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TEMPERATURE AND MORTALITY IN NINE U.S. CITIES

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), conducts public interest research, development, and demonstration (RD&D) projects to benefit California's electricity and natural gas ratepayers. The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

In 2003, the California Energy Commission's Public Interest Energy Research (PIER) Program established the **California Climate Change Center** to document climate change research relevant to the states. This Center is a virtual organization with core research activities at Scripps Institution of Oceanography and the University of California, Berkeley, complemented by efforts at other research institutions. Priority research areas defined in PIER's five-year Climate Change Research Plan are: monitoring, analysis, and modeling of climate; analysis of options to reduce greenhouse gas emissions; assessment of physical impacts and of adaptation strategies; and analysis of the economic consequences of both climate change impacts and the efforts designed to reduce emissions.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

Temperature and Mortality in Nine U.S. Cities is the final report for the Climate Change Impacts: Potential Impact of High Temperatures and Air Pollution on Public Health project (contract 500-99-013, work authorization BOA-118) conducted by Antonella Zanobetti and Joel Schwartz.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

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Abstract

Several studies have found that extreme temperatures are associated with increased mortality worldwide. The extent by which this occurrence is confounded or modified by air pollutants remains unclear. This study examined the association between mean apparent temperature (an individual's perceived air temperature, given the humidity) and total mortality in nine U.S. cities during May to September, 1999 to 2002.

Researchers applied both case-crossover and time-series analyses to the data, adjusting for day of the week and season in time-series analysis. City-specific estimates were combined using a meta-analysis. A total of 213,438 deaths for all causes occurred in these cities during the study period. Researchers found a significant effect of apparent temperature on mortality with a 1.8 percent increase (95 percent confidence interval: 1.09–2.5) in mortality per 5.5°C (10°F) increase in apparent temperature in the case-crossover analysis, and a 2.7 percent increase (95 percent confidence interval: 2.01– 3.5) in the time-series analysis. Ozone and fine particulate were not found to be significant confounders or effect modifiers.

This study provides evidence of increased mortality from mean temperature exposure, even when adjusting by air pollution. Climate change is a serious public health issue; to prevent heat-related morbidity and mortality, more studies are warranted to help identify where public health programs should be directed.

Keywords: Temperature, humidity, apparent temperature, mortality, air pollution, epidemiology, case-crossover, time-series, climate change

Executive Summary

Introduction

Greenhouse gas emissions from human activity are projected to increase overall average temperatures, as well as the frequency of extreme weather events (such as heat waves) across the world. Several studies have found that extreme temperatures are associated with increased mortality worldwide. However, the extent to which air pollutants play a role in that increased mortality remains unclear.

Purpose

This study sought to investigate the association between weather and mortality during the summer months, focusing on the average temperature exposure that is commonly experienced during summer, and to examine confounding and effect modification by air pollutants. *Confounding* is a variable that is not considered in a study but can affect the outcome.

Project Objective

This study examined the association between apparent temperature (an individual's perceived air temperature, given the humidity) and total mortality during the summer months May to September using two modern statistical approaches: time-series analysis and case-crossover analysis.

For the study, researchers selected nine U.S. cities outside California that had sufficient mortality and daily air pollution data and were representative of both cold and warm climates. A similar analysis previously focused on nine California counties.

The National Center for Health Statistics (NCHS) provided individual mortality data for 1999 and 2000, and the state public health departments provided the same for 2001 and 2002. The mortality files provided information on the exact date of death and the underlying cause of death. For this study researchers selected all-cause daily mortality, excluding any deaths from accidental causes.

The research team obtained local meteorological data from the United States Surface Airways and Airways Solar Radiation hourly data. The team focused on apparent temperature because this index should characterize the physiological experience better than temperature alone.

Data for particulate air matter with aerodynamic diameter less than 2.5 micrograms ($PM_{2.5}$) and ozone were obtained from U.S. Environmental Protection Agency's Air Quality System Technology Transfer Network. The two major pollutants associated with mortality (fine particles and ozone) were considered as either confounders (adding each pollutant separately in the model) or effect modifiers by including in the model a bivariate smoothing (a curved surface between apparent temperature and pollution) and investigating possible interactions by looking at the three-dimensional plots.

To investigate the association between weather and mortality, the researchers used both time series and case-crossover analyses, including a linear term for apparent temperature on the same day in the model. The case-crossover design compares each subject's exposure experience in a period just before a case-defining event with that subject's exposure at other times.

The researchers conducted sensitivity analyses to explore the possibility that moving averages longer than one day are better predictors of the temperature-mortality association. Researchers also looked at other temperature definitions such as mean, minimum, and maximum temperature; days with apparent temperature greater than 23.8°C (75°F); and a regional analysis. City-specific estimates were then combined using a meta-analysis incorporating a random effect, whether or not there was a significant heterogeneity.

Conclusion

In this study the authors found a significant effect of apparent temperature on mortality from non-accidental causes in summer months, when the dose-response relationship between temperature and mortality has been shown to be linear, with around a 2 percent increase in apparent temperature per 10°F. The same results were obtained when using other representations of temperature (such as maximum daily temperatures).

Significantly, the authors found no effect modification by either particles or ozone, no confounding by particles, but a moderate degree of confounding by ozone. The analysis of mean, maximum, and minimum temperature produced similar estimates compared to the main results. In regional analyses, the authors also found a smaller risk in the warmer southern cities (excluding Phoenix) than in the colder cities.

