

**Examining the Association Between Temperature and Emergency Room Visits
from Mental Health-Related Outcomes in California**

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Running head: Temperature and Mental-health Related Outcomes

Abstract

Temperature and morbidity has been explored previously. However, the association between temperature and mental health-related outcomes, including violence and self-harm, remains relatively unexamined. We obtained daily counts of mental health-related emergency room visits involving injuries with external cause from the California Office of Statewide Health Planning and Development from 16 California climate zones from 2005 to 2013, and combined them with data on mean apparent temperature, a combination of temperature and humidity. Using Poisson regression models, we estimated climate zone-level associations, then used random-effects meta-analyses to produce overall estimates. Analyses were stratified by season (warm: May-October; cold: November-April), race/ethnicity, and age. A 10-degree Fahrenheit increase in same-day mean apparent temperature was associated with a 4.8% (95% confidence interval, 3.6-6.0%), 5.8% (4.5-7.1%), and 7.9% (7.3-8.4%) increase in visits for mental health disorders, self-injury/suicide, and intentional injury/homicide, respectively, during the warm season. High temperatures during the cold season were also positively associated with these outcomes. Variations were observed by race/ethnicity, age group, and sex, with Hispanics, Whites, 6-18 year olds, and females at greatest risk for most outcomes. Increasing mean apparent temperature was found to have acute associations with mental health outcomes and intentional injuries, and warrants further studies in other locations.

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The association between elevated temperatures and morbidity from heat stroke and dehydration has been well established (1). The mentally ill have been identified as at-risk from extreme heat, especially those taking medications that interfere with physiological homeostasis, causing higher mortality (2, 3), heat-related illnesses (4), and physiologically impaired heat tolerance (5). Very few studies have examined the direct impact of temperature on mental-health related outcomes (6-8), which would identify specific populations at enhanced risk and help anticipate health care utilization for mental disorders. Violence and self-harm, more prominent during hotter weather (9-13), may also be related to mental states of aggression. There is limited evidence temperature and mental disorders, violence, and self-harm are mediated by individual factors such as age, sex, and education (6, 7, 14) and warrants further investigation.

In this study, we examined the association between temperature and emergency room (ER) visits for mental health-related outcomes in California from 2005 to 2013. With a large number of ER visits so that we were able to examine effect modification by race/ethnicity, age, sex, and region. Additionally, we explored specific mental disorder categories, specifically psychosis and neurotic disorders, and violent outcomes possibly related to mental health, including self-inflicted injury/suicides and inflicted injury/homicides. Though the latter two outcomes are not directly documented as mental health outcomes, exploring their association with temperature could be indicative of overall trends in mental health as they relate to outdoor temperature.

Methods

Study Population

We obtained daily count data of ER visits from the California Office of Statewide Health Planning and Development from 16 California climate zones from 2005 to 2013. Climate zone boundaries were classified based on weather and energy use factors (15). We focused on primary diagnoses and limited our analyses to visits involving injuries with external causes to focus on high-risk groups. The outcomes examined included: all mental disorders (ICD-9 codes 290-319) and subcategories of psychosis (290-299) and neurotic disorders, including neurotic, personality disorders, and other non-psychotic mental disorders (300-316). We also examined visits with external causes of injury identified as self-inflicted injury/suicides (E950-E959) or being a victim of inflicted injury/homicides (E960-E969), regardless of primary diagnosis. Race/ethnicity (white non-Hispanic [White], black non-Hispanic [Black], Asian non-Hispanic [Asian], Hispanic), age (6-18, 19-64, 65+ years), and sex (male, female) were also abstracted. To examine potential seasonal effect modification, ER visits were stratified by warm (May 1 through October 31) and cold seasons (November 1 through April 30) for all analyses. We were unable to differentiate between incident and prevalent visits, and multiple visits may have occurred for the same person.

Exposure Data

Because previous studies have shown that temperature, rather than humidity, sunshine, or other meteorological factors is most associated with mental health-related outcomes such as self-injury and suicides (14, 16), we considered mean, minimum and maximum apparent temperature to take into account the combined exposure of temperature and humidity. Apparent temperature

data were provided by the US EPA Data Mart (17), the California Irrigation Management Information System (18), and the National Oceanic Atmospheric Administration (19). These data were restricted to December 2004 (one month prior to the study period) to account for lagged temperature for ER visits occurring at the beginning of January 2005 to December 31, 2013. In total, 401 monitors had temperature and humidity daily data for the study period, and we restricted the data to monitors with at least 98% completeness.

For each population-weighted zip-code tabulation area centroid in a climate zone, we estