Impact of the 2003 Heatwave on All-Cause Mortality in 9 French Cities

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Background: A heatwave occurred in France in August 2003, with an accompanying excess of all-cause mortality. This study quantifies this excess mortality and investigates a possible harvesting effect in the few weeks after the heatwave.

Methods: A time-series study using a Poisson regression model with regression splines to control for nonlinear confounders was used to analyze the correlation between heatwave variable and mortality in 9 French cities.

Results: After controlling for long-term and seasonal time trends and the usual effects of temperature and air pollution, we estimated that 3,096 extra deaths resulted from the heatwave. The maximum daily relative risk of mortality during the heatwave (compared with expected deaths at that time of year) ranged from 1.16 in Le Havre to 5.00 in Paris. There was little evidence of mortality displacement in the few weeks after the heatwave, with an estimated deficit of 253 deaths at the end of the period.

Conclusions: The heatwave in France during August 2003 was associated with a large increase in the number of deaths. The impact estimated using a time-series design was consistent with crude previous estimates of the impact of the heatwave. This finding suggests that neither air pollution nor long-term and seasonal trends confounded previous estimates. There was no evidence to suggest that the extras deaths associated with the heatwave were simply brought forward in time.

(*Epidemiology* 2006;17: 75–79)

For 15 days between 4 and 18 August 2003, average daily temperatures across France exceeded 35°C, well in excess of the seasonal norm. These unprecedented temperatures resulted in a dramatic increase in the number of deaths during the heatwave period compared with the seasonal average from previous years. For the entire country, Hémon and Jougla[1] estimated that 14,802 excess deaths occurred from 1 to 20 August 2003, an overall 60% increase in mortality compared with the seasonal norm. The impact of the heatwave was not uniform across the country, with more deaths occurring in the northern part of France away from the Atlantic coast compared with the south and coastal areas. The authors also compared the observed number of deaths from the first 20 days of August 2003 with the mean number of deaths over the previous 3 years (2000–2002) during the same period. However, potential confounders such as long-term trends in mortality, seasonal effects reflecting patterns of meteorology (excluding the heatwave), and air pollution were not taken fully into account. These potential confounders should also be considered when investigating the possible displacement, or bringing forward, of deaths (also known as harvesting).

The impact of high temperatures on mortality has been widely studied. In a review of epidemiologic findings on this subject, Basu and Samet[2] counted 49 studies published between 1970 and 2002. Among these, many were descriptive studies of the effects of heatwaves on mortality such as the one conducted by Hemon and Jougla.[1] Fewer studies have used time-series methods to explore the links between high temperatures and mortality. Time-series studies have measured the effect of temperature variations on total and cause-specific mortality and morbidity in various locations,[3–11] and to explore possible delayed effects or harvesting.[3,4,6,10,11]

The objectives of our study were to use advanced time-series methods to analyze the effects of the heatwave on total mortality, controlling for the usual effects of meteorologic and air pollution variables, and to estimate mortality displacement.

METHODS

This study was set in the 9 French cities included in the PSAS-9 program.[12,13] This program aims to monitor the health effects of air pollution in 9 of the largest French cities: Bordeaux, Le Havre, Lille, Lyon, Marseille, Paris, Rouen, Strasbourg, and Toulouse. We studied all-cause mortality (International Classification of Diseases, 10th Revision codes A00–R99) because high temperatures are thought to be a contributing factor in deaths from a variety of causes.[14] Table 1 shows the size of the population and the daily mean number of deaths in each city from all causes, for all ages, and for people over 65 years, from 1996 to 2003. Mortality data were obtained from the National Institute of Statistics and Eco-

Submitted 26 November 2004; accepted 14 June 2005.
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ISSN: 1044-3983/06/1701-0075
DOI: 10.1097/01.ede.0000187650.36636.1f

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TABLE 1. Demographic Characteristics and Daily Mean Number of Deaths for Total Mortality (all Causes) for All Ages and for People Over 65 Years, Daily Mean and Maximum for Minimum and Maximum Temperature, Daily Mean and Maximum for O_3 8 Hr in 9 French Cities (1996–2003)