Recommendations

Climate change is a serious public health issue, and specific policies to reduce the effects of heat waves would be appropriate public policy. To be effective, these policies need to target interventions that are successful and populations that are at risk. Previous research has suggested that air conditioning use is an important mitigation strategy, and other studies have identified race, age, and poverty as modifiers of heat effects. Further research is warranted to help identify future directions for public health programs, in order to prevent heat-related morbidity and mortality, and to examine whether other interventions such as green space, tree planting, and changes in roofing can also modify these effects. This study focused on total mortality and included too few cities to provide good information on the role of various effect modifiers. Finally, few studies have evaluated the effect of hot weather on hospital admissions; additional analyses of weather effects on morbidity would help improve understanding of the mechanisms involved and provide more information to support prevention efforts.

Benefits to California

This study provides evidence of increased mortality due to mean temperature exposure in nine U.S. cities (outside California) that were representative of both cold and warm climates. An analysis done with methods similar to those in this study but focusing on nine California counties found an approximately 3 percent increase in all-cause mortality per 10°F increase in apparent temperature—an increase slightly higher than that found in this study. The same study also found a lower percentage increase in mortality in inland areas compared to the coastal areas, and this could be due to some acclimatization for people living in inland areas, characterized by higher temperatures during summer months; similarly, this analysis found evidence of acclimatization.

This epidemiologic study therefore gives important information about the relationship between temperature and mortality from cities with a different climate than California's, showing results that are consistent with the California results, thereby providing evidence that the California results are unlikely to be chance findings and that appropriate interventions are worthwhile.

1.0 Introduction

Greenhouse gas emissions from human activity are projected to increase overall average temperatures, as well as the frequency of extreme weather events such as heat waves, across the world (Karl, Knight et al. 1995; Easterling, Meehl et al. 2000; McMichael 2000; Houghton, Ding et al. 2001; McGeehin and Mirabelli 2001). These changes will have potentially serious implications for human health, and the evaluations of the links between climate change and health in terms of describing and quantifying the impact of these changes can help identify vulnerable populations and inform policy makers seeking to take preventive actions (Patz, Engelberg et al. 2000; Patz, McGeehin et al. 2000; McMichael 2001; Patz and Khaliq 2002). In colder climates, the increase of global temperature may benefit health (Martens and Huynen 2001), although other studies have suggested that the wintertime increase in mortality in some countries is due to infections disease, and not direct effects of cold weather (Reichert, Simonsen et al. 2004). Because climate change will likely increase the average temperature, this study focused on the summer effects of weather.

The effect of temperature extremes in association with increased mortality are well studied (Keatinge, Donaldson et al. 2000; Braga, Zanobetti et al. 2001; Huynen, Martens et al. 2001; Curriero, Heiner et al. 2002; Hajat, Kovats et al. 2002; Basu and Samet 2003; Mercer 2003; O'Neill, Zanobetti et al. 2003; Schwartz 2005a; Le Tertre, Lefranc et al. 2006; Medina-Ramon, Zanobetti et al. 2006); (Kysely 2004; Hajat, Armstrong et al. 2005)); greater susceptibility has been reported for the elderly and for those with a lower socioeconomic status (Curriero, Heiner et al. 2002; Diaz, Jordan et al. 2002; O'Neill, Zanobetti et al. 2003; Schwartz 2005b; Medina-Ramon, Zanobetti et al. 2006) and for those without air conditioning (O'Neill M, Zanobetti et al. 2005). The underlying mechanisms for the increase in mortality may be related to the stress placed on the respiratory and circulatory systems to increase heat loss through skin surface blood circulation, particularly in the elderly and other vulnerable subgroups who may not be able to thermoregulate efficiently (Basu and Samet 2002; Bouchama and Knochel 2002).

Inadequate thermoregulation may occur when too much blood is diverted, putting increased stress on the heart and lungs. Moreover, increase in blood viscosity and cholesterol levels due to high temperatures (Keatinge, Coleshaw et al. 1986) may increase the risk for cardio-respiratory deaths. A higher sweating threshold in the elderly may also trigger heat-related mortality in susceptible individuals (Astrand, Rodahl et al. 2003).

What is less clear is the extent to which these previously reported associations are confounded by air pollution. O'Neill examined this issue in two Mexican cities and reported a moderate degree of confounding[1] by air pollution (O'Neill M, Hajat et al. 2005), but this issue, and the

[1] *Confounding* is a variable which is associated with both disease and exposure, but is not an effect of exposure.

parallel issue of effect modification,[2] is under-explored. Moreover, examination of effect modification, when done, has generally used simple multiplicative interaction terms, whereas with thin plate splines, the potential exists to examine more complex types of interactions.

This study's hypothesis is that weather, expressed by apparent temperature,[3] increases total mortality, and that the effect is independent of air pollution. Therefore the authors examined the association between apparent temperature and mortality in nine U.S. cities with a range of climatic and pollution patterns. Researchers focused on apparent temperature and the summer season and examined confounding by air pollutants and effect modification by air pollutants, using both time series and case-crossover analyses.

