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Airport and city-centre temperatures in the evaluation of the association between heat and mortality

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Abstract A variety of ambient exposure indicators have been used to evaluate the impact of high temperature on mortality and in the identification of susceptible population sub-groups, but no study has evaluated how airport and city centre temperatures differ in their association with mortality during summer. This study considers the differences in temperatures measured at the airport and in the city centre of three Italian cities (Milan, Rome and Turin) and investigates the impact of these measures on daily mortality. The case-crossover design was applied to evaluate the association between daily mean apparent temperature (MAT) and daily total mortality. The analysis was conducted for the entire population and for subgroups defined by demographic characteristics, socioeconomic status and chronic comorbidity (based on hospitalisation during the preceding 2 years). The percentage risk of dying, with 95% confidence intervals (95% CI), on a day with MAT at the 95th percentile with respect to the 25th percentile of the June–September daily distribution was estimated. Airport and city-centre temperature distributions, which vary among cities and between stations, have a heterogeneous impact on mortality. Milan was the city with the greatest differences in mean MAT between airport and city stations, and the overall risk of dying was greater when airport MAT (+47% increase, 95%CI 38–57) was considered in comparison to city MAT (+37% increase, 95%CI 30–45). In Rome and Turin, the results were very similar for both apparent temperature measures. In all cities, the elderly, women and subjects with previous psychiatric conditions, depression, heart and circulation disorders and cerebrovascular disease were at higher risk of dying during hot days, and the degree of effect modification was similar using airport or city-centre MAT. Studies on the impact of meteorological variables on mortality, or other health indicators, need to account for the possible differences between airport and city centre meteorological variables in order to give more accurate estimates of health effects.

Keywords Ambient exposure · Temperature ·
Heat-related mortality · Individual vulnerability factors

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Introduction

The effect of high temperature on mortality is well documented and has been studied both during specific extreme episodes, known as heat waves (Basu and Samet 2002a; Semenza et al. 1996; Naughton et al. 2002; Rooney et al. 1998; Michelozzi et al. 2004) and over longer time

periods using the time-series approach (Alberdi et al. 1998; Braga et al. 2001; Curriero et al. 2002; Hajat et al. 2002). A "J" or "U" shaped relationship between daily temperature and mortality with a short-term lag effect has been identified, where temperature increases rapidly above a threshold value (Curriero et al. 2002; Hajat et al. 2002; Ballester et al. 1997; Michelozzi et al. 2006). After the 2003 heat wave, which had a dramatic death toll in most of Europe, research has focussed on the identification of susceptible subgroups at which public health strategies should be targeted. Recent studies have identified subgroups who may be more vulnerable to the effects of high temperatures due to their clinical (Basu and Samet 2002a; Braga et al. 2002; Schwartz 2005; Stafoggia et al. 2006, 2007) or demographic and socio-economical conditions (Basu and Samet 2002a; Stafoggia et al. 2006, 2007; O'Neill et al. 2003; Michelozzi et al. 2005).

Different temperature measures, including mean (Hajat et al. 2002; Ballester et al. 1997) maximum (Alberdi et al. 1998; Diaz et al. 2002; Huynen et al. 2001; Kovats et al. 2004; Kyselý 2004) and minimum (Schwartz 2005) temperature, as well as composite indices such as apparent temperature (Michelozzi et al. 2005; Smoyer 1998; Smoyer-Tomic and Rainham 2001; Weisskopf et al. 2002; Kalkstein and Valimont 1986) and biometeorological indices (Koppe and Jendritsky 2005) have been used as exposure variables for modelling the effects on mortality and morbidity in epidemiological studies. These indices are, however, only an indicator of the thermal stress that populations are exposed to, as microclimate within an urban area varies considerably. Very few studies have assessed urban microclimatic conditions and the different impacts on mortality, and no investigation, to our knowledge, has evaluated the different effect of temperature on mortality using meteorological data collected at the airport or in the city centre. The majority of studies regarding the effect of weather on health have considered airport meteorological data as exposure variables, principally because it is a readily available source of data. In addition, airport meteorological stations belong to the Global Telecommunication System (GTS) of the World Meteorological Organisation (WMO), and are characterised by standardised instrumentation that measures and records data in a standard format. The use of standardised datasets ensures the homogeneity of data and enables direct worldwide comparisons. However, airports are often located far from the city centre and urban areas where the majority of the population lives. In addition, the urban heat island effect is generally observed in densely populated urban areas, so that population exposure to thermal stress in the city centre may be better estimated by meteorological variables measured in the city rather than at the airport. Thus, it seems appropriate to investigate the possible heterogeneous impact on mortality of thermal stress indicators recorded at different locations.

