A MULTI-COUNTY ANALYSIS IDENTIFYING THE VULNERABLE POPULATIONS FOR MORTALITY ASSOCIATED WITH HIGH AMBIENT TEMPERATURE IN CALIFORNIA

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Preface

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In 2003, the California Energy Commission's 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.

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Abstract

The association between ambient temperature and mortality has been established worldwide, including our prior study in California. Here, we examined cause-specific mortality, age, race/ethnicity, gender, and education level to identify vulnerable subgroups of high ambient temperature. We obtained data from nine California counties from May to September 1999 to 2003, provided by the National Climatic Data Center (countywide weather) and the California Department of Health Services (individual mortality). Using a time-stratified case-crossover approach, we obtained county-specific estimates of mortality, which were combined in meta-analyses. A total of 231,676 non-accidental deaths were included. Each 10 degree Fahrenheit increase in mean daily apparent temperature corresponded to a 2.6 percent (95 percent confidence interval (CI): 1.3, 3.9) increase for cardiovascular mortality, with the most significant risk found for ischemic heart disease. Elevated risks were also found for persons at least 65 years of age (2.2 percent, 95 percent CI: 0.04, 4.0), infants one year of age and under (4.9 percent, 95 percent CI: -1.8, 11.6), and Black racial/ethnic group (4.9 percent, 95 percent CI: 2.0, 7.9). No differences were found by gender or education level. To prevent mortality associated with ambient temperature, persons with cardiovascular disease, the elderly, infants, Blacks among others should be targeted.

Keywords: Temperature, heat, mortality, vulnerable populations, effect modifiers, California

1.0 Introduction

Elevated ambient temperature has been linked with increased mortality in five continents throughout the world. Researchers investigating the 2003 heat wave in Western Europe have indicated an excess of up to 35,000 deaths. Many of these deaths occurred prematurely among the elderly living in urban areas. With climate change and a rapidly growing elderly population particularly in larger cities, mortality from heat waves and other extreme weather events is a significant public health burden that may only continue to worsen in the future.

From previous case reports following heat waves, several high-risk populations have been identified including: the elderly who have some specific pre-existing disease or who take certain medications (i.e., beta-blockers, major tranquilizers, and diuretics), people with lower socioeconomic status (e.g., those engaging in outdoor occupations), and socially isolated populations (e.g., living alone, especially on higher floors of apartment buildings). Few epidemiologic studies have focused on identifying vulnerable subgroups for mortality associated with ambient temperature using modern statistical methods. Models of the relation between ambient temperature exposure and mortality are needed to prevent heat-related deaths that may occur from exposure to elevated ambient temperature. No epidemiologic study has identified high-risk groups specifically for California, where the temperature and humidity levels are generally lower than the rest of the country and pollutant levels tend to be higher with distinct sources and patterns of exposure. In addition, temperature effects may differ from other areas since individuals are likely to spend more time outdoors, and there may be a lower prevalence of air conditioning, especially in coastal areas.

In this study, we evaluated specific causes and vulnerable subgroups of ambient temperature-related mortality using data from nine counties in California. We used the time-stratified case-crossover approach, while limiting our data to the warmer months of 1999 to 2003 to focus on heat effects.

2.0 Methods

2.1. Death Certificate Data

The California Department of Health Services, Health Data and Statistics Branch, provided data on daily mortality for all California residents for our study period from May 1 ,1999, to September 30, 2003. We used data from the same nine counties that were used in previous mortality studies to examine the effects of fine particulate matter and temperature (Ostro et al. 2006; Basu et al. 2008): Contra Costa, Fresno, Kern, Los Angeles, Orange, Riverside, Sacramento, San Diego, and Santa Clara. These counties were originally chosen, since they account for approximately 65% of the state's population and had sufficient data available during our study period for analysis.

