was expected to be monotonic and quite smooth and has been probably included in the analysis by controlling in long term trend in summer mortality.

Conclusions

The large effect of heat on medium-term mortality highlighted in this study enhances the importance of bioclimatic discomfort as a primary environmental risk factor and suggests appropriate investments in prevention policies, such as setting up heat warning systems. These alert systems should, however, take into account that the daily variability of mortality is very high, especially in cities with populations equal to or less than Bologna where the random component of the mortality fluctuations is dominant. In fact, if bioclimatic discomfort accounts for about 51% of the variability of summer total mortality and about 23% of the monthly one, it accounts only for about 8% of the daily variability. Owing to the entities of the random fluctuations, the daily mortality becomes hard to predict, and this should be carefully evaluated in setting up a bioclimatic warning system and its communication and assistance components.

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