The aim of this study was to investigate the differences in airport and city-centre apparent temperatures and the impact of these variables on mortality in three Italian cities (Milan, Rome and Turin). In particular, we aimed to evaluate whether airport temperature, where measurements are often taken, differs from the temperature in the city centre, where most of the population lives, and if city-centre temperatures are better predictors of heat-related mortality than airport temperatures.

Materials and methods

This study was part of a population-based case-crossover analysis on the effects of heat on mortality aimed at the identification of susceptible subgroups defined by demographic and socioeconomic status, and episodes of hospitalisation for various conditions during the preceding 2 years. Details of the methodology and results of the main analysis have been reported in a previously published paper (Stafoggia et al. 2006), hereafter referred to as the "original paper". Briefly, mortality data was retrieved from Regional Cause of Death Registers and comprised all deaths from natural causes in the resident populations of Rome, Milan and Turin aged 35+ years (International Classification of Diseases, 9th revision, ICD IX: 1–799). The periods of study were 1999–2003 for Milan, 1998–2001 for Rome, and 1997–2003 for Turin. Data on gender and age were also included. A record linkage procedure with city-specific population registries provided information on marital status (Milan and Turin only) and median population income for each census tract of residence (the smallest administrative unit for census purposes with about 500 inhabitants per tract). Census tract family income, relative to 1998, was considered as an area-based indicator of socioeconomic status and was provided by the Italian Ministry of Finance (Stafoggia et al. 2006). Area-level socioeconomic status has been consistently associated with mortality in Italy (Cesaroni et al. 2006) and elsewhere (Krieger et al. 2002).

The city-specific mortality datasets were then linked to the regional hospital discharge datasets. All hospital admissions during the 2 years preceding death (excluding the last 28 days) were selected, considering both primary causes of admission and secondary contributing diagnoses. Individual hospitalisations were classified into a list of 28 groups of diagnoses chosen a priori by adapting the Elixhauser list of comorbidities (Elixhauser et al. 1998). The 28-day window was applied to distinguish a sudden deterioration of health, in the few days prior to death, from chronic conditions. Thus, hospitalisations during the last weeks were excluded from the definition of chronic

conditions and were instead used to identify the place of death. Place of death was categorised as out-of-hospital (no admission or discharge in the last 28 days), discharged 2–28 days before death, in-hospital, or in a nursing home (for Milan and Turin only).

Environmental data

Meteorological data, measured every 6 hours, was provided courtesy of the Italian Air Force Meteorological Service and comprised data on air temperature, dew point temperature and sea-level barometric pressure measured at the airport closest to the city: Linate for Milan (20 km), Ciampino for Rome (7 km), and Caselle for Turin (15 km). City-centre data comprising the same meteorological variables and the same time intervals was provided by Regional Environmental Protection Agency (ARPA) monitoring networks in Milan and Turin, and by the Central Office of Agricultural Ecology (UCEA) in Rome. The locations of the urban sites were in the city centre, which coincide with the most densely populated areas for the three cities, making them quite comparable. At the urban sites, dew point temperature was not measured directly and was derived from relative humidity. Airport and city centre datasets were collected for the period 1999–2003 in Milan, 1998–2001 in Rome and 1997–2003 in Turin. Mean apparent temperature[1] (MAT) (Kalkstein and Valimont 1986; O'Neill et al. 2003), an index of thermal discomfort based on air temperature and dew point temperature, was chosen as the "exposure" variable in this study. The daily value was calculated as the average of the four 6-h measurements of apparent temperature, and the average between the same day and the previous day value was considered (lag 0–1). Data on particulate matter with aerodynamic diameter lower than 10 μm (PM10) was also collected and was included in the statistical model as a variety of studies have documented a short-term effect (lag 0–1) of PM10 on mortality (Katsouyanni et al. 1997; Samet et al. 2000; Biggeri et al. 2004). Furthermore, the possible confounding effect of ozone was also evaluated in the original paper (Stafoggia et al. 2006).

Data analysis

The analysis was conducted for the entire year, but the main focus was the summer period (June–September). The analysis was structured in three parts: firstly, the time-series approach, using the generalised additive models (GAM) framework (Hastie and Tibshirani 1990), was employed to estimate the exposure–response curves of the apparent temperature–mortality relationship for each city on the

full-year range. Site-specific Poisson regression models, accounting for over-dispersion, were built and controlled for a series of confounders. A penalised spline (Wood 2000) for long-term and seasonal trend was included, where the number of degrees of freedom was chosen to optimise the fitting of the model as well as minimising the partial autocorrelation of residuals. Day of the week, temporary population decrease in the summer period, holidays, influenza epidemics and linear terms for PM10 (lag 0–1) and sea-level pressure (lag 0) were also included in the regression models. MAT (lag 0–1) was added to the regression equation as a penalised spline, with different degrees of freedom for each city (Stafoggia et al. 2006).