Data abstracted from death certificates included date, county, and underlying cause of death and up to five secondary causes of death. We analyzed deaths from all causes, excluding accidents, suicides, and homicides (i.e., non-accidental deaths). Causes of death were categorized using *International Classification of Diseases, 10th Revision* (ICD-10) codes as follows (WHO 1993): cardiovascular disease (CVD) (ICD-10 codes I00–I99), respiratory disease (J00–J98), and diabetes (E10–E14). We evaluated specific CVD diseases, including ischemic heart disease (IHD) (I20–I25), acute myocardial infarction (MI) (I21–I22), conduction disorders, cardiac dysrhythmia and congestive heart failure (CHF) (I44–I50), cerebrovascular disease (I60–I69), stroke (I64), and atheroscelorosis (I70). We also considered the following secondary respiratory causes of death to assess co-morbidities with CVD deaths as the primary underlying cause: all respiratory causes, all chronic lower respiratory mortality (including asthma, other chronic obstructive pulmonary disease [COPD], bronchitis, and emphysema) (J40–J47), and mortality from other COPD (J44), asthma (J45–J46) and chronic bronchitis (J41–J42).

Additional variables abstracted from death certificates included age (≤1 year, ≤5 years, ≥65 years, ≥75 years, ≥85 years), racial/ethnic group (White non-Hispanic, Black non-Hispanic, Hispanic), gender (male, female), education level (high school graduates, non-high school graduates), and place of death (in or out of the hospital).

2.2. Weather Data

Hourly weather data were obtained from the National Oceanic and Atmospheric Administration National Climatic Data Center (NOAA 2004). We calculated mean daily apparent temperature in degrees Fahrenheit (°F), also known as *heat index,* to incorporate the effects of both temperature and relative humidity using formulas published previously (Ostro et al. 2006).

We used one centrally located meteorologic monitor that recorded both temperature and relatively humidity exposure for each county for the entire study period, except for Orange County, where the monitor was relocated to another nearby location in the same city in 2003. Only monitors that recorded at least 18 hours of daily observations were included for each county so that we could ensure that the meteorologic data were based on at least three-quarters of the day, rather than relying on only a few sparse measurements. Since heat-related mortality has been reported to be an acute event in previous reports (Basu and Samet 2002), county of death served as the index for assessing the effects of ambient temperature.

2.3. Study Design and Data Analysis

We used the case-crossover study design for our analysis, using the time-stratified approach as described by Levy et al. (2001). This design is similar to a matched case-control study; however, in a case-crossover study, each case serves as his/her own control. Thus, individual-level differences are inherently controlled for by design. In this study, each case period (death) was matched with up to ten referent periods for the same individual. Referent periods were selected every third day of the same month and year as the case period. The time-stratified referent selection minimizes confounding by time-varying factors, since referent periods were selected within a short period of time from the case period. Furthermore, the estimate for mortality risk would not be biased by referent period sampling as could occur with bidirectional sampling, since referent periods were selected at random with respect to the time that the case occurred. Day of the week was added to the model as indicator variables to account for potential confounding. Thus, every model had mortality (total non-accidental or cause-specific) as the outcome variable and mean daily apparent temperature and indicators for the day of the week as the independent variables. In models examining age, race, gender or education level, total non-accidental mortality served as the outcome, and we stratified by each demographic variable to assess its potential effect modification. All analyses were conducted using the PHREG procedure for conditional logistic regression in SAS (2000). Odds ratios (ORs) and 95% confidence intervals (CIs) were reported per 10°F increase in mean daily apparent temperature. The results are presented as the percent change in mortality to ease their interpretation using the following calculation: (OR - 1) X 100%. All analyses were conducted in two steps: we first obtained county-specific estimates using the same model for each county and then combined the estimates from all nine counties in a meta-analysis using the random effects model (DerSimonian and Laird 1986).

Air pollutants were not considered in these analyses, since we found no indication of significant confounding or effect modification by ozone, particulate matter, nitrogen dioxide, or carbon monoxide using the same data in a previous study (Ostro et al. 2006). We had also found that unlagged (i.e., lag 0) apparent temperature provided the best fit with non-accidental mortality and for cause-specific mortality relative to other lags (i.e., four-day and three-day cumulative lags). Thus, all results are provided using models with unlagged apparent temperature in this study. Furthermore, mean apparent temperature provided a better fit than simply using dry bulb temperature and the linear assumption was sustained in the warm season.

3.0 Results

A total of 231,676 non-accidental deaths were included in our analysis, with 41% of these deaths classified as cardiovascular (CVD), 9% as respiratory, 8% as cerebrovascular, and 3% as diabetes (CVD and respiratory deaths by county are shown in Table 1). Table 1 also depicts the means and standard deviations (SD) for apparent temperature (70.6, 7.6 overall), age (73.7 years, 17.9 years overall), and percentages for race (71.8 White, 8.7 Black, 11.9 Hispanic overall), high school graduates (71.8 overall), and males (48.6 overall) in our study by county and for the overall study population.

As shown in Table 2, mortality from all CVD diseases combined had a significant association with apparent temperature, with a 2.6% (95% confidence interval (CI): 1.3, 3.9) per 10°F (5.5°C) increase in mean daily apparent temperature. A further analysis of disease-specific mortality among CVD deaths (Table 2) demonstrated that CHF, IHD, and MI had elevated risks.

Mortality risk for both diabetes and cerebrovascular diseases were elevated, although neither finding was significant (also shown in Table 2). No elevated association was found specifically for stroke (result not shown), and none of the respiratory mortality outcomes were elevated when considered as a primary (Table 2) or secondary cause of death (all respiratory deaths as secondary cause of death: 0.03% increase per 10°F mean daily apparent temperature, 95% CI: -5.36, 6.46%; n = 67,393 cases). Similarly, none of the respiratory disease subcategories considered (i.e., all chronic lower respiratory mortality or COPD), listed as an underlying or a secondary cause of death, were associated with apparent temperature (results not shown). During our study period, sufficient numbers of cases of asthma (n = 958 for all nine counties) or chronic bronchitis (n = 147 for all nine counties) mortality were not available for analyses as secondary causes of death.

We also evaluated effect modification by several demographic characteristics for all non-accidental deaths. When we examined various age groups, we found elevated mortality among infants one year of age and under, children less than five years, and the elderly at least 65 years of age, as shown in Figure 1. The increased mortality risk was especially pronounced in infants and young children under five years. The elderly subgroups all had nearly equal risk, regardless of age cut-off. The estimates for the elderly subgroups were slightly higher compared to all age groups combined in our previous study (2.3%, 95% CI: 1.0, 3.6) (Ostro et al. 2006), since most deaths occurred among the elderly. When we examined other various age groups (e.g., 5–17 years, 18–64 years), we did not find a significant risk. As demonstrated in Figure 2, Blacks had the most elevated risk of the racial/ethnic groups examined. Whites and Hispanics also had increased risks, although the association was not significant for Hispanics. Dying out of the hospital (3.8%; 95% CI: 1.3, 6.3) had a significantly greater risk than dying in a hospital (1.5%; 95% CI: 0.3, 2.7). However, no significant difference was found between males (2.8%; 95% CI: 1.1, 4.6) and females (2.6%; 95% CI: 1.2, 3.9) or between those who graduated high school (3.1%; 95% CI: 2.0, 4.1) and those who did not (2.7%; 95% CI: 1.2, 4.3).

