Title

Temperature and mortality in nine U.S. counties.

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Preface

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Temperature and mortality in nine U.S. counties is the interim report for the Climate Change Impacts of High Temps & Air Pollution on Public Health, Project contract number 500-99-013, work authorization number BOA#118-P-05 conducted by the California Office of Environmental Health Hazard Assessment. The information from this project contributes to PIER's Environmental Area Program.

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Abstract

Several studies found that extremes temperatures are associated with increased mortality worldwide. The extent to which this represents confounding by air pollutants, or is modified by those pollutants, remains unclear. We examined the association between mean apparent temperature and total mortality in nine cities across the US during from May to September 1999 to 2002.

We applied both case-crossover and time-series analyses, 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. We found a significant effect of apparent temperature on mortality with a 1.8% increase (95%CI: 1.09-2.5) per 5.5 °C (10°F) increase in apparent temperature in the case-crossover analysis, and a 2.7% increase (95% CI: 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 due to mean temperature exposure, even when adjusting by air pollution. Global warming is a serious public health issue; more studies to help identifying where public health programs should be directed in order to prevent heat-related morbidity and mortality are warranted.

Abstract word count: 200

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

Executive summary

Introduction

Emissions of greenhouse gases from human activity are projected increase overall average temperatures as well as the frequency of extreme weather events across the world, including heat weaves and other effects. Several studies found that extremes temperatures are associated with increased mortality worldwide. The extent to which this represents confounding by air pollutants, or is modified by those pollutants, remains unclear.

Purpose

The main purpose of the study is 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 modification of risk by air pollutants.

Project Objective

In this study, we examined the association between apparent temperature and total mortality during the summer months May to September, using two modern statistical approaches.

We selected nine cities, excluding cities from California, with sufficient mortality and daily air pollution data, and representative of both cold and warm climates.

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

The researchers obtained local meteorological data from the United States Surface Airways and Airways Solar Radiation hourly data. The authors focused on apparent temperature, the individual's perceived air temperature given the humidity, as this index should characterize the physiological experience better than temperature alone.

The researchers obtained particulate air matter with aerodynamic diameter less than 2.5 μg ($PM_{2.5}$) and ozone data from US Environmental Protection Agency's Air Quality System Technology Transfer Network. The two major pollutants associated with mortality (ozone and fine particles) were considered as either confounders (adding each pollutant separately in the model) or effect modifiers by including in the model a bivariate smoothing of 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.

As sensitivity analyses the researchers considered the possibility that longer moving averages than one day are better predictors of the temperature-mortality association, other temperature definitions such as mean, minimum, and maximum temperature, days with apparent temperature greater than 23.8 °C (75 °F), and finally 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 our 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 mortality and temperature has been shown to be linear, with around a 2% increase per 10 °F. The risk was robust to the use of other weather definitions. Importantly, 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) compared to the colder cities.

Recommendations

Global warming is a serious public health issue and specific policies to reduce the effects of high temperatures 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 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, etc can also modify the effects. Our 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 the effect of weather on morbidity would help improve our understanding of the mechanisms, and provide more information for prevention efforts.

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 similar methods of this study but carried out in nine counties in California, found around three percent increase in all-cause mortality per 10ºF increase apparent temperature. This result is slightly higher than the percent increase found in our study. The same study also found 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. Our analysis also found evidence of acclimatization, although we also saw that acclimatization was not complete.

This epidemiologic study therefore gives important information about the human impact of climate change from cities with a different climate than in California, showing results that are consistent with the results in California, and hence providing evidence that the California results are unlikely to be chance findings, and that appropriate interventions are worthwhile.

1.0 Introduction

Emissions of greenhouse gases from human activity are projected increase overall average temperatures as well as the frequency of extreme weather events across the world, including heat weaves and other effects (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 implication 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 population and inform policy makers in order to take preventive actions(Patz, Engelberg et al. 2000; Patz, McGeehin et al. 2000; McMichael 2001; Patz and Khaliq 2002). In colder climate, the increase of global temperature may benefit health (Martens and Huynen 2001), although other studies have suggested that the wintertime increase in mortality is due to infections disease, and not direct effects of cold weather (Reichert, Simonsen et al. 2004). Because global warming will likely increase the average temperature we focused this study on the summer effects of weather.

The effect of extremes of temperature 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 2005; Medina-Ramon, Zanobetti et al. 2006); greater susceptibility has been reported for the elderly and for those with a lower socio-economic status(Curriero, Heiner et al. 2002; Diaz, Jordan et al. 2002; O'Neill, Zanobetti et al. 2003; Schwartz 2005; Medina-Ramon, Zanobetti et al. 2006). 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 (Basu and Samet 2002; Bouchama and Knochel 2002). This coupled with an increase in blood viscosity and cholesterol levels with high temperatures (Keatinge, Coleshaw et al. 1986) may increase the risk for cardio-respiratory deaths.

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 by air pollution (O'Neill M, Hajat et al. 2005), but this issue, and the parallel issue of effect modification, 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. In this study, the authors examined the association between temperature and mortality in nine cities with a range of climatic and pollution patterns across the US; focused on apparent temperature and on the summer season, examined confounding by air pollutants, modification of risk by air pollutants, and used both time series and case-crossover analysis.

2.0 MATERIALS AND METHODS

2.1. Mortality data

The researchers selected nine cities in the United States, excluding cities from California, with sufficient mortality and daily air pollution data, and representative of both cold and warm climates: Birmingham, Alabama; Boston, Massachusetts; Chicago, Illinois; Detroit, Michigan; Dallas, Houston, Texas; Minneapolis/St. Paul, Minnesota; Philadelphia, Pennsylvania; Phoenix, Arizona. These cities represent a range on summer temperatures (from 21 to 32 °C) and of PM2.5 co-exposures (from 8 to 26 $\mu g/m^3$).

The authors did the analyses on 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 from for the years 1999 and 2000, and the state public health departments of Massachusetts, Michigan, Minnesota, Texas, and Pennsylvania for the years 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 particulate air matter with aerodynamic diameter less than 2.5 μg ($PM_{2.5}$) and ozone data from US Environmental Protection Agency's Air Quality System Technology Transfer Network (USEPA Technology Transfer Network, 2005). In most cities particulate air matter with aerodynamic diameter less than 2.5 μg ($PM_{2.5}$) 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 this data was more complete. For ozone the researchers used 8 hour daily mean concentrations during the hours of 8am to 5pm. When multiple monitors were present in a city we estimated an average daily value for the city, and we accounted for the impact of occasional missing values using an algorithm previously described (Zanobetti, Schwartz et al. 2000). However, before applying this algorithm, we made sure that all monitors in one city represented general ambient exposures, and not rather a local source. For this, we calculated the correlation between city monitors. We obtained multiple correlation coefficients for each monitor (correlated with all other monitors in the city), from which we extracted the median values. Those monitors falling in the low 10th 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, minimum temperature, and dew point temperature, from the United States Surface Airways and Airways Solar Radiation hourly data (National Environmental Satellite and Data 2003). The researchers also computed apparent temperature (AT), defined as an individual's perceived air temperature given the humidity. AT was calculated with the following formula (Steadman 1979; Kalkstein and Valimont 1986).

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

where Ta is air 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 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. Since there is perfect matching on all measured or unmeasured subject characteristics that do not vary over time there can be no confounding by those characteristics. If in addition, the control days are chosen to be close to the event day, slowly varying subject characteristics are also controlled by matching.

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. Lumley and Levy (Levy, Lumley et al. 2001) showed that a time stratified approach to choosing controls resulted in a proper conditional logistic likelihood, and Schwartz and coauthors (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 month and year and on every third day. The data were analyzed using a conditional logistic regression (PROC PHREG in SAS, SAS software release 8.2. 2001, SAS Institute, Cary NC).

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 model the researchers controlled for season using natural splines with 4 degrees of freedom per year, and day of the week with indicator variables.

These models were fit in R (The Comprehensive R Archive Network: http://cran.r-roject.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 done by fitting time series models for the full year in each city, using natural splines for apparent temperature with 4 df. These models used 4 df/year to control for season. 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 we also controlled for long term time trends using natural splines with 4 degrees of freedom 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 suggestive 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 2 degrees of freedom 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 longer moving averages 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 previous three days (lag 03) or the previous three days (lag 13). 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. They also analyzed only days with apparent temperature greater than 23.8 °C (75 °F); and finally considered a regional analysis.

The use of a linear term for pollution to control for confounding risks missing several aspects of confounding. If the association with the confounder is nonlinear, or if it varies over time, there may be residual confounding. The effect of ozone on lung function, for example, is stronger earlier in the ozone season than latter. To protect against these risks, we used an alternative approach of matching control days to have the same concentrations of the air pollutants as case days (Schwartz 2005).

