A Multicounty Analysis Identifying the Populations Vulnerable to Mortality Associated with High Ambient Temperature in California

Rupa Basu and Bart D. Ostro

From the California Office of Environmental Health Hazard Assessment, Oakland, CA.

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The association between ambient temperature and mortality has been established worldwide, including the authors’ prior study in California. Here, they examined cause-specific mortality, age, race/ethnicity, gender, and educational level to identify subgroups vulnerable to high ambient temperature. They obtained data on nine California counties from May through September of 1999–2003 from the National Climatic Data Center (county-wide weather) and the California Department of Health Services (individual mortality). Using a time-stratified case-crossover approach, they obtained county-specific estimates of mortality, which were combined in meta-analyses. A total of 231,676 nonaccidental deaths were included. Each 10°F (4.4°C) increase in mean daily apparent temperature corresponded to a 2.6% (95% 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%, 95% CI: 0.04, 4.0), infants 1 year of age or less (4.9%, 95% CI: −1.8, 11.6), and the Black racial/ethnic group (4.9%, 95% CI: 2.0, 7.9). No differences were found by gender or educational level. To prevent the mortality associated with ambient temperature, persons with cardiovascular disease, the elderly, infants, and Blacks among others should be targeted.

California; effect modifiers (epidemiology); heat; mortality; temperature; vulnerable populations

Abbreviations: CI, confidence interval; COPD, chronic obstructive pulmonary disease; ICD-10, International Statistical Classification of Diseases and Related Health Problems, Tenth Revision.

Elevated ambient temperature has been linked with increased mortality in five continents throughout the world (1–5). Researchers investigating the 2003 heat wave in Western Europe have indicated an excess of up to 35,000 deaths (6–8). 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 preexisting 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) (2). Few epidemiologic studies have focused on identifying subgroups vulnerable 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 those of the rest of the country and pollutant levels tend to be higher with distinct sources and...
patterns of exposure (9). In addition, temperature effects may differ from those of other areas because 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 subgroups vulnerable to 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 1999–2003 to focus on heat effects.

MATERIALS AND METHODS

Death certificate data

The Health Data and Statistics Branch, California Department of Health Services, 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 (10, 11): Contra Costa, Fresno, Kern, Los Angeles, Orange,Riverside, Sacramento, San Diego, and Santa Clara. These counties were originally chosen, because they account for approximately 65 percent of the state’s population and had sufficient data available during our study period for analysis.

The data abstracted from death certificates included the date, county, and underlying cause of death, as well as up to five secondary causes of death. We analyzed deaths from all causes, excluding accidents, suicides, and homicides (i.e., nonaccidental deaths). Causes of death were categorized by using International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10), codes as follows (12): cardiovascular disease (codes I00–I99), respiratory disease (codes J00–J98), and diabetes (codes E10–E14). We evaluated specific cardiovascular diseases, including ischemic heart disease (ICD-10 codes I20–I25), acute myocardial infarction (codes I21–I22), conduction disorders, cardiac dysrhythmia, and congestive heart failure (codes I44–I50), cerebrovascular disease (codes I60–I69), stroke (code I64), and atherosclerosis (code I70). We also considered the following secondary respiratory causes of death to assess comorbidities with cardiovascular disease 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) (ICD-10 codes J40–J47), and mortality from other COPD (code J44), asthma (codes J45–J46), and chronic bronchitis (codes 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), educational level (high school graduates, non-high school graduates), and place of death (in or out of the hospital).

Weather data

Hourly weather data were obtained from the National Climatic Data Center, National Oceanic and Atmospheric Administration (13). We calculated the mean daily apparent temperature in degrees Fahrenheit (°F), also known as the heat index, to incorporate the effects of both temperature and relative humidity using formulas published previously (10).

We used one centrally located meteorologic monitor that recorded both temperature and relative 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. Because heat-related mortality has been reported to be an acute event in previous reports (2), county of death served as the index for assessing the effects of ambient temperature.

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. (14). 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 10 referent periods for the same individual (example shown in figure 1). 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 an indicator variable 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 educational 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 software (15). Odds ratios and 95 percent confidence
intervals were reported per 10°F (−4.7°C) increase in mean daily apparent temperature. The results are presented as the percent change in mortality to ease their interpretation using the following calculation: (odds ratio−1) × 100 percent. 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 (16).

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 as in a previous study (10). We had also found that unlagged (i.e., lag 0) apparent temperature provided the best fit with nonaccidental mortality and for cause-specific mortality relative to other lags (i.e., 4-day and 3-day cumulative lags). Thus, all results are provided using models with unlagged apparent temperature in this study. Furthermore, the mean apparent temperature provided a better fit than simply using dry bulb temperature, and the linear assumption was sustained in the warm season.

**RESULTS**

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

As shown in table 2, mortality from all cardiovascular diseases combined had a significant association with apparent temperature, with a 2.6 percent (95 percent confidence interval [CI]): 1.3, 3.9) per 10°F increase in mean daily apparent temperature. A further analysis of disease-specific mortality among cardiovascular disease deaths (table 2) demonstrated that congestive heart failure, ischemic heart disease, and acute myocardial infarction had elevated risks.