Table 1. Descriptive characteristics by county, May through September 1999–2003

County	No. non-accidental deaths[2]	Mean apparent temperature (SD)	Mean age (SD)	% White, Black, Hispanic	% High school graduates	% Male	% CVD deaths	% Respiratory deaths
Contra Costa (Concord)	12,306	66.8 (7.7)	75.7 (15.7)	79.8, 9.7, 4.5	79.2	47.0	46	12
Fresno (Fresno)	9,452	75.4 (8.5)	73.6 (17.5)	70.2, 5.8, 18.3	59.2	49.6	44	10
Kern (Bakersfield)	8,353	78.1 (8.6)	72.8 (17.3)	76.9, 5.7, 14.5	59.9	49.1	47	12
Los Angeles (downtown LA)	92,250	69.2 (6.0)	73.0 (18.5)	61.4, 14.5, 15.3	72.9	48.7	40	8
Orange (Anaheim)	19,445	72.6 (6.8)	75.4 (17.2)	81.3, 1.3, 8.7	77.0	46.2	31	6
Riverside (Riverside)	20,234	75.7 (8.1)	75.1 (16.0)	83.3, 4.8, 10.0	72.5	49.7	46	11
Sacramento (Sacramento)	17,974	70.7 (7.8)	72.6 (18.3)	78.5, 8.4, 5.4	72.9	48.6	49	12
San Diego (Escondido)	34,714	71.1 (7.3)	74.6 (17.6)	80.0, 4.5, 10.2	77.0	48.5	41	10
Santa Clara (San Jose)	16,948	64.8 (6.4)	72.9 (19.2)	71.6, 3.1, 11.1	74.1	49.4	35	11
Total study	231,676	70.6 (7.6)	73.7 (17.9)	71.8, 8.7, 11.9	71.8	48.6	41	9

[1] Cities where monitors were located are in parentheses
[2] Non-accidental deaths: all deaths excluding deaths from homicides, suicides and accidents according to ICD-10 codes

Table 2. Estimated percent change associated with a10°F increase in mean daily apparent temperature and risk of disease-specific mortality[1] in nine California counties, May through September 1999–2003

Disease (ICD-10 codes)	Percent change	95% confidence interval
All cardiovascular (I00–I99)	2.6	1.3, 3.9
Congestive heart failure (I44–I50)	5.4	-8.2, 21.1
Ischemic heart disease (I20–I25)	2.5	0.4, 4.6
Acute myocardial infarction (I21–I22)	2.7	-0.4, 5.9
All respiratory (J00–J98)	0.9	-1.8, 3.5
All cerebrovascular (I60–I69)	1.2	-1.7, 4.2
Diabetes (E10–E14)	2.7	-4.0, 10.0