[2] *Effect modification* refers to the situation in which a measure of effect changes over values of another variable. For example, A factor, *Z,* is said to be an effect modifier of a relationship between a risk factor, *X,* and an outcome measure, *Y,* if the strength of the relationship between the risk factor, *X,* and the outcome, *Y,* varies among the levels of *Z.*

[3] *Apparent temperature* is an individual's perceived air temperature, given the humidity.

2.0 Materials and Methods

2.1. Mortality Data

The researchers selected nine U.S. cities outside of California that had sufficient mortality and daily air pollution data and were representative of both cold and warm climates:

- Birmingham, Alabama
- Boston, Massachusetts
- Chicago, Illinois
- Detroit, Michigan
- Dallas, Texas
- Houston, Texas
- Minneapolis/St. Paul, Minnesota
- Philadelphia, Pennsylvania
- Phoenix, Arizona

These cities represent a range of summer temperatures (with the average apparent temperature ranging from 20°C to 32°C) and a range of particulate air matter with aerodynamic diameter less than 2.5 micrograms ($PM_{2.5}$) co-exposures (from 8 to 26 micrograms per cubic meter [$\mu g/m^3$]).

The authors conducted the analyses at the city level, which in most cases was restricted to a single county. However, the authors used multiple counties for Minneapolis-St.Paul (Ramsey and Hennepin), and Boston (Middlesex, Norfolk, Suffolk), where the city's population extends beyond the boundaries of one county.

The National Center for Health Statistics (NCHS) provided individual mortality data for the years 1999 and 2000, and the state public health departments of Massachusetts, Michigan, Minnesota, Texas, and Pennsylvania provided the same for 2001 and 2002. The mortality files provided information on the exact date of death and the underlying cause of death.

For this study the researchers selected all-cause daily mortality, excluding any deaths from accidental causes (ICD-code 10th revision: V01-Y98, ICD- code 9th revision: 1-799).

2.2. Environmental Data

The authors obtained $PM_{2.5}$ and ozone data from the U.S. Environmental Protection Agency's Air Quality System Technology Transfer Network (USEPA Technology Transfer Network, 2005).[4]

[4] These data are publicly available online at: www.epa.gov/ttn/airs/airsaqs/detaildata/downloadaqsdata.htm.

In most cities $PM_{2.5}$ monitoring started in 1999. For the Boston area the authors used daily $PM_{2.5}$ concentration extracted from the Harvard School of Public Health monitor located in downtown Boston, as these data were more complete. For ozone the researchers used 8-hour daily mean concentrations during the hours of 8 a.m. to 5 p.m. When multiple monitors were present in a city, researchers estimated an average daily value for the city and accounted for the impact of occasional missing values using an algorithm previously described (Zanobetti, Schwartz et al. 2000). However, before applying this algorithm, the researchers obtained multiple correlation coefficients for each monitor (correlated with all other monitors in the city), from which median values were extracted. Those monitors falling in the low tenth percentile of the distribution of the median values, across all cities, were excluded from the analyses.

The authors obtained local meteorological data such as mean, maximum, and minimum temperature, and dew point temperature, from the United States Surface Airways and Airways Solar Radiation hourly data (National Environmental Satellite, Data, and Information Service 2003). The researchers also computed apparent temperature (AT), defined as an individual's perceived air temperature given the humidity. Apparent temperature was calculated for each day with the following formula (Steadman 1979; Kalkstein and Valimont 1986).

$$AT = -2.653 + (0.994*Ta) + (0.0153*Td^2)$$

where Ta is the mean temperature and Td is dew point temperature.

2.3. Methods

To investigate the association between weather and mortality the researchers used both time series and case-crossover analyses.

The case-crossover design was developed as a variant of the case-control design used to study the effects of transient exposures on acute events (Maclure 1991). This design compares each subject's exposure experience in a time period just prior to a case-defining event with that subject's exposure at other times. That is, person time is sampled in the same individual for the case (death) and control (non-death) periods. Each subject serves as his or her own control, providing perfect matching on all measured or unmeasured subject characteristics that do not vary over time. If, in addition, the control days are chosen to be close to the event day, slowly varying subject characteristics are also controlled by matching.

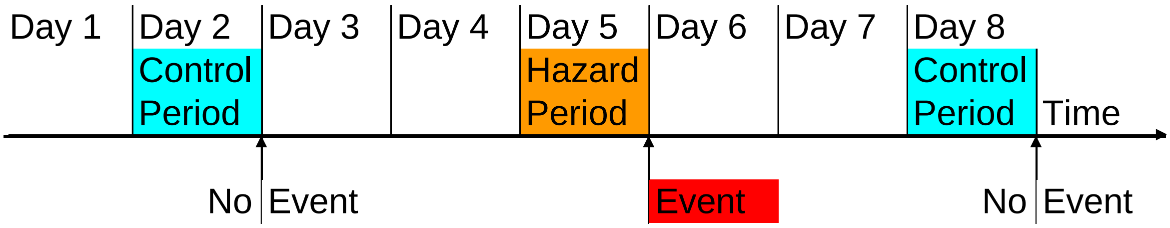

Figure 1. Schematic representation of the symmetric bidirectional case-crossover approach

Figure 1 shows an example of how controls are chosen within the same year and month. If for example the event was on Day 5, the control periods will be chosen before and after that day, every third day in the same month and year as the event.