Mortality risk for both diabetes and cerebrovascular diseases was elevated, although neither finding was significant (table 2). No elevated association was found specifically for stroke (result not shown), and none of the respiratory mortality outcomes was elevated when considered as a primary (table 2) or a secondary cause of death (all respiratory deaths as secondary cause of death: 0.03 percent increase per 10°F increase in mean daily apparent temperature, 95 percent 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, was 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 nonaccidental deaths. When we examined various age groups, we found elevated mortality among infants 1 year of age or less, children aged 5 years or less, and the elderly at least 65 years of age, as shown in figure 2. The increased mortality risk was especially pronounced in infants and young children aged 5 years or less. The elderly subgroups all had nearly equal risk,

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**TABLE 1. Descriptive characteristics by county, California, May through September, 1999–2003**

<table>
<thead>
<tr>
<th>County (city*)</th>
<th>No. of nonaccidental deaths†</th>
<th>Mean apparent temperature, degrees Fahrenheit‡ (SD§)</th>
<th>Mean age, years (SD)</th>
<th>Race/ethnicity</th>
<th>High school graduates (%)</th>
<th>Male (%)</th>
<th>Cardiovascular disease deaths (%)</th>
<th>Respiratory deaths (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contra Costa (Concord)</td>
<td>12,306</td>
<td>66.8 (7.7)</td>
<td>75.7 (15.7)</td>
<td>79.8</td>
<td>9.7</td>
<td>4.5</td>
<td>79.2</td>
<td>47.0</td>
</tr>
<tr>
<td>Fresno (Fresno)</td>
<td>9,452</td>
<td>75.4 (8.5)</td>
<td>73.6 (17.5)</td>
<td>70.2</td>
<td>5.8</td>
<td>18.3</td>
<td>59.2</td>
<td>49.6</td>
</tr>
<tr>
<td>Kern (Bakersfield)</td>
<td>8,353</td>
<td>78.1 (8.6)</td>
<td>72.8 (17.3)</td>
<td>76.9</td>
<td>5.7</td>
<td>14.5</td>
<td>59.9</td>
<td>49.1</td>
</tr>
<tr>
<td>Los Angeles (downtown Los Angeles)</td>
<td>92,250</td>
<td>69.2 (6.0)</td>
<td>73.0 (18.5)</td>
<td>61.4</td>
<td>14.5</td>
<td>15.3</td>
<td>72.9</td>
<td>48.7</td>
</tr>
<tr>
<td>Orange (Anaheim)</td>
<td>19,445</td>
<td>72.6 (6.8)</td>
<td>75.4 (17.2)</td>
<td>81.3</td>
<td>1.3</td>
<td>8.7</td>
<td>77.0</td>
<td>46.2</td>
</tr>
<tr>
<td>Riverside (Riverside)</td>
<td>20,234</td>
<td>75.7 (8.1)</td>
<td>75.1 (16.0)</td>
<td>83.3</td>
<td>4.8</td>
<td>10.0</td>
<td>72.5</td>
<td>49.7</td>
</tr>
<tr>
<td>Sacramento (Sacramento)</td>
<td>17,974</td>
<td>70.7 (7.8)</td>
<td>72.6 (18.3)</td>
<td>78.5</td>
<td>8.4</td>
<td>5.4</td>
<td>72.9</td>
<td>48.6</td>
</tr>
<tr>
<td>San Diego (Escondido)</td>
<td>34,714</td>
<td>71.1 (7.3)</td>
<td>74.6 (17.6)</td>
<td>80.0</td>
<td>4.5</td>
<td>10.2</td>
<td>77.0</td>
<td>48.5</td>
</tr>
<tr>
<td>Santa Clara (San Jose)</td>
<td>16,948</td>
<td>64.8 (6.4)</td>
<td>75.4 (17.2)</td>
<td>71.6</td>
<td>3.1</td>
<td>11.1</td>
<td>74.1</td>
<td>49.4</td>
</tr>
<tr>
<td>Total study</td>
<td>231,676</td>
<td>70.6 (7.6)</td>
<td>73.7 (17.9)</td>
<td>71.8</td>
<td>8.7</td>
<td>11.9</td>
<td>71.8</td>
<td>48.6</td>
</tr>
</tbody>
</table>

* Cities where monitors were located.
† “Nonaccidental deaths” are defined as all deaths excluding deaths from homicides, suicides, and accidents according to International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10), codes.
‡ To convert values given in degrees Fahrenheit (°F) to degrees Celsius (°C): (°F − 32) × 0.556 = °C.
§ SD, standard deviation.
regardless of age cutoff. The estimates for the elderly sub-
groups were slightly higher compared with all age groups
combined in our previous study (2.3 percent, 95 percent
CI: 1.0, 3.6) (10), because most deaths occurred among
the elderly. When we examined various other age groups
(e.g., 5–17 years, 18–64 years), we did not find significant
risks. As demonstrated in figure 3, Blacks had the most
elevated risk of the racial/ethnic groups examined. Whites
and Hispanics also had increased risks, although the asso-
ciation was not significant for Hispanics. Dying out of the
hospital (3.8 percent, 95 percent CI: 1.3, 6.3) had a signifi-
cantly greater risk than dying in a hospital (1.5 percent, 95
percent CI: 1.2, 3.9) or between those who graduated from high school (3.1 percent, 95 per-
cent CI: 2.0, 4.1) and those who did not (2.7 percent, 95 percent CI: 1.2, 4.3).