The apparent temperature–mortality curves were inspected to identify two break points: the first where mortality starts to increase in a non-linear fashion, and the second where the relationship assumes a steep linear pattern. The objective was to approximate the smoothed curve into three straight lines in order to simplify the overall relationship (Muggeo 2003). Alternative approaches were tested as sensitivity analyses in the original paper, and the piece-wise spline with two inner knots turned out to be the best in terms of model fitting (minimum AIC and deviance). Analyses were performed using the "mgcv" and "segmented" libraries in R software version 2.1.0 (The R Foundation for Statistical Computing 2004).

The case-crossover design was then adopted as it is more appropriate for addressing effect modification by individual characteristics (Maclure 1991). The "time-stratified" approach (Levy et al. 2001) was used to select control periods; the study period was divided into monthly strata and control days for each case were selected as the same days of the week in the stratum. A conditional logistic regression was performed for each city, modelling the exposure variable in three straight lines according to city-specific cut-points.

From a descriptive investigation of the meteorological data during June–September, a difference in the MAT distribution in the airport and city datasets was observed. In order to have a more realistic comparison of the effect of apparent temperature on mortality at the two stations, it seemed appropriate to carry out the analysis by estimating the effect of MAT between the 25th and 95th percentile of the distribution during June–September, rather than 20–30°C as used in the original paper, as these points comprised different sections of the two curves in each city. The model controlled for the same confounders as those used in the GAM approach, while time-trends and day of the week were implicitly accounted for by design. STATA version 8 software was used for the analysis.

All results are expressed as the percent increase, with 95% confidence intervals (95% CI), of dying on a day with apparent temperature at the 95th percentile of its distribution (June–September), compared to a day with apparent

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[1] T_{app}= -2.653 + 0.994Ta + 0.0153(Td^2)

temperature at the 25th percentile. Effect modification was tested, and levels of 85% and 95% were chosen as measures of statistical significance.

Results

The mortality characteristics of the three cities included in the study are described in Table 1. The distribution by age group and gender is homogeneous among the three cities considered, with a higher proportion of elderly (over 60% aged 75 years and above) and an equal distribution of females and males. Place of death registers the greatest heterogeneity among cities; Turin has the highest percentage of in-hospital deaths (65.7%) while Milan has the lowest (46.1%); this is partly explained by the fact that the very ill are transferred to nursing homes (13.5%). The distributions do not change when considering the summer (June–September) period.

The location of the airports in the three cities is shown in Fig. 1, and a difference in the distance from the city centre can be noted (Rome 20 km southeast; Turin 15 km north; Milan 7 km east). A comparison of the two meteorological datasets (for the period June–September) was carried out in order to describe the differences between airport and city-centre stations in each city, considering daily minimum, mean and maximum air temperatures, mean dew point temperature and MAT (Table 2, Fig. 2). The temperature distributions for Rome and Turin show higher values in the city centre than at the airport, suggesting an urban heat-island effect. The city-centre and airport distributions are further apart for minimum temperature and closer for maximum temperature in Rome and Turin (Table 2). Average minimum temperature for Turin city station exceeds the average airport minimum temperature by +1.5°C, while the difference for maximum temperatures is only +0.7°C. A similar trend is observed in Rome, where city-centre average minimum temperatures are +1.9°C higher and the difference in average maximum temperatures is only +1°C. In Milan, a different pattern is observed as Linate airport is located closer to the city centre without a real break between the urban area and the airport site: minimum temperature trends are virtually the same, while average maximum temperatures are higher at the airport (+1.7°C) (Table 2). Meteorological indicators measured at the airport and at the city centre were highly correlated for all three cities, with smaller values for minimum air temperature and mean dew point temperature.

Dew point temperature distributions are higher at airport stations in both Milan and Rome, while in Turin they are

Table 1 Description of mortality counts by period (full-year and June–September), age (years), gender, place of death and chronic comorbidities (previous hospital admissions) in Milan, Rome and Turin