[1] Listed as primary underlying cause on death certificate

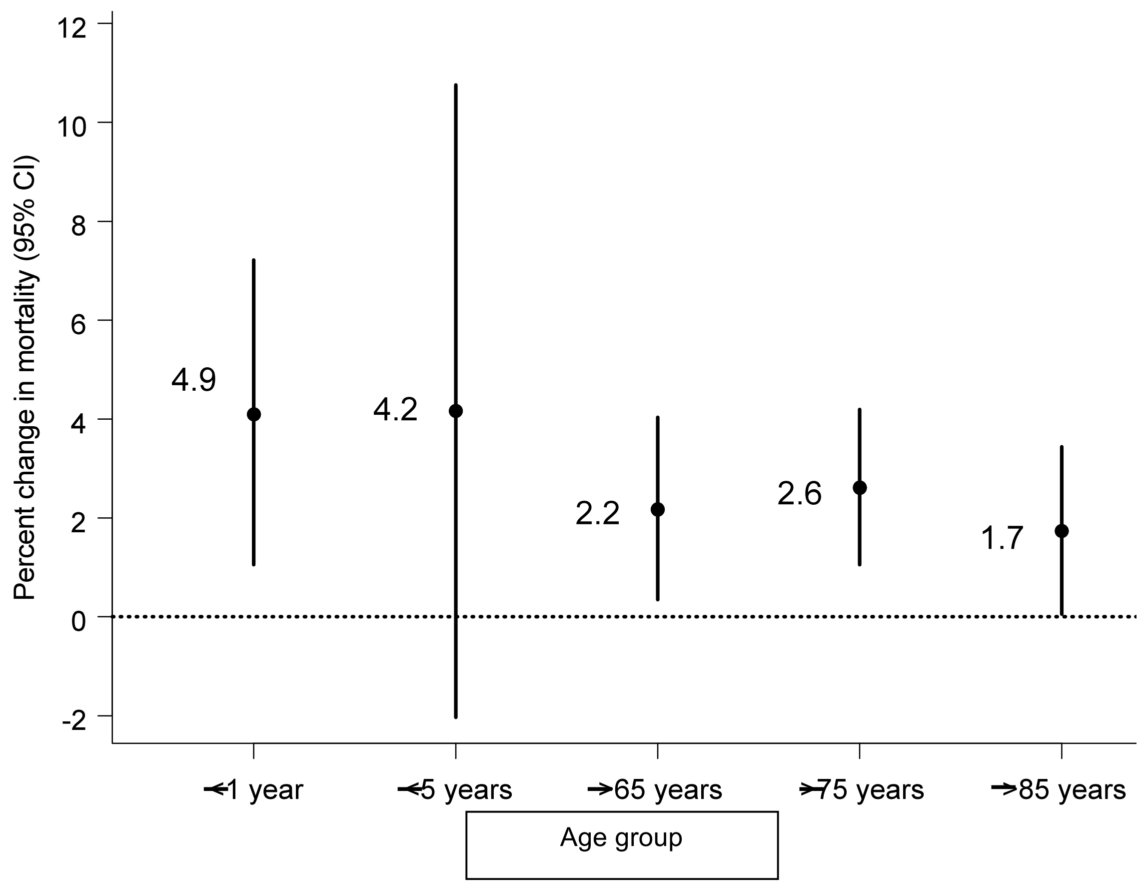

Figure 1. Estimated percent change associated with a 10°F increase in mean daily apparent temperature and non-accidental mortality by age group in nine California counties, May through September 1999–2003