**DISCUSSION**

We found several populations that appeared to be partic-
ularly vulnerable to mortality from ambient temperature
exposure in California, including people who died from
cardiovascular disease, the elderly, infants, young children,
and Blacks.

We further examined cardiovascular disease deaths by
disease and found that congestive heart failure had the high-
est, although nonsignificant mortality estimate. The esti-
mates for ischemic heart disease and acute myocardial
infarction were also elevated, although ischemic heart dis-
ease was the only significant disease subcategory. Investi-
gators using data from 50 US cities also reported elevated
risks for cardiovascular disease risks, specifically cardiac
arrest and acute myocardial infarction, from exposure to
cold or hot extreme ambient temperatures (4). Revich
et al. (17) found mortality from coronary heart, cerebrovas-
cular, and especially respiratory diseases to be associated
with ambient temperature above 18°C. This study was con-
ducted in Moscow, Russia, and further supports the impor-
tance of examining subgroups in specific locations, since
risk factors may vary. In this study, mortality from any res-
piratory disease was not significantly associated as the
underlying cause or secondary causes of deaths, probably
because of the low number of respiratory deaths that oc-
curred during the warm season. In future analyses incorpo-
rating 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 con-
sider morbidity, by examining the association between
apparent temperature and hospitalizations or emergency

<table>
<thead>
<tr>
<th>Disease (ICD-10 codes)</th>
<th>Percent change</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cardiovascular (I00–I99)</td>
<td>2.6</td>
<td>1.3, 3.9</td>
</tr>
<tr>
<td>Congestive heart failure (I44–I50)</td>
<td>5.4</td>
<td>-8.2, 21.1</td>
</tr>
<tr>
<td>Ischemic heart disease (I20–I25)</td>
<td>2.5</td>
<td>0.4, 4.6</td>
</tr>
<tr>
<td>Acute myocardial infarction (I21–I22)</td>
<td>2.7</td>
<td>-0.4, 5.9</td>
</tr>
<tr>
<td>All respiratory (I00–J99)</td>
<td>0.9</td>
<td>-1.8, 3.5</td>
</tr>
<tr>
<td>All cerebrovascular (I60–I69)</td>
<td>1.2</td>
<td>-1.7, 4.2</td>
</tr>
<tr>
<td>Diabetes (E10–E14)</td>
<td>2.7</td>
<td>-4.0, 10.0</td>
</tr>
</tbody>
</table>

* Equivalent increase: 4.7°C.
† Listed as the primary underlying cause on death certificate.
room visits, specifically for respiratory disease outcomes. The risk for diabetes was elevated, although not significantly, since we considered only 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 (4, 18).

Although a higher risk was found for Blacks, we did not find a higher risk for Hispanics compared with Whites. One explanation may be that Hispanics are generally likely to live with extended families and place a high value on social networks (19), and those who are isolated are more vulnerable to heat-related mortality and other adverse health outcomes, particularly among the elderly (20). Another possibility is that Blacks in our study sample may have comorbidities 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 US cities, for example, Black households were found to be significantly less likely to have air conditioners in their homes compared with White households (21). We did not have information on air conditioning use, because 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, because people with higher socioeconomic status generally live in coastal areas but may not have air conditioners (22) 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 that of 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 biologic 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 (2, 4, 23–25), but very few studies have considered infants and young children (26), although investigators have established that health effects of children must be considered in climate change research (27). 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 (28). Inadequate thermoregulation may occur when too much blood is diverted, putting increased stress on the heart and lungs (28). Increased blood viscosity, elevated cholesterol levels associated with higher temperatures, and a higher sweating threshold may also trigger heat-related mortality (29).

Although we did not find a differential effect by gender or education, two recent epidemiologic studies (23, 24) and several studies following heat waves (2) have identified women to be at higher risk, while others showed no difference by gender (5). 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 (2, 5) and by economic development of a country (30). 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 on only 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., racial/ethnic group by education, elderly subgroups, or cardiovascular disease) 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 (4, 5). This finding, however, may have other implications rather than being a risk factor for death, such as serving 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 (31), we could obtain individual exposure data and 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 farther away from a monitor, particularly for larger counties, such as Los Angeles, Riverside, Orange, and San Diego. 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 (3, 30), 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 preexisting 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 at least 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.

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