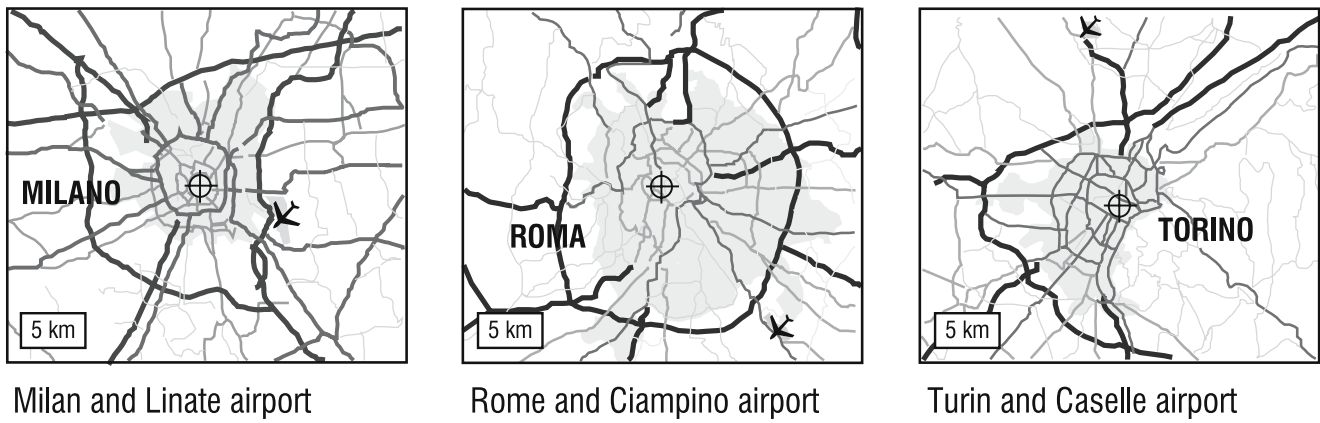| Variables	Milan (1999–2003)				Rome (1998–2001)				Turin (1997–2003)			
	Full year		June–September		Full year		June–September		Full year		June–September	
	n	%	n	%	n	%	n	%	n	%	n	%
Total	52,908	100.0	15,717	100.0	83,253	100.0	25,114	100.0	52,246	100.0	15,850	100.0
Age groups (years)												
35–64	7,090	13.4	2,167	13.8	13,287	16.0	4,074	16.2	7,790	14.9	2,406	15.2
65–74	10,736	20.3	3,174	20.2	18,729	22.5	5,664	22.6	11,369	21.8	3,436	21.7
75+	35,082	66.3	10,376	66.0	51,237	61.5	15,376	61.2	33,087	63.3	10,008	63.1
Gender												
Males	24,814	46.9	7,296	46.4	41,281	49.7	12,385	49.3	25,622	49.0	7,735	48.8
Females	28,094	53.1	8,421	53.6	41,872	50.3	12,729	50.7	26,624	51.0	8,115	51.2
Place of death												
Out of hospital	17,084	32.3	4,800	30.5	31,848	38.3	9,242	36.8	11,740	22.5	3,476	21.9
Hospitalised in the last 2–28 days	4,286	8.1	1,304	8.3	6,291	7.6	1,907	7.6	2,889	5.5	859	5.4
In Hospital	24,403	46.1	7,310	46.5	45,114	54.2	13,965	55.6	34,329	65.7	10,404	65.7
Nursing homes[a]	7,135	13.5	2,303	14.7	–	–	–	–	3,288	6.3	1,111	7.0
Chronic comorbidities												
Psychoses	1,861	3.5	580	3.7	2,766	3.3	876	3.5	1,893	3.6	582	3.7
Depression	547	1.0	162	1.0	766	0.9	254	1.0	537	1.0	172	1.1
Heart and circulation disorders	1,002	1.9	298	1.9	2,507	3.0	765	3.0	649	1.2	187	1.2
Cerebrovascular disease	7,284	13.8	6,657	13.9	9,682	11.6	3,126	12.4	6,214	11.9	1,906	12.0

[a] Milan and Turin only

Fig. 1 Location of airport sites in Milan, Rome and Turin

Table 2 Distribution of meteorological variables at the airport and city-centre stations in Milan (1999–2003), Rome (1998–2001) and Turin (1997–2003) during June–September and Pearson correlation coefficients