Bateson and Schwartz (Bateson and Schwartz 1999; Bateson and Schwartz 2001) demonstrated that by choosing control days close to event days, even very strong confounding of exposure by seasonal patterns could be controlled by design in the case control approach (symmetric bidirectional case-crossover approach). Levy, Lumley et al. (2001) showed that a time-stratified approach to choosing controls resulted in a proper conditional logistic likelihood, and Schwartz, Zanobetti et al. (2003) demonstrated with simulation studies that this approach gave unbiased effect sizes and coverage probabilities even with strong seasonal confounding. The researchers used this same stratified approach, and defined the hazard period as the day of death, choosing control days as days in the same year and month and on every third day. The data were analyzed using a conditional logistic regression (PROC PHREG in SAS, SAS software release 8.2. 2001).

A generalized additive model, with a quasi-Poisson link function to account for overdispersion was applied to investigate the time series of daily counts of mortality and daily weather. In the generalized additive model the outcome is assumed to depend on a sum of linear variable and a sum of smooth functions. The model is of the form:

$$Cases_t \sim Poisson(exp\{\beta_0 + \beta_1 Monday + \ldots + f(seasonality) + \beta_n Apparent\ temperature\})$$

where the Cases are the daily count of deaths on day t and *f* is a smooth function for seasonality; specifically, the authors used natural splines.

In time-series analysis, changes in smoking, diet, and fitness are not confounders, as they do not change on a daily basis as temperature does.

In the model the researchers controlled for seasonality and trend using natural splines with four degrees of freedom per year and subsetting for summer months, and day of the week with indicator variables.

These models were fit in R (The Comprehensive R Archive Network: http://cran.r-project.org/).

2.4. Data Analysis

2.4.1. Exploratory Analysis

The authors first conducted exploratory analyses to determine whether the use of linear temperature terms for the warm seasons was appropriate. This was accomplished by fitting time series models for the full year in each city, using natural splines for apparent temperature with four degrees of freedom (df). In addition these models included a natural spline for seasonality with four df/year and day of the week with indicator variables. If the exploratory plots from those models looked roughly linear for warm temperatures, the remaining models, restricted to the warm season, were conducted using linear temperature terms, which facilitate the reporting of odds ratios.

2.4.2. Main Analysis

The analysis was first conducted in each city separately; individual deaths were used in the case-crossover study and aggregated counts of daily deaths for the time-series analysis. In each model the researchers controlled for day of the week with indicator variables. For time series analysis, this study controlled for long-term time trends using natural splines with four df for year subsetting for each May to September period.

The authors investigated the association between weather and mortality during the summer period (May–September) using a linear term for apparent temperature on the same day in the model. They examined confounding and effect modification by each pollutant. The researchers added each pollutant separately in the model to see if they confounded the association between apparent temperature and mortality. The researchers analyzed effect modification and nonlinearity in the association with temperature by including in the model a bivariate thin plate regression spline of apparent temperature and pollution and investigated possible interactions by looking at the three-dimensional plots. If any plot was indicative of possible interactions, the researchers considered multiplicative interaction terms between the temperature and the pollutant. The authors considered an interaction to be significant if either the multiplicative interaction term was statistically significant, or if a thin plate spline with more than two df was significant in a likelihood ratio test compared to a model with linear terms for pollution and temperature. The degrees of freedom for the thin plate spline were chosen using cross-validation.

2.4.3. Sensitivity Analyses

The authors applied several sensitivity analyses. First, the researchers considered the possibility that moving averages longer than one day are better predictors of the temperature-mortality association, comparing the effect of the same day temperature exposure (lag 0) to moving averages of the same day and the previous three days (lag 03) or the moving averages of the previous three days (lag 13). The model with the higher adjusted deviance was chosen**.** The authors then looked at other temperature definitions, replacing apparent temperature with models containing the combination of either mean, minimum, and maximum temperature with dew point temperature and using adjusted deviance to choose the best fitting among these models. To test for linearity of the temperature-mortality association during summer months, researchers analyzed only days with apparent temperature greater than 23.8°C (75 °F).

Finally, researchers considered a regional analysis. In the regional analysis the cities were divided by colder cities (Boston, Chicago, Detroit, Minneapolis/St. Paul, and Philadelphia) and warmer cities (Birmingham, Dallas, and Houston). Phoenix was excluded because the dry weather of this city cannot be compared to the other warmer cities.

If a linear term is used for pollution, to control for confounding, several aspects of confounding could be missed. If the association with the confounder is nonlinear, or if it varies over time, there may be residual confounding. To protect against these risks, the research team used an alternative approach of matching control days to the same concentrations of air pollutants as case days (Schwartz 2005b).

2.4.4. Combined Results

In a second stage of the analysis, the city-specific estimates were combined using the meta-regression technique of Berkey and coworkers (Berkey, Hoaglin et al. 1998). Heterogeneity in the pooled effect across the cities was addressed by using a random effects meta-analysis; to be conservative, the researches report the results incorporating a random effect, whether or not there was a significant heterogeneity.

The combined result across cities gives a more unified and reliable estimate of the temperature-mortality association, because it takes into account differences among the cities by incorporating a random effect and eliminates possible publication bias, spurious results, random findings, or differences attributable to adaptation (Anderson, Atkinson et al. 2005).

The authors report the results as percent increases in mortality for a 5.5°C (10°F) increase in apparent temperature.