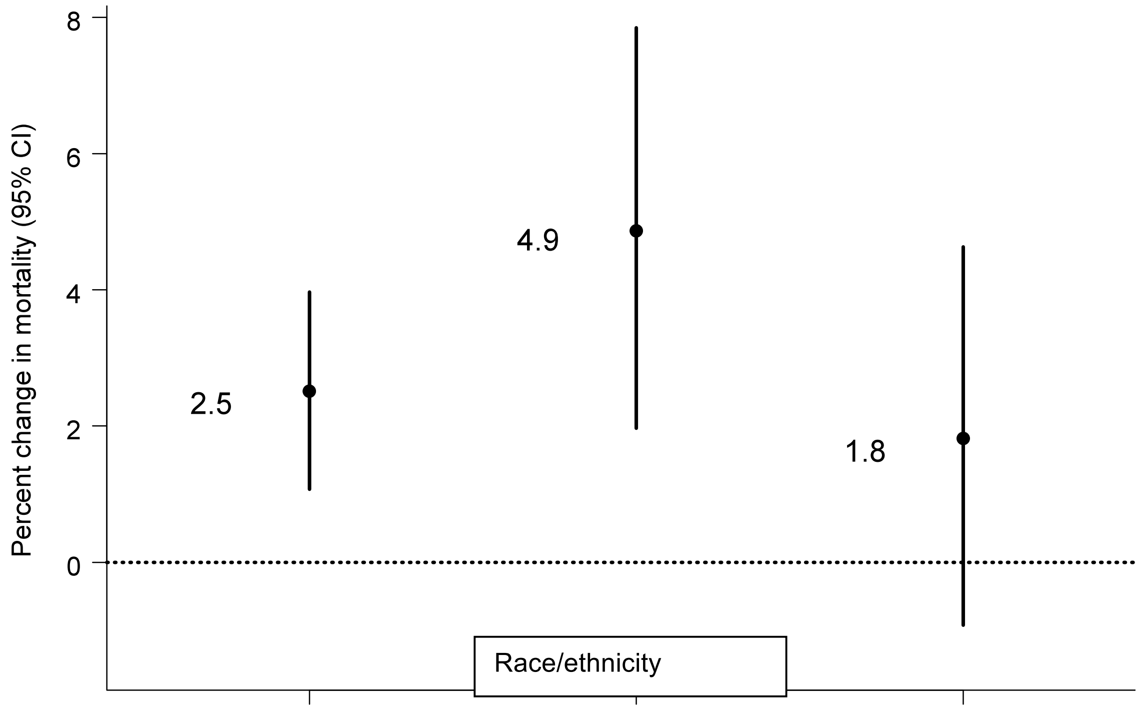

Figure 2. Estimated percent change associated with a 10°F increase in mean daily apparent temperature and non-accidental mortality by race/ethnic group in nine California counties, May through September 1999–2003

4.0 Discussion

We found several populations that appeared to be particularly vulnerable to mortality from ambient temperature exposure in California, including people dying from CVD, the elderly, infants, young children (although not statistically significant), and Blacks.

We further examined CVD deaths by disease and found that CHF had the highest, although non-significant, mortality estimate. The estimates for IHD and MI were also elevated, although IHD was the only significant disease subcategory. Investigators using data from 50 U.S. cities also reported elevated risks for CVD risks, specifically cardiac arrest and MI, from exposure to cold or hot extreme ambient temperatures (Medina-Ramon et al. 2006). Revich et al. (2008) found mortality from coronary heart disease, cerebrovascular, and especially, respiratory diseases to be associated with ambient temperature above 18°C (64°F) (Revich and Shaposhnikov 2008). This study was conducted in Moscow, Russia, and further supports the importance of examining subgroups in specific locations, since risk factors may vary. In this study, mortality from any respiratory disease was not significantly associated as the underlying cause or secondary causes of deaths, probably due to the low number of respiratory deaths that occurred during the warm season. In future analyses incorporating the full-year or focusing on the cold season, respiratory mortality may play a larger role with temperature-related mortality.

It would also be interesting to consider morbidity, by examining the association between apparent temperature and hospitalizations or emergency room visits, specifically for respiratory disease outcomes. The risk for diabetes was elevated, although not significantly, since we only considered diabetes as the primary underlying cause of death, and mortality for diabetics may often result from other primary causes. With additional years of data, we may find diabetics to be at increased risk, as was reported in two other recent epidemiologic studies (Medina-Ramon et al. 2006; Schwartz 2005).

Although a higher risk was found for Blacks, we did not find a higher risk for Hispanics compared to Whites. One explanation may be that Hispanics are generally likely to live with extended families and place a high value on social networks (Mulvaney-Day et al. 2007), and those who are isolated are more vulnerable to heat-related mortality and other adverse health outcomes, particularly among the elderly (Tomaka et al. 2006). Another possibility is that Blacks in our study sample may have co-morbidities that enhance their susceptibility to higher temperatures. An additional factor could be the availability and use of air conditioning and environmental justice issues, since some minority populations may use air conditioning less because of lower access and/or lower income, and therefore, experience higher levels of temperature exposure. In a study of four U.S. cities, for example, Black households were found to be significantly less likely to have air conditioners in their homes compared to White households (O'Neill et al. 2005). We did not have information on air conditioning use, since we were limited to variables provided on the death certificates. However, air conditioning use may be less of a marker of socioeconomic status in California, since people with higher socioeconomic status generally live in coastal areas, but may not have air conditioners (English 2007) since temperatures are mild and air conditioners have generally not been needed. In our previous study, we found the mortality estimate for coastal areas to be slightly higher than inland areas, which may provide some indication of acclimatization. People living in inland areas are more exposed to hotter temperatures, and therefore, have developed some biological adaptation and have more air conditioners in their homes. Finally, there may be some differential misclassification by location of the meteorologic monitors; for example, if some ethnic groups are more likely to live closer to the monitors, their exposures could be better characterized.