		Variable[a]	Percentiles							Mean	Pearson correlation coefficient[b]
			1	5	25	50	75	95	99		
Milan	City	T_{min}	10.7	13.7	16.8	19.3	21.5	24.4	26.4	19.1	0.83
		T_{mean}	14.5	16.6	20.6	23.1	25.7	28.4	30.9	23.0	0.94
		T_{max}	16.3	19.6	24.6	27.2	29.7	32.6	35.2	26.9	0.98
		T_{dew}	5.7	8.6	13.1	15.4	17.1	18.2	19.9	14.8	0.75
		MAT	12.9	15.9	20.9	24.0	27.0	30.4	32.6	23.7	0.95
	Airport	T_{min}	8.5	12.1	16.7	19.1	21.1	23.7	25.6	18.6	–
		T_{mean}	14.4	17.0	21.3	24.1	26.3	28.8	30.4	23.7	–
		T_{max}	17.7	20.9	26.0	29.0	31.5	34.5	36.7	28.6	–
		T_{dew}	8.4	11.5	15.6	18.1	19.8	21.6	24.5	17.6	–
		MAT	12.7	16.3	22.0	25.9	29.1	33.0	35.3	25.5	–
Rome	City	T_{min}	12.4	14.6	18.0	20.0	22.0	24.1	25.8	19.8	0.91
		T_{mean}	17.9	19.5	22.7	24.7	26.5	28.7	29.6	24.5	0.97
		T_{max}	21.9	23.5	27.2	29.5	31.5	34.6	36.3	29.3	0.96
		T_{dew}	5.7	8.4	12.7	14.7	16.7	19.4	20.8	14.5	0.70
		MAT	16.0	18.7	22.9	25.4	27.8	30.3	31.9	25.1	0.95
	Airport	T_{min}	11.0	13.0	16.4	18.0	20.0	21.7	23.1	17.9	–
		T_{mean}	16.8	18.7	21.3	23.1	25.2	27.2	28.7	23.1	–
		T_{max}	20.8	22.8	26.0	28.4	30.6	33.6	35.6	28.3	–
		T_{dew}	8.1	10.7	14.8	17.0	18.7	21.4	22.7	16.6	–
		MAT	15.9	18.4	22.3	24.8	27.6	30.1	31.7	24.8	–
Turin	City	T_{min}	9.4	11.9	15.9	18.5	20.6	23.5	25.4	18.1	0.79
		T_{mean}	13.8	16.2	19.6	22.4	24.5	27.5	29.7	22.0	0.95
		T_{max}	16.0	19.4	23.6	26.5	28.8	32.3	35.1	26.2	0.93
		T_{dew}	0.8	6.8	12.3	15.2	17.3	19.7	20.8	14.4	0.90
		MAT	12.5	15.1	19.3	23.2	26.0	29.7	31.9	22.7	0.96
	Airport	T_{min}	6.3	10.6	14.5	17.0	19.2	21.7	23.2	16.6	–
		T_{mean}	13.1	15.3	18.6	21.4	23.4	26.1	27.9	21.0	–
		T_{max}	15.4	18.6	23.0	25.9	28.2	31.2	33.4	25.5	–
		T_{dew}	3.1	7.8	13.1	15.9	18.4	20.9	22.5	15.5	–
		MAT	10.4	14.0	18.7	22.6	25.5	29.9	32.0	22.1	–

[a] T_{min} minimum air temperature, T_{mean} mean air temperature, T_{max} maximum air temperature, T_{dew} mean dew point temperature, MAT mean apparent temperature

[b] Refers to the correlations of the same variables across stations in each city
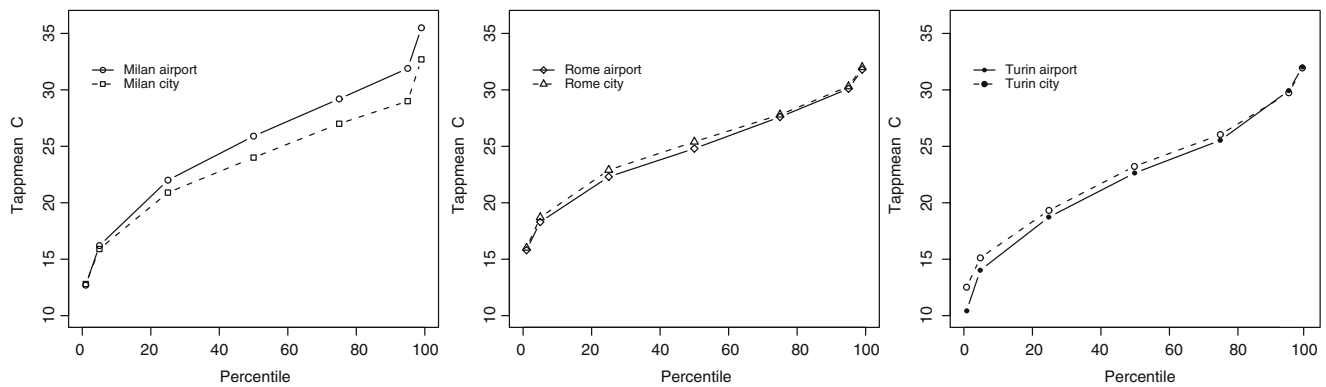
Fig. 2 Distribution of mean apparent temperature for airport (*solid line*) and city centre meteorological stations (*dotted line*) in Milan (1999–2003), Rome (1998–2001) and Turin (1997–2003) during June–September

virtually the same. The greatest difference however, is seen in Milan. When considering the "exposure" variable, MAT, the distributions for Rome and Turin are similar for both stations while in Milan it is higher at the airport (Fig. 2).