	Demographic Characteristics		Daily Mean Number of Deaths		Temperature				Ozone	
					Minimum		Maximum			
Zones	Population Size	% Over 65 Yr	All Ages	% Over 65 Yr	Mean	Maximum	Mean	Maximum	Mean	Maximum
Bordeaux	584,164	15.8	13.3	10.6	9.3	23.1	18.9	40.7	88.2	244
Le Havre	254,585	15.1	6.1	4.6	9.2	24.3	14.0	36.3	78.8	178
Lille	1,091,156	12.8	23.7	17.4	7.5	20.8	14.8	36.6	67.0	202
Lyon	782,828	15.7	16.7	13.3	8.1	24.7	17.1	39.9	113.7	224
Marseille	856,165	18.7	23.0	18.6	11.2	25.2	20.3	37.6	101.7	190
Paris	6,164,418	13.2	122.0	92.0	9.0	25.7	16.1	39.3	74.7	214
Rouen	434,924	15.2	10.2	7.8	6.8	21.9	14.5	37.9	81.7	195
Strasbourg	451,133	13.3	9.2	7.1	6.6	21.3	15.5	38.4	92.4	208
Toulouse	690,162	13.5	12.7	10.0	9.5	23.8	18.5	40.4	94.7	177

nomic Studies (INSEE). The cities have a total population close to 11 million, including 6 million in Paris. The daily mean number of deaths ranged from 6 in Le Havre to 122 in Paris. The proportion of deaths occurring among people over 65 years ranged from 73% in Lille to 81% in Marseille.

Temperature data were obtained from the national meteorologic institute (Météo-France) and ozone indicators from local network monitoring. Descriptive data on temperature and ozone levels are also shown in Table 1. Summer (April to September) daily mean of maximum of 8-hour measurements of ozone (O_3—8 hours) was the highest in Lyon and the lowest in Lille. The highest means of maximum and minimum temperatures were encountered in Marseille.

The daily data from the 9 cities were analyzed with time-series methods using Poisson regression models allowing for overdispersion. We controlled for possible confounders, including long-term trend, season, days of the week, bank holidays, influenza epidemics, minimum temperature on the current day, maximum temperature on the previous day, and O_3—8 hour mean of the current and the previous days (0–1 day lag) as a linear term following the APHEA-2 (Air Pollution and Health: a European Approach) methodology.[15] The weather and air pollution variables included in the models captured the expected effects of these variables on daily mortality, independent of the heatwave. Temperature and season variables were modeled using penalized cubic regression spline.[16] The degree of smoothing of the spline function for season was chosen to remove seasonal and long-term temporal trends and to minimize autocorrelation in the residuals. Temperature terms were modeled using 3 degrees of freedom for each. To capture the effect of the heatwave, we added a penalized cubic regression spline function of time for a 43-day period centered on 12 August, the day with the maximum number of deaths during that period. This period, from 22 July to 2 September, was chosen to allow us to examine the possibility of short-term mortality displacement. The degree of smoothing of the heatwave spline function was chosen to minimize autocorrelation in the residuals. This penalized cubic regression spline hence captured the specific effects of the heatwave, excluding longer-term temporal trends and the usual effects of air pollution and temperature (which were taken into account by the other specific variables introduced in the model). The predicted values from this spline function minus the usual seasonal pattern represented the daily relative risk of the specific effect of the heatwave. The usual seasonal patterns were defined as the predicted values by the seasonal spline function from the model during that period, denoted "seasonal prediction." Also, we were interested in calculating the overall number of excess deaths during that period, ie, those attributable to the heatwave and to air pollution and meteorologic covariates, to compare our results with those from the initial analysis.[1] Therefore, we estimated the predicted values from the full model, denoted "full prediction." Reference levels for meteorologic and ozone covariates were defined on their respective mean during the same period over the last 3 years. Data were analyzed using MGCV package[17] in the R software.[18]

RESULTS

For each of the 9 cities, the daily relative risk from 22 July to 2 September 2003 was calculated using the seasonal prediction as the baseline. Figure 1 shows the daily fluctuations of the relative risk for each city. The number of degrees of freedom selected to model the heat wave ranged from 4 in Le Havre to 14 in Paris (Table 2). Cities exhibiting a sharp increase in mortality are those requiring more degrees of freedom. These numbers need to be compared with those selected to control the overall long-term and seasonal pattern, which are around 3 to 4 degrees of freedom per year.

Except in Le Havre (where the heatwave was limited in time and intensity), the daily relative risk exhibits the same pattern in each city, with an increase at the beginning of August, reaching a peak around 12 August, and then going back to usual levels around 20 August. The maximum relative risks observed during that period are presented in Table 2.