3.0 Results

In each city's exploratory analysis, the researchers first plotted the smoothing function of apparent temperature for all four seasons over all of the years of the study, to look at possible nonlinearity (Figure 2). From the plots it is clear that starting from an apparent temperature of 10°C or 15°C, depending on the city, the association between mortality and apparent temperature is linear.

The sensitivity analyses found that lag 0 apparent temperature had the best model fit compared to the moving averages of multiple days, according to the higher adjusted deviance. The authors therefore report here the results analyzing the effect of apparent temperature only during warmer months (May to September) and used a linear term for apparent temperature at lag 0.

Tables 1 and 2 present the city-specific descriptive statistics for the months May to September.

Table 1. Descriptive statistics by county, May–September 1999–2002

City	State	Years of study	2000 Pop. (in 1000s)	Total deaths from all causes	Mean daily all-cause deaths	Days with apparent temperature data
Birmingham	AL	1999–2000	662	6775	22.1	306
Boston	MA	1999–2002	2806	33111	54.1	610
Chicago	IL	1999–2000	5377	33752	110.3	306
Dallas	TX	1999–2002	2219	21830	35.7	612
Detroit	MI	1999–2002	2061	28401	46.4	612
Houston	TX	1999–2002	3401	34118	55.7	612
Minneapolis/St.Paul	MN	1999–2002	1627	13028	21.3	612
Philadelphia	PA	1999–2002	1518	25822	42.2	612
Phoenix	AZ	1999–2000	3072	16601	54.3	306

The total population in the study consisted of 213,438 deaths from all causes. The study had three cities with two years of data, and the mean daily deaths in the nine cities ranged between 21.3 and 110.3.

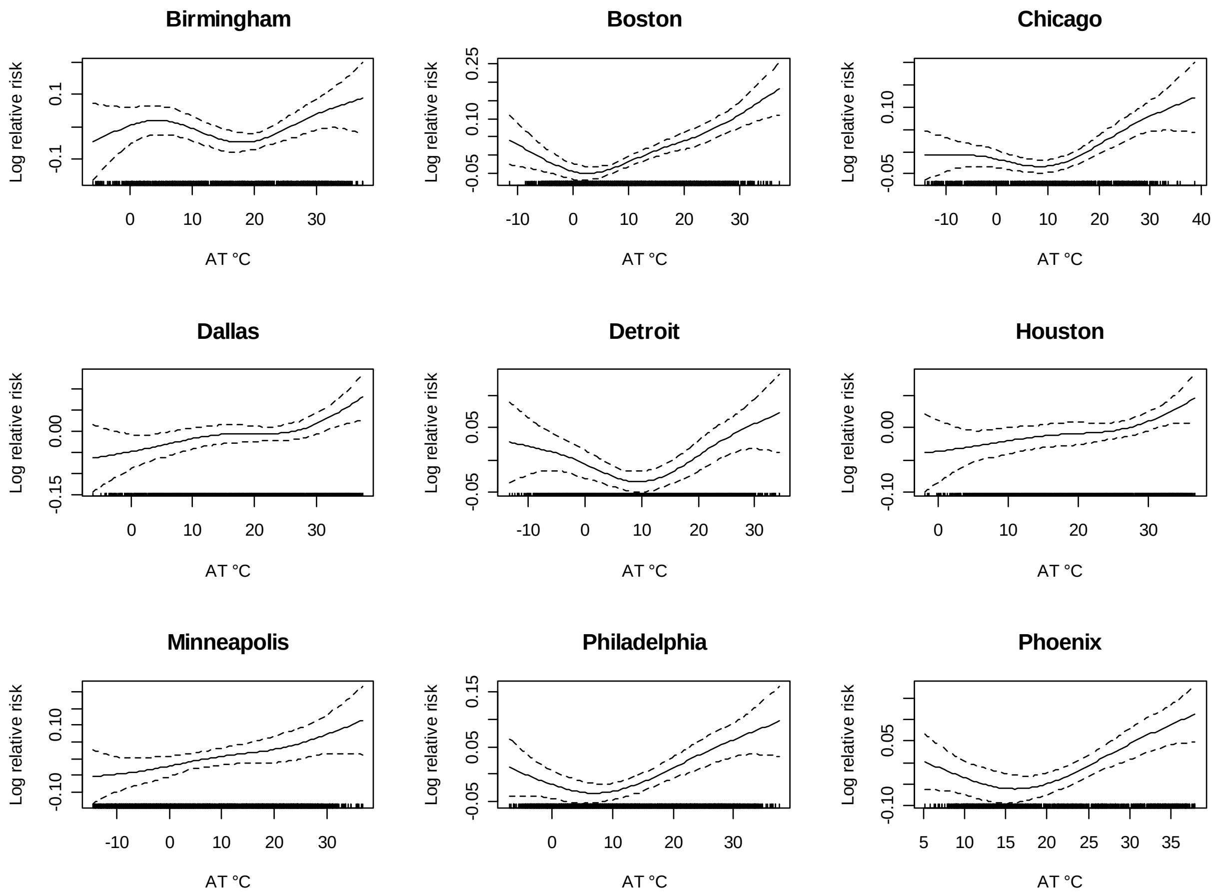

Figure 2. City-specific plots of the smoothing function of apparent temperature over all year

Table 2 shows the city-specific descriptive for apparent temperature and the pollutants. Apparent temperature means for the nine counties ranged from 20.1°C to 31.6°C, the 8-hour daily mean ozone concentrations ranged from 39.2 to 57.5 parts per billion (ppb), and $PM_{2.5}$ ranged from 8.2 to 23.3 μg/m^3.