Figure 3 shows the relationship between daily MAT (lag 0–1) and mortality for the two stations in each city. The range of MAT varies both among cities and within city stations, with Milan presenting the greatest variability while Rome has the smallest variability. The two curves for Milan differ more than those in the other cities, with a higher number of extreme MAT values at the airport and a steeper curve for extreme values in the city. Both in Rome and in
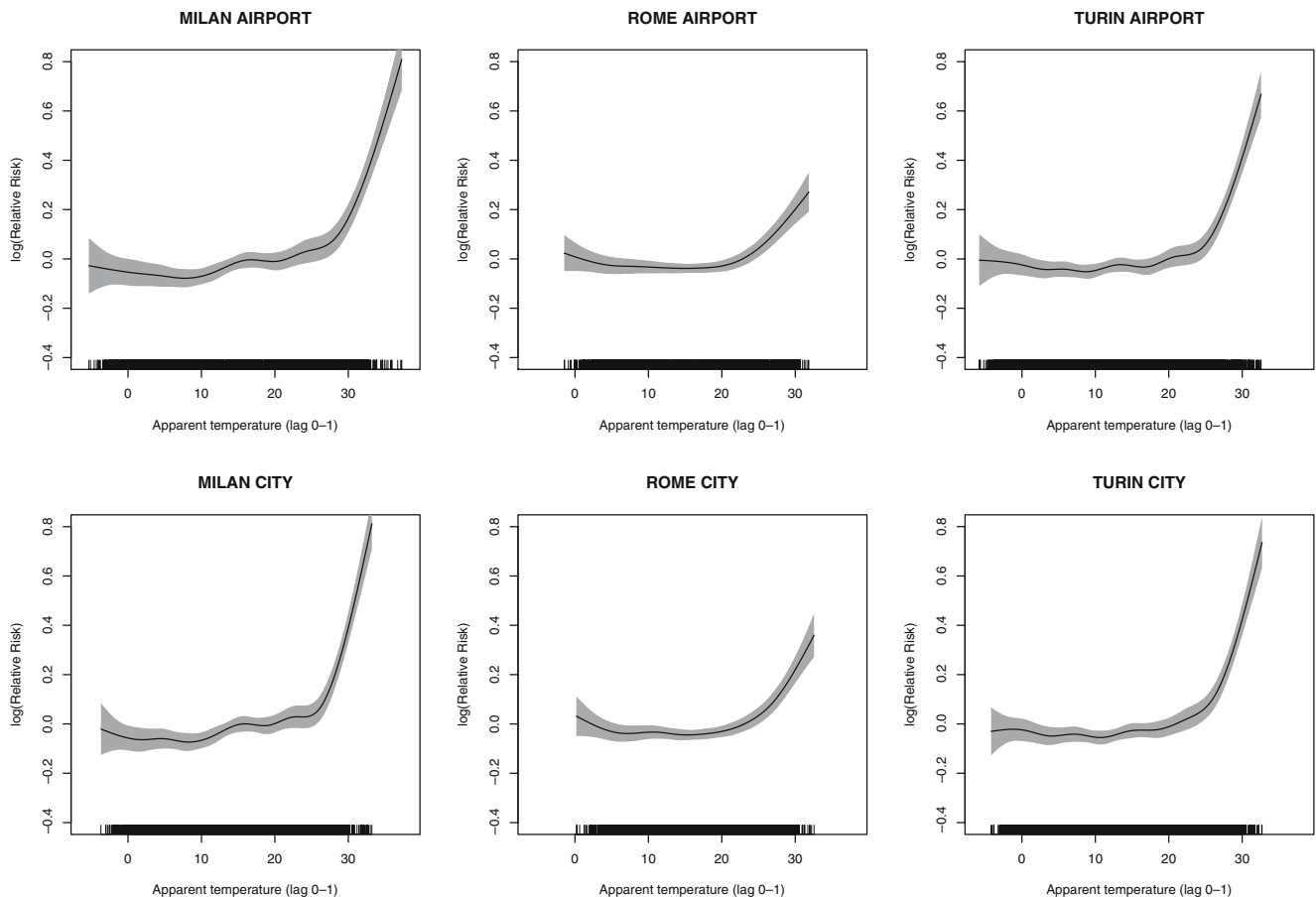
Fig. 3 Relationship between mean apparent temperature (lag 0–1) and all natural mortality, age 35+ years, in Milan (1999–2003), Rome (1998–2001) and Turin (1997–2003). The curves show penalised splines of apparent temperature from city-specific generalised additive models (GAM). The models control for seasonal and long-term time trend (using penalised splines with 4 df/year), day of week, population decrease during summer period, holidays, influenza epidemics, particulate matter with aerodynamic diameter lower than 10 μm (PM10) (lag 0–1) and barometric pressure (lag 0). The x-axes represent apparent temperature, the y-axes the natural logarithms of risks of death centred at zero. The distributions of the actual values of mean apparent temperature (MAT) are represented as *small black bars* on the x-axes

Turin the airport and city curves are very similar and the right-hand slope is slightly steeper in the city centre. The turning points of the right hand side slope of the two curves (city centre and airport) are virtually the same in both cities.