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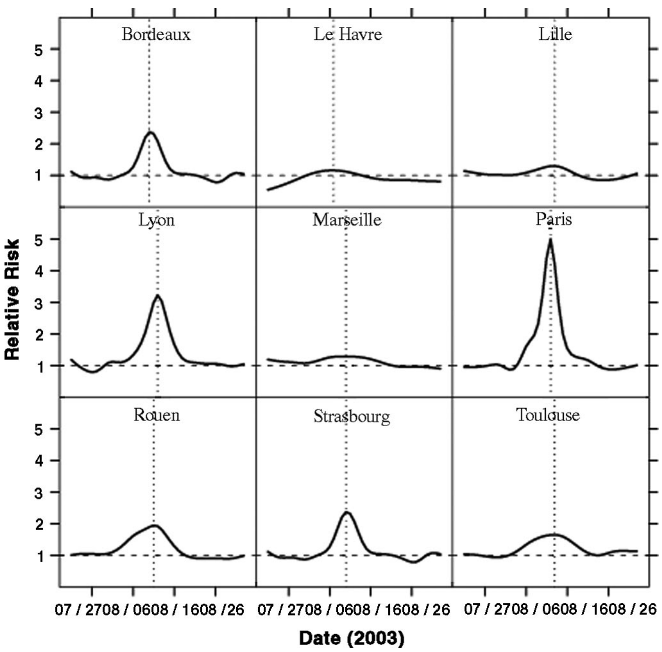

FIGURE 1. Daily relative risks of death for each city during the heatwave (22 July to 2 September 2003) with dotted vertical line located on day with the highest risk.

The relative risk for all-cause mortality on the day with the highest mortality was 5.00 (95% confidence interval = 4.62–5.40) in Paris and 1.16 (0.93–1.44) in Le Havre (Table 2). Except in Le Havre, the maximum risk in each city was significant and occurred during a 4-day period from 10 to 13 August.

There was some evidence of short-term mortality displacement with a small deficit of deaths during the week after the heatwave (Fig. 1). Bordeaux, Lille, Marseille, Rouen, and Paris exhibited a slight harvesting effect, with daily relative risks under 1.0 between 20 and 30 August. The number of deaths between 22 July and 2 September, predicted with a spline function capturing the effect of the heatwave, was compared with the full prediction. Table 3 shows the excess of deaths during that period, the harvesting effect, and the net effect (defined as the difference between excess and harvesting effects). The excess rate, expressed as the net effect per 100,000 inhabitants, is also given. In these 9 cities, 3,096 extra deaths were estimated during the 43-day period; 253 deaths were estimated to be displaced by less than 3 weeks, giving a net excess of 2,843 deaths. The short-term harvesting contribution, defined as harvesting over excess, ranges from 1% of the excess in Strasbourg to 30% in Lille. This proportion was around 6% in Paris and Lyon. More than 30 people per 100,000 died in excess in Paris and Lyon during the heatwave.

TABLE 2. Maximum Daily Relative Risk of Mortality (RR_{max}) Between 22 July and 2 September 2003, Date When This Maximum Was Reached, and Number of Degrees of Freedom (*df*) Used to Control Heatwave

City	RR_{max} (95% CI)	Date	*df*
Bordeaux	2.37 (1.94–2.89)	10 August	12
Le Havre	1.16 (0.93–1.44)	7 August	4
Lille	1.30 (1.13–1.49)	13 August	7
Lyon	3.22 (2.73–3.80)	12 August	12
Marseille	1.28 (1.12–1.47)	10 August	7
Paris	5.00 (4.62–5.40)	12 August	14
Rouen	1.94 (1.59–2.38)	11 August	7
Strasbourg	2.00 (1.60–2.50)	11 August	10
Toulouse	1.65 (1.39–1.95)	13 August	7

TABLE 3. Number of Excess Deaths During the Heatwave, Harvesting Effect, the Net Effect, and the Net Excess Mortality Rate in 9 French Cities (22 July to 2 September 2003)

	Number of Deaths			
City	Excess	Harvesting	Net	Net Excess Mortality Rate per 100,000
Bordeaux	119	−24	95	16.3
Le Havre	10	−26	−16	−8.4
Lille	57	−17	40	3.7
Lyon	266	−16	250	31.9
Marseille	121	−15	106	12.4
Paris	2,228	−143	2085	33.8
Rouen	105	−8	97	22.3
Strasbourg	91	−1	90	20.0
Toulouse	99	−3	96	13.9
Total	3,096	−253	2843	

To compare our results with those previously published,[1] we calculated for the Paris region (4 administrative departments) the excess number of deaths from 22 July to 2 September using 2 approaches. We compared the observed number of deaths during the heatwave with the mean number over the last 3 years for the average of July to September (reference level used in the initial analysis).[1] We also calculated the prediction of our full model, including heatwave, temperature, and O_3 effects, taking as baseline level the mean of all covariates during the last 3 years over the same period. Both methods gave very similar results.