2.4.4. Combined results

In a second stage of the analysis, the city specific results were combined using the multivariate meta-regression technique of Berkey and coworkers (Berkey, Hoaglin et al. 1998). To be conservative the researches report the results incorporating a random effect, whether or not there was a significant heterogeneity.

The authors report the results as percent increases in mortality for 5.5 °C, which correspond to 10 °F, increase in apparent temperature.

3.0 Results

In each city the researchers first plotted the smoothing function of apparent temperature over all year to look at possible nonlinearity (Figure 1). From the plots it is clear the associations for values of apparent temperature over 10 °C to 15 °C are linear.

In the sensitivity analyses, we found that lag 0 apparent temperature had the best model fit compared to the moving averages of multiple days. 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.

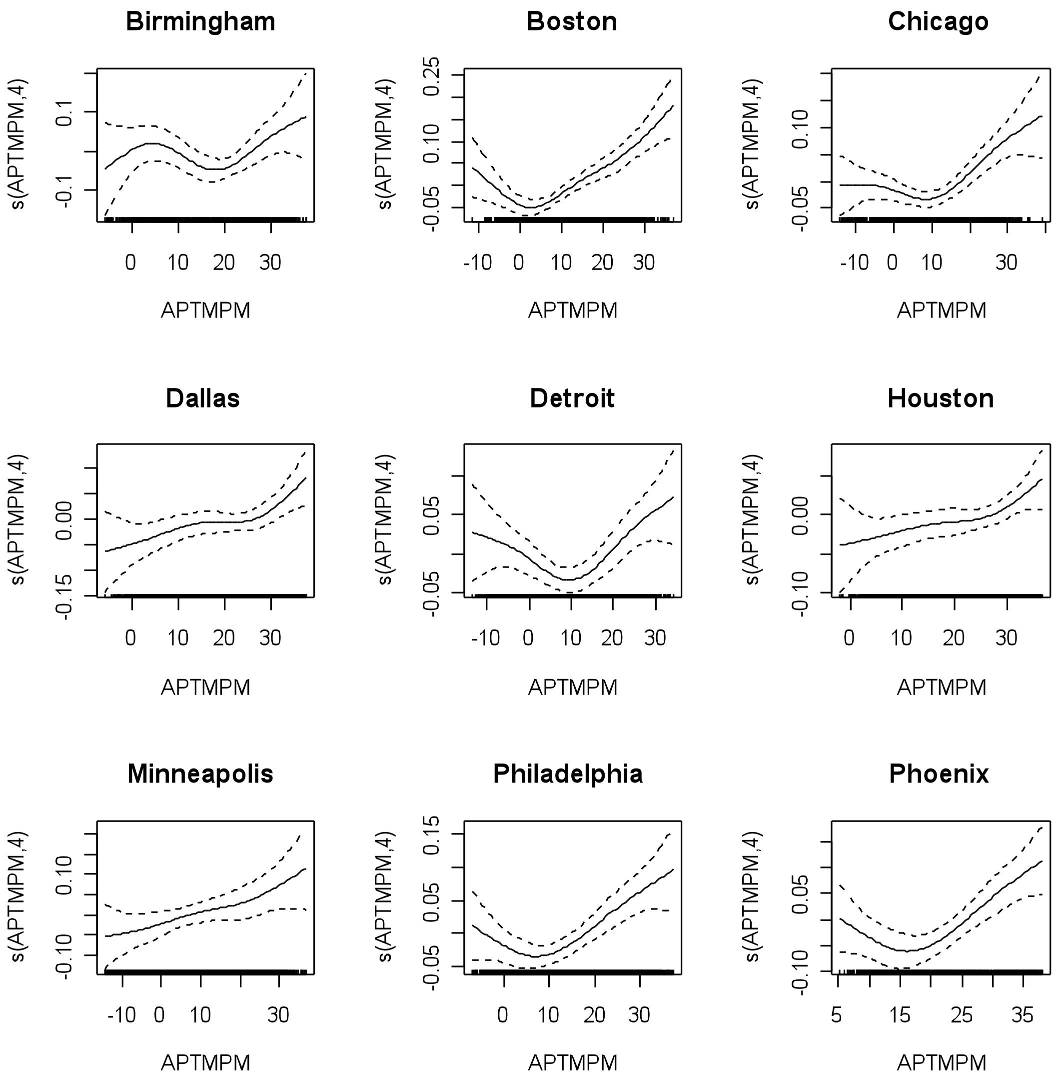
Tables 1 and 2 present the city-specific descriptive statistics for the months May to September.