Table 2. Minimum, mean, 25% quartile, 75% quartile, and maximum for apparent temperature and mean, 25% quartile, 75% quartile for pollutants by county, May–September, 1999–2003

	$PM_{2.5}$ (mg/m^3)			Ozone mean 8h (ppb)			Apparent temperature (°C)				
	mean	25%	75%	mean	25%	75%	min	mean	25%	75%	max
Birmingham	23.3	16.3	29.4	55.5	41.4	68.0	12.4	27.7	24.7	31.0	37.4
Boston	11.7	6.0	15.0	42.1	30.1	51.2	4.1	20.1	15.9	24.4	37.0
Chicago	16.2	9.4	20.6	39.2	29.1	47.6	5.4	21.0	16.3	25.7	38.8
Dallas	14.1	9.2	17.4	50.6	35.9	64.1	11.3	30.1	27.6	33.9	37.6
Detroit	16.5	9.1	21.5	44.0	31.8	54.4	3.0	20.7	15.9	25.7	34.4
Houston	13.3	9.2	16.1	44.5	27.5	58.8	13.8	31.2	29.7	34.0	36.7
Minneapolis	10.0	6.1	12.2				3.3	20.0	14.9	25.2	36.9
Philadelphia	16.0	8.9	20.7	45.2	33.0	56.7	7.9	23.6	19.2	28.2	37.6
Phoenix	8.2	6.7	9.4	57.5	49.6	64.6	14.9	31.6	29.0	35.2	38.0

Figure 3 shows the results for each county, followed by the meta-analyses estimates for all nine counties. The research team found a significant effect of apparent temperature on mortality, with a 1.8% increase (95% confidence interval [CI]: 1.09–2.5) for a 5.5°C (10°F) increase in apparent temperature when using case-crossover analysis, and a 2.7% increase (95% CI: 2.01–3.5 from the time-series analysis. City-specific results show that warmer cities (Houston, Dallas, Birmingham, and Phoenix) have the lower effect (that is, lower percent increase in mortality) estimates or the larger confidence intervals, and these are not significant. The results, in terms of the two methods used, are similar in most cities. Different results across cities do not affect the meta-analysis results, which give an overall effect across the study domain, because differences among the cities are taken into account.

Table 3 present the results for all-cause mortality, using both methods, for apparent temperature alone and where the study evaluated confounding by each air pollutant**.** The results did not change when adjusting for $PM_{2.5}$; however, the effect decreased when adjusting for ozone. The table also presents the results of a case-crossover analysis where the research team matched by ozone, to reduce the possibility of residual confounding that may have resulted from simply adding each pollutant to the model. Because the number of days with the same ozone concentration was very low, the research team chose controls by matching with concentrations rounded by 2 ppb of ozone, to include more control days. This result produced a similar estimate effect (1.8%:[5] 95% CI: -0.3–4.01) as in the original analysis.

[5] The percentages referenced here and throughout the text represent the percent increase in total mortality for a 10°F increase in apparent temperature.

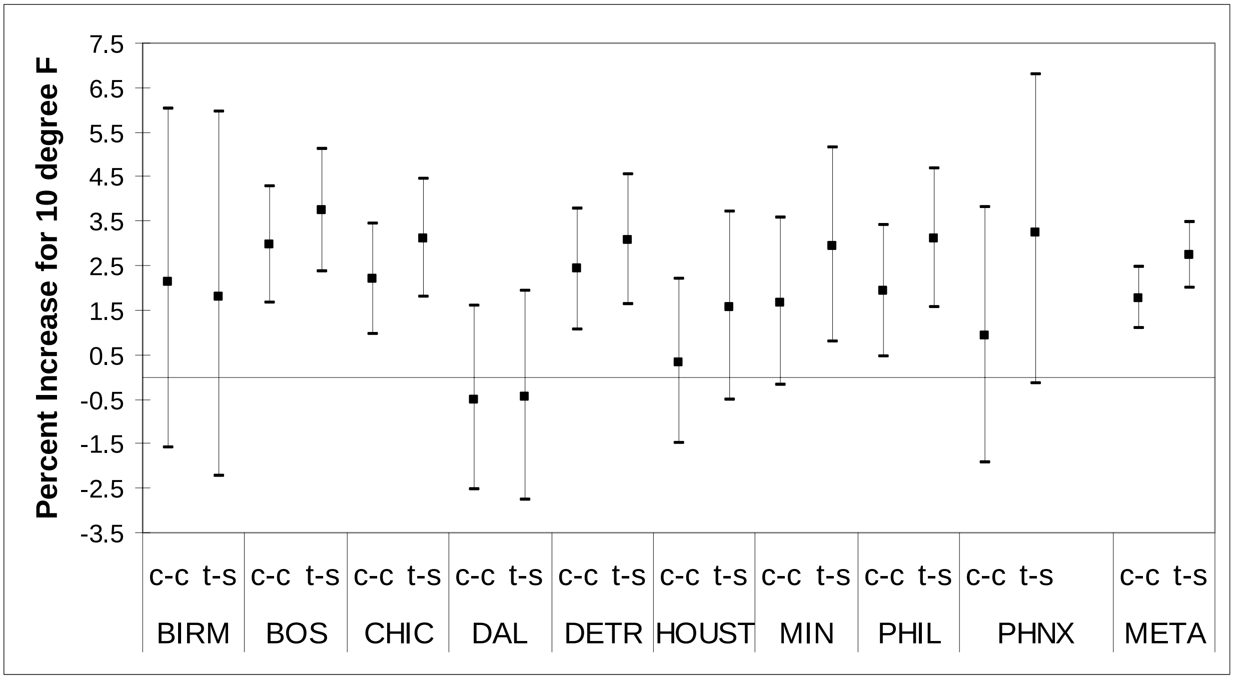

Figure 3. County-specific and meta-analysis results for mean apparent temperature (per 5.5°C [10°F]) and non-accidental mortality in nine U.S. counties, for case-crossover (c-c) and time series (t-s) analysis

Table 3. Meta-analysis results for apparent temperature (lag 0) and non-accidental mortality, and adjusted by individual pollutant (lag 01) for nine U.S. counties. Percent increases (%) for 5.5°C (10°F).

	Time-series analysis			**Case-crossover analysis**		
POOLED	**%**	**95% CI**		**%**	**95% CI**	
Apparent temperature	2.74	2.01	3.48	1.78	1.09	2.48
Ozone lag 01	2.07	1.34	2.81	0.99	0.31	1.68
Match by ozone				1.81	-0.34	4.01
$PM_{2.5}$ lag 01	2.76	1.75	3.78	1.69	0.88	2.51

When the authors included the bivariate thin plate spline between apparent temperature and air pollution in the model to examine possible interactions, the Generalized Cross-validation Criterion choose always two degrees of freedom for the spline in each city, indicating that the interactions were not significant. Therefore there was no effect modification between apparent temperature and the pollutants.

Figure 4 shows the three-dimensional plot of the bivariate thin plate spline between apparent temperature and ozone estimated with two degrees of freedom for the city of Boston.

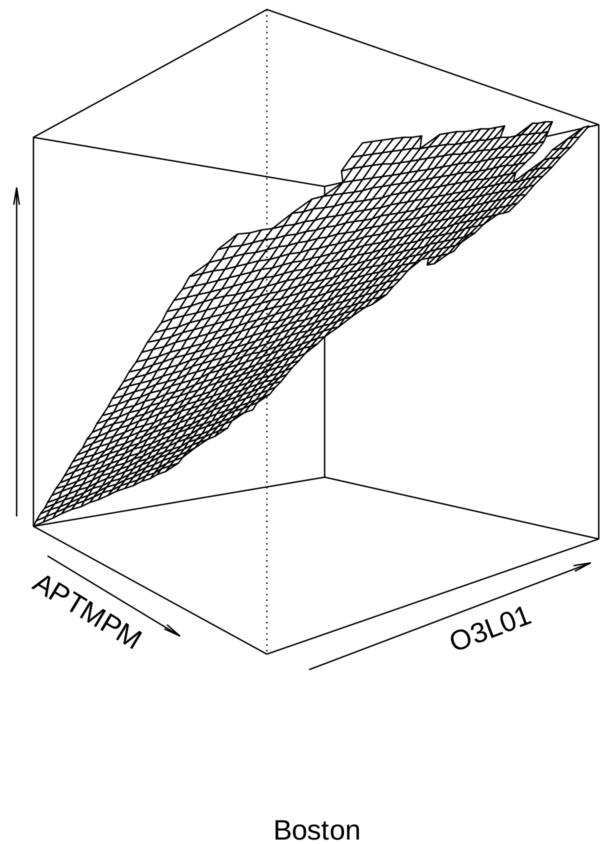

Figure 4. Boston, Massachusetts. Three-dimensional plot of the bivariate thin plate spline between apparent temperature and ozone lag 01, with two degrees of freedom.

The results of the sensitivity analysis by looking at the effect of mean, maximum, and minimum temperature produced similar estimates, even if the results for mean temperature were higher using both methods (Table 4).

In regional analyses, the authors found that the three southern cities (excluding Phoenix) had a significantly lower risk (that is, a lower percent increase in mortality) (0.22% increase, 95% CI: -1.1–1.5) compared to the results of the other five colder cities combined (2.3% increase, 95% CI: 1.7–2.9). These results were from the case-crossover analysis, although the time-series study produced similar findings.

Table 4. Meta-analysis results for various temperature definitions and non-accidental mortality for nine U.S. counties. Percent increases (%) for 5.5°C (10°F).

	Time series analysis			Case-crossover analysis		
POOLED	**%**	**95% CI**		**%**	**95% CI**	
Mean temperature	3.58	1.54	5.65	2.69	0.84	4.57
Minimum temperature	3.14	1.22	5.10	2.09	0.45	3.75
Maximum temperature	2.27	0.75	3.81	1.85	0.39	3.34
Temperature > 75°F	2.29	0.69	3.92	1.90	-0.03	3.86

4.0 Conclusion and Recommendations

4.1. Conclusions

This study found a significant effect of apparent temperature on mortality from non-accidental causes in summer months, when the dose-response relationship between temperature and mortality has been shown to be linear. The same results were obtained when using other representations of temperature, even though the effect was higher when using mean temperature; the risk was not much increased when the research team examined days with temperature higher than 75°F instead of looking at summer months. Importantly, researchers found no effect modification by either particles or ozone and no confounding by particles, but did find a moderate degree of confounding by ozone.