DISCUSSION

The estimated excess mortality identified by our analysis was consistent with a previous estimate,[1] indicating that usual air pollution and temperature effects, longer-term temporal trends, and seasonal fluctuations did not appear as the main factors affecting mortality during the heatwave. We focused our analysis on short-term temporal displacement because most of the persons who died during that period were elderly. More than 90% of the heatwave victims in our 9 cities would not have been expected to die of other causes in the immediate future. This finding supports results of previous studies[19–21]: increases in nonspecific mortality during heatwaves do not primarily represent deaths in extremely

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debilitated individuals. Thus, interventions designed to prevent spikes in mortality during heatwaves should have a tangible effect on life expectancy in at-risk populations. Socioeconomic status or educational attainment have been shown to be major effect modifiers of the effect of heat on mortality.[9] A case–control study[22] conducted in France after the 2003 heatwave found that several individual risk factors such as socioeconomic status, isolation, cardiac or psychiatric diseases, and disability were associated with the probability of dying.

The data analyzed in our study were from 9 cities in France. We chose to focus on these cities because a permanent information system linking mortality to air pollution was already available, and the areas in the system were selected to be almost homogeneous in terms of air pollution and temperature. If we had included rural areas, the exposure would not have been uniform across the study population and we would have assigned exposures to these populations, not necessarily representative of the true exposures. The cities selected for analysis represent less than 20% of the total population in France and are not representative of rural exposure. Thus, the present findings should not be extrapolated to the whole of France. We were not able to investigate differential effects of the heatwave by cause of death because these data were not available at the time of this study.

The exact nature of the observed effect is not precisely known. We think that the exceptional nature of the heatwave in terms of the high temperatures and high levels of photochemical air pollution and the duration of the heatwave combined in some way to produce the very strong observed effect.

One of the characteristics of this heatwave was the lack of evidence of substantial short-term mortality displacement. The observed harvesting effect was considerably less than the excess mortality, showing that most of the people who died during the heatwave were not expected to die in the immediate future. This finding appears to be a unique characteristic of the 2003 heatwave in France. A harvesting effect is often observed with high temperatures. In 12 U.S. cities, hospital admissions for heart diseases,[11] total mortality,[3] and cardiovascular and myocardial infraction[4] increased with temperature, but the effect of high temperatures was consistent with harvesting, with fewer admissions or deaths several days after an episode of high temperatures. Similar results were found for both cold and hot temperature effects on mortality in Sofia,[10] and to a lesser extent for high temperatures in London[10] and Dublin.[6] However, these observations of mortality displacement correspond to weather conditions typically encountered; they represent the averaged effect of harvesting on the whole range of temperature. Results obtained in the present study seem to show that during a heatwave, the exceptionally high temperatures and the long duration of exposure, may change the characteristics of individuals affected by the heat effects, including some individuals who were not especially frail. To study harvesting beyond 6 weeks, a different study design is required because the seasonal pattern begins to confound the long-term relationships between temperature and daily deaths. Some recent studies[23–26] tried to address this issue, but their conclusions remain somewhat confusing. Noninstitutionalized people who died during the August 2003 heatwave in France had a larger demand on health services and on prescription drugs during the 5 months preceding the heatwave when compared with appropriate controls.[23] Mortality during the last months of 2003 was not lower than during a control period,[24] but mortality during the first months of year 2004 was much lower than during a control period.[25] However, an analysis of 2004 mortality statistics in France[26] shows that the decrease in mortality during 2004 was larger than the increase due to the heatwave in 2003; furthermore, the geographic distribution of the mortality "deficit" was not consistent with the geographic distribution of excess mortality during the heatwave.

Further studies are therefore needed, first for a better understanding of the role of meteorologic variables and air pollution during heatwaves and, second, for a better knowledge of the characteristics of the target-sensitive population and the causes of deaths.

Our results justify the implementation of response plans, combining a watch–warning system and accompanying measures to reduce the impact of the heatwave on mortality.[27] Simple preventive measures may help to reduce the toll of extreme weather in summer; they are effective only if taken in time. This needs better forecast of extreme weather, better response by the health system, and better information for health professionals and the public, especially elderly people and their relatives and neighbors.[28] A new alert system recently implemented in France[27] may help reduce the death toll of future extreme heat episodes.

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