Table 3 illustrates the percent risk of dying from heat in the three cities under the two exposure scenarios (city and airport). The overall risk of excess death when apparent temperatures rise from the 25th percentile to the 95th percentile in summer was similar for Rome and Turin for both airport or city-centre temperatures. In Milan, the effect was stronger when considering airport temperatures. In all cities, an increasing risk was observed with age, with the highest excess for those older than 75 years. Women exhibited a greater susceptibility than men. No effect modification for area-based income was detected, although the percent increase in risk was slightly lower among those in the highest quartile of the distribution in all cities (data not shown). The percent increase of in-hospital mortality was around +30%. Furthermore, a significant effect modification was observed for people in nursing homes in Milan, and the highest value was recorded with airport apparent temperature (+89%, 95%CI 60–124).

Of the 28 groups of diagnoses investigated as a primary or secondary cause of hospital admissions in the 2 years before death, those with a significant effect modification are shown in Table 3. Psychoses, depression, circulation disorders of the heart and cerebrovascular diseases were important effect modifiers in all cities.

When considering place of death, Milan airport exposure displays the highest association with mortality. It is nteresting to note that for clinical conditions there is greater heterogeneity among stations. For example, in Milan and Turin psychoses is a statistically significant (95% level) effect modifier of the effect of heat with an airport exposure, while in Rome, city centre exposures have the greatest effect. Although not significant, Milan airport is the only place where cerebrovascular disease led to a higher increase in mortality, while Rome and Turin have a similar percentage increase for both exposures. Finally, depression (+166%, 95%CI; 35–424) is a significant effect modifier only in Rome with a city centre exposure.

Discussion

The study shows that mean apparent temperatures recorded at the airport and at the city-centre can have a heterogeneous relationship with mortality. In Milan, the apparent temperature differed to a great extent between stations, while in Rome and Turin the exposure values are very similar. Furthermore, apparent temperature recorded at the airport in Milan had a stronger relationship with mortality than apparent temperature recorded in the city.

Our results confirm that the elderly, women and subjects with psychiatric conditions, depression, heart circulation disorders and previous cerebrovascular disease are at higher risk of dying during hot days (Stafoggia et al. 2006). In addition, people in nursing homes or in hospital are also at risk of heat-related mortality during extreme heat events (Stafoggia et al. 2007). Generally, these results for effect modification are not sensitive to the location of the recorded exposure indicator.

When considering single exposures, it was interesting to observe the heterogeneous effect of airport and city-centre exposures on mortality in the three cities. In Rome and Turin, the MAT distribution and percentage increase in mortality with both exposures was virtually the same for all the conditions considered. On the other hand, in Milan, temperature levels at the two stations differ, and the airport levels were higher for maximum temperature, mean dew point temperature and the exposure variable MAT. As consequence, MAT recorded at the airport had the greatest relationship with heat-related mortality.

The comparison between temperature distributions suggests an urban heat-island effect in Rome and Turin with higher values for the urban area datasets. Here airports are located at a significant distance from the urban area (20 km and 15 km, respectively) (Fig. 2). Urban heat-island intensity ($\Delta T_{u-r} = T_{urban\ area} - T_{rural\ area}$) is typically higher during the night and lower during the warmest hours of the day, meaning the difference between city-centre and airport stations is greatest when considering minimum temperatures rather than maximum temperatures, which is what was observed in both Rome and Turin. This temperature pattern was also observed in a similar study conducted in the United States (Basu and Samet 2002b). However, this was not the case for Milan, where minimum temperature trends were virtually the same, and the average maximum temperature was higher at the airport (+1.8°C). This can be explained by the fact that Linate airport is located only 7 km east of the city centre without a real break between the urban area and airport sites. When considering MAT differences between urban and rural areas the same patterns are observed; higher values in the city centre for Rome and Turin, while in Milan the airport has a higher MAT.

To better understand the differences in temperatures and to assess the urban heat island effect in the three cities, spatial mapping of the urban heat island (Voogt and Oke 2003; Hafner et al. 1999) would be an interesting future study. Furthermore, such mapping techniques could help identify spatial patterns of heat sensitivity in the urban population.