When comparing the results in terms of methodology type, the use of time-series analysis showed higher risks with respect to the case-crossover analysis, but this was not true in each county. The reason for this could be a better control for seasonality in case-crossover analysis; long-term seasonal trends are an important potential confounder in the study of mortality and temperature, and in a previous time-series study (O'Neill M, Hajat et al. 2005) halving the number of degrees of freedom for the seasonal spline induced confounding. Other studies, which analyzed the mortality-temperature relationship comparing case-crossover and time-series analysis, found similar results with the two methods (Basu, Dominici et al. 2005; Schwartz 2005b).

An important feature of this analysis was the inclusion of the pollutants to examine confounding and effect modification. Some studies of the association between mortality and temperature have not controlled for the effects of any air pollutants (Braga, Zanobetti et al. 2001; Curriero, Heiner et al. 2002); some controlled for particles(Ren and Tong 2006); (Hales, Salmond et al. 2000; Basu, Dominici et al. 2005; O'Neill, Hajat et al. 2005) or for several pollutants (Gouveia, Hajat et al. 2003; Filleul, Cassadou et al. 2006), but the results are mixed.

The authors did not find confounding by fine particulates; however, the researcher team observed a lower effect when adjusting for ozone. The result of the case crossover analysis matching by ozone instead did not show a decrease in the temperature effect; again this could be explained by a better control of seasonality with the case-crossover analysis, because matching by ozone in the same year and month result in controlling for season but also for the interaction between season and ozone.

In this study the authors used apparent temperature as weather indicator; this index should characterize the physiological experience better than temperature alone because it takes into account the effect of humidity on the body. Apparent temperature has been used in previous studies (O'Neill, Hajat et al. 2005; Stafoggia, Forastiere et al. 2006) to examine extreme temperature effects; while in this study the researchers present the effect of the average temperature exposure that is commonly experienced during summer, indicating that extreme temperatures may not be necessary to produce excess mortality.

The analysis also shows a smaller risk in the warmer southern cities (excluding Phoenix) compared to the colder cities. This result was previously found (Keatinge, Donaldson et al. 2000; Braga, Zanobetti et al. 2002; Curriero, Heiner et al. 2002) and could be explained by the fact that people in warmer climates tend to be more acclimatized to warm weather and tend to be more vulnerable to cold weather, while heat-related deaths occur more in cities where extreme heat is rare; adaptation to the local climate might occur by physiologic acclimatization, behavioral patterns, or other adaptive mechanisms (Kalkstein 2000).

One limitation of this study was that the research team could not examine socioeconomic variables and personal characteristics such as race, age, income level, or air conditioning use, which has previously shown to modify the association (Curriero, Heiner et al. 2002; Diaz, Jordan et al. 2002; O'Neill, Zanobetti et al. 2003; Schwartz 2005a; Medina-Ramon, Zanobetti et al. 2006). This study focused on total mortality and did not examine specific causes of mortality which might identify susceptible population.

Another limitation of this study was that only one monitor in each county was used to represent the weather variables in that county. The potential for misclassification is greater for those who died further away from a monitor, particularly for larger counties.

In conclusion, this study provides evidence of increased mortality due to mean temperature exposure during non heat-wave periods, even when adjusting for air pollution; researchers also found evidence of acclimatization.

4.2. Recommendations

Climate change is a serious public health issue and specific policies to reduce the effects of heat waves would be appropriate public policy. To be effective, these policies need to target interventions that are successful and populations that are at risk. Previous research has suggested that air conditioning use is an important mitigation strategy, and other studies have identified race, age, poverty, and diabetes (Khosla and Guntupalli 1999) as modifiers of the effects of heat. Nevertheless, further research is warranted to help identify where public health programs should be directed in order to prevent heat related morbidity and mortality and to examine whether other interventions such as green space, tree planting, changes in roofing, and other factors can also modify these effects. This study focused on total mortality and included too few cities to provide good information on the role of various effect modifiers.

Finally, few studies have evaluated the effect of hot weather on hospital admissions; additional analyses of weather effects on morbidity would help improve understanding of the mechanisms involved and provide more information to support prevention efforts.

4.3. Benefits to California

This study provides evidence of increased mortality due to mean temperature exposure in nine cities across the US, excluding cities from California, and representative of both cold and warm climates.

An analysis done with methods similar to those in this study but focusing on nine California counties, found an approximately three percent increase in all-cause mortality per 10°F increase in apparent temperature (Basu, Feng et al. in preparation)—an increase slightly higher than that found in this study.

The same study also found a lower estimate in inland areas compared to the coastal areas, and this could be due to some acclimatization for people living in inland areas, characterized by higher temperatures during summer months; similarly, this analysis found evidence of acclimatization.

This epidemiologic study therefore gives important information about the relationship between temperature and mortality from cities with a different climate than California's, showing results that are consistent with the California results; thereby providing evidence that the California results are unlikely to be chance findings and that appropriate interventions are worthwhile.

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