Table 1: Descriptive statistics by county, May-September 1999-2002

City	State	Years of study	2000 Pop (*1000)	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 for all causes. Our study had 3 cities with 2 years of data, and the mean daily deaths in the nine ranges between 21.3 and 110.3.

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


Birmingham

Boston

Chicago

Dallas

Detroit

Houston

Minneapolis

Philadelphia

Phoenix

Figure 1. City-specific plots of the smoothing function of apparent temperature over all year.

Table 2: Mean (25% quartile, 75% quartile) for temperature and pollutants by county,
May-September 1999-2003

	PM25 (mg/m3)			Ozone mean 8h (ppb)			Apparent temperature (°C)		
	mean	**25%**	**75%**	**mean**	**25%**	**75%**	**mean**	**25%**	**75%**
Birmingham	23.3	16.3	29.4	55.5	41.4	68.0	27.7	24.7	31.0
Boston	11.7	6.0	15.0	42.1	30.1	51.2	20.1	15.9	24.4
Chicago	16.2	9.4	20.6	39.2	29.1	47.6	21.0	16.3	25.7
Dallas	14.1	9.2	17.4	50.6	35.9	64.1	30.1	27.6	33.9
Detroit	16.5	9.1	21.5	44.0	31.8	54.4	20.7	15.9	25.7
Houston	13.3	9.2	16.1	44.5	27.5	58.8	31.2	29.7	34.0
Minneapolis	10.0	6.1	12.2				20.0	14.9	25.2
Philadelphia	16.0	8.9	20.7	45.2	33.0	56.7	23.6	19.2	28.2
Phoenix	8.2	6.7	9.4	57.5	49.6	64.6	31.6	29.0	35.2

Figure 2 shows the results for each county followed by the meta-analyses estimates for all nine counties. We found a significant effect of apparent temperature on mortality with a 1.8% increase (95%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.

Table 3 present the results for all-cause mortality, using both methods, for apparent temperature alone and where we evaluated confounding by each air pollutant. The results didn't change when adjusting for $PM_{2.5}$, while the effect decreased when adjusting for ozone. In the table we also present the results of a case-crossover analysis where we matched by ozone, in order 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 is very low, to include more control days we choose controls by matching with concentrations rounded by 2 ppb of ozone. This result produced a similar estimate effect (1.8%; 95% CI: -0.3, 4.01) as in the original analysis.

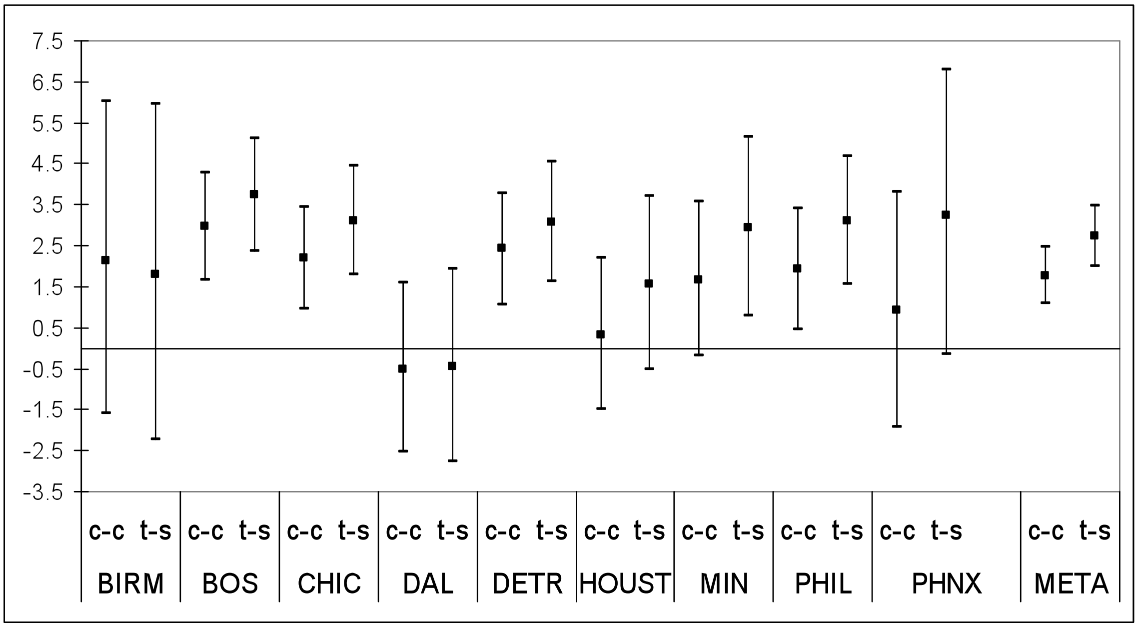


Figure 2: County-specific and meta-analysis results for mean apparent temperature (per 5.5 °C or 10°F) and non-accidental mortality in nine US counties, for case-crossover (c-c) and time series (t-s) analysis.