Several factors must be considered when interpreting these results. Throughout the literature, the main criteria for the selection of meteorological data is the availability of the data itself, in terms of the variables required and length of

Table 3 Percentage increase in the risk of death in Milan, Rome and Turin on days with MAT (lag 0–1) at the 95th percentile versus days with mean apparent temperature (lag 0–1) at the 25th percentile (June–September), by age, gender, previous hospital admissions and place of death. Airport data compared to city-centre data

Variables	Milan-Airport			Milan-City centre			Rome-Airport			Rome-City centre			Turin-Airport			Turin-City centre		
	%	95%CI		%	95%		%	95%		%	95%		%	95%		%	95%	
		Inf	Sup		Inf	Sup		Inf	Sup		Inf	Sup		Inf	Sup		Inf	Sup
Total	47	38	57	37	30	45	32	23	41	33	24	42	44	36	52	43	35	51
Age (years)																		
35–64	33	11	58	25	7	45	11	−6	31	12	−5	33	13	−4	32	18	1	38
65–74	26	9	45	20	6	36	24	7	42	26	10	45	36*	20	55	35	19	53
75+	57*	45	70	46**	36	56	41**	30	54	41**	30	53	52**	42	63	50**	40	61
Gender																		
Males	28	17	41	22	12	32	23	12	35	24	13	36	35	24	46	33	23	45
Females	65**	51	80	52**	41	65	41*	28	55	42**	29	56	53**	41	65	52**	41	65
Place of death																		
Out of hospital	52	36	71	40	26	55	35	20	50	38	24	54	53	36	72	52	35	70
Hospitalised in the last 2–28 days	34	6	69	24	0	52	−7**	−27	19	−6**	−16	35	34	5	71	30	2	66
In Hospital	34	22	47	28	17	39	36	24	49	33	22	45	38	28	48	38	28	48
Nursing homes	89**	60	124	73**	48	101	–	–	–	–	–	–	70	35	114	61	28	102
Chronic comorbidities																		
Psychoses																		
No	44	35	54	36	28	44	30	22	40	31	23	40	42	34	50	42	34	50
Yes	157**	82	264	91**	40	161	69	18	143	82*	28	158	93**	47	152	73	32	126
Depression																		
No	47	37	56	37	29	45	31	22	40	32	23	41	44	36	52	43	35	52
Yes	72	−8	221	65	−6	189	146*	25	382	166**	35	424	52	−16	173	32	−25	135
Heart and circulation disorders																		
No	46	37	56	37	29	45	30	22	39	32	23	41	44	36	52	43	35	52
Yes	79	12	184	65	10	148	96**	32	190	79*	23	162	46	−16	151	44	−16	149
Cerebrovascular disease																		
No	45	35	55	35	27	44	29	20	39	30	21	39	42	34	51	41	33	50
Yes	59	34	89	48	27	73	50	24	81	51*	26	82	55	31	83	56	32	83

* 85% and ** 95% statistically significant effect modification: modification is calculated respect to the first category of each variable, taken as reference group

time series. Furthermore, when more cities are included in a study, WMO stations, typically airport stations, guarantee that measurements are registered and collected using standardised procedures, thus favouring comparisons. However, most airports are located at some distance from the urban area, and thus may not be entirely representative of the actual climatic conditions a local population is exposed to. On the other hand, although city centre data may be more representative of true urban exposure, the quality of the data is less accurate. There are no clear regulations as to the location and measurement procedures of city-centre stations and, as a result, datasets are generally less comparable as variables are not measured in a standardised way between cities. In our study, we compared airport data with city-centre data although the data were not directly comparable as the variables collected differed and were measured with diverse instrumentation. For example, the city centre stations measured relative humidity instead of dew point temperature, hence we had to derive the latter to calculate the MAT. This is a limitation to the study as a small component of the difference in exposure could be the result of differences in the humidity parameter used.

Within an urban area, temperatures vary considerably. The amount of time spent outdoors, as well as indoor exposure, varies among individuals. Access to air conditioning, the type of housing and personal habits may also modify exposure to heat (Basu and Samet 2002a; Smoyer-Tomic and Rainham 2001). It is important to recall that although ambient temperature is the most common and readily available source of data, it is only a proxy of the real exposure to heat of the population. Ambient measurements may not adequately represent personal exposure, as suggested in an exposure assessment study conducted in the United States (Basu and Samet 2002b). This latter study showed that personal ambient temperature was slightly lower than airport and city temperatures, and that there was no clear association between body temperature and ambient temperatures. Thus, the exposure error resulting from using ambient temperatures (airport or city-centre data), as a surrogate for personal exposure, can potentially lead to a slight bias in the estimated effect of heat on health, and this can be more pronounced among the elderly and frail subgroups who are more likely to spend most of their time indoors. In our study, the use of meteorological variables collected at Linate airport could overestimate the net effect of heat on mortality because the higher values of humidity recorded at the airport compared with the city centre make the former a poorer proxy of the unknown personal exposure within the city.

In light of the differences presented in this study, it seems important to consider diverse ambient exposures when assessing the impact of temperature on mortality in order to account for the possible heterogeneous impact on health they may have. Although ambient temperatures are a proxy for personal exposure, the exposure used has to be representative of the local conditions in order to ensure that impact estimates are as accurate as possible.

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