Previous reports on heat waves and high ambient temperature exposure have identified the elderly to be at increased risk (Basu and Samet 2002; Medina-Ramon et al. 2006; Hajat et al. 2007; Stafoggia et al. 2006; Basu et al. 2005), but very few studies have considered infants and young children (O'Neill et al. 2005), although investigators have established that health effects of children must be considered in climate change research (Shea 2007). It would be interesting to further analyze infants and young children by cause-specific outcomes or demographics, such as racial/ethnic group using a larger data set including additional years. Similar mechanisms may be involved for these vulnerable subgroups, who may not be able to thermoregulate efficiently. When body temperatures rise, blood flow generally shifts from the vital organs to underneath the skin's surface in an effort to cool down (Bouchama and Knochel 2002). Inadequate thermoregulation may occur when too much blood is diverted, putting increased stress on the heart and lungs (Bouchama and Knochel 2002). Increased blood viscosity, elevated cholesterol levels associated with higher temperatures, and a higher sweating threshold may also trigger heat-related mortality (Astrand et al. 2003).

Although we did not find a differential effect by gender or education, two recent epidemiologic studies (Hajat et al. 2007; Stafoggia et al. 2006) and several studies following heat waves (Basu and Samet 2002) have identified women to be at higher risk, while others showed no difference by gender (O'Neill et al. 2003). In our study, a difference between males and females may not have been observed because we focused on ambient temperature, rather than on heat waves. Other researchers have reported differences in vulnerability by lower socioeconomic status (Basu and Samet 2002; O'Neill et al. 2003) and by economic development of a country (Hajat et al. 2005). We relied on educational attainment as a proxy for socioeconomic status, since we did not have any information on household income from the death certificate data. Perhaps a measure based only on having completed at least a high school education, however, may not have been a good proxy for socioeconomic status. We attempted to examine socioeconomic status by other subgroups (i.e., Black elderly, Black CVD, or racial ethnic group by high school education), and still did not find any key difference by subgroup (results not shown).

Dying outside of the hospital had a greater risk than dying in the hospital, as was reported in two other recent epidemiologic studies of ambient temperature (Medina-Ramon et al. 2006; O'Neill et al. 2003). This finding, however, may have other implications rather than be a risk factor for death, such as serve as a surrogate for disease severity, accessibility to care, socioeconomic factors, and/or hospital distance.

Our study has some limitations generally present in semi-ecologic analyses. With personal monitoring, as was done in a previous study (Basu and Samet 2002), we could obtain individual exposure data as well as gather information on key time-activity factors. In the study presented here, one monitor was used to represent apparent temperature exposure for the entire county. Although the monitor was centrally located to areas where many people reside, the potential for misclassification of apparent temperature exposure could be greater for those persons who died further away from a monitor, particularly for larger counties, such as Los Angeles, Riverside, Orange, and San Diego. However, we suspect that the bias from the potential misclassification of exposure would be very small, and thus, the estimates presented here could be slightly overestimated or underestimated. Our study also did not consider the effect of harvesting to determine whether mortality may have been advanced by only a few days. Previous studies have addressed the issue of harvesting (Braga et al. 2002; Hajat et al. 2005), and the methods presented can be used in a future study.

This study adds to the growing body of evidence of the association between short-term ambient temperature and mortality, while identifying vulnerable subgroups. People with pre-existing cardiovascular disease, the elderly, infants, young children, and Blacks among others should be especially targeted to prevent heat-related mortality. In several cities, group-watch alerts have been implemented and have been successful at reducing mortality during heat waves, especially when they are based on city-specific exposures and have considered differences in adaptability. We found that temperature-related mortality was elevated for specific subgroups during exposure to ambient temperature exposure, and in a preliminary analysis, have observed that the effect estimates are likely to be three times higher during heat waves. As the frequency, duration and intensity of heat waves are likely to increase in the future, the implications for heat-related mortality may be considerably worse, particularly for high-risk groups.

5.0 References

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