Table 3: Meta-analysis results for apparent temperature (lag 0) and non-accidental mortality, and adjusted by individual pollutant (lag 01) for nine US 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
PM2.5 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 2 degree of freedom for the spline in each city indicating that no significant interactions were present. Figure 3 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.

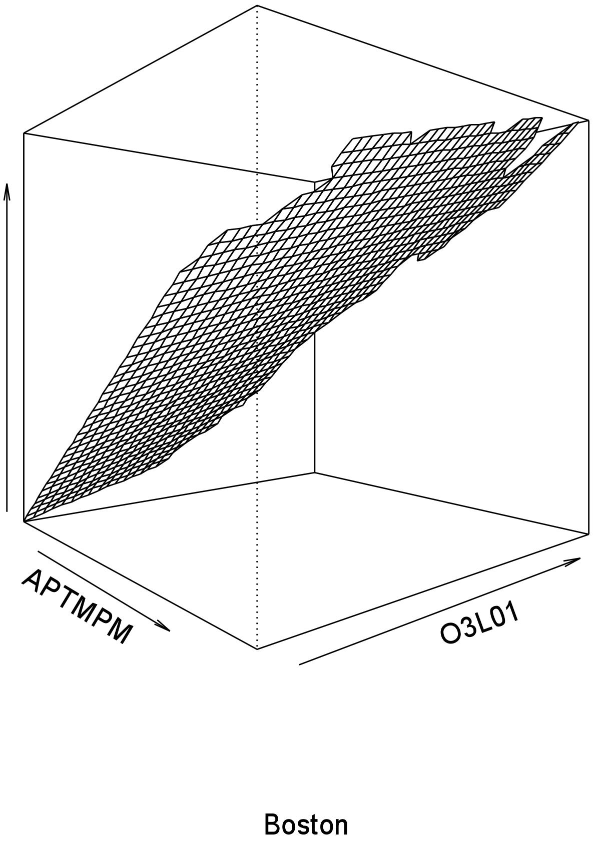


Figure 3: Boston, MA - Three-dimensional plot of the bivariate thin plate spline between apparent temperature and ozone lag 01, with two degrees of freedom.

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 3 southern cities (excluding Phoenix) had a significantly lower risk (0.22% increase, 95% CI: -1.1, 1.5) compared to the results of the other 5 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 US 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

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

When comparing the results in terms of the type of methodology, the use of time series analysis showed higher risks respect to the case-crossover analysis, but this was not true in each county. The reason for this could be a better control for season in case-crossover analysis; long-term seasonal trends are 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 degree 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 2005).

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) (Basu, Dominici et al. 2005; O'Neill, Hajat et al. 2005) or for several pollutants (Gouveia, Hajat et al. 2003), but the results are mixed.

The authors didn't find confounding by fine particulates, while we 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 persons 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).

A limitation in this study is that we couldn't 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 2005; Medina-Ramon, Zanobetti et al. 2006). We focus on total mortality and didn't examine specific causes of mortality which might identify susceptible population.

In conclusion our study provides evidence of increased mortality due to mean temperature exposure during non heat-wave periods, even when adjusting by air pollution; we also found evidence of acclimatization. Even though increases in high temperatures due to global climate change might be mitigated by adaptive mechanism, the adverse impact of heat is expected to outweigh these benefits.

4.2. Recommendations

Global warming is a serious public health issue and specific policies to reduce the effects of high temperatures 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 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, etc can also modify the effects. Our 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 the effect of weather on morbidity would help improve our understanding of the mechanisms, and provide more information for 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 similar methods of this study but carried out in nine counties in California, found around three percent increase in all-cause mortality per 10°F increase apparent temperature (Basu et al. submitted). This result is slightly higher than the percent increase found in our study. The same study also found 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. Our analysis also found evidence of acclimatization, although we also saw that acclimatization was not complete. This epidemiologic study therefore gives important information about the human impact of climate change from cities with a different climate than in California, showing results that are consistent with the results in California, and hence providing evidence that the California results are unlikely to be chance findings, and that appropriate interventions are worthwhile.

5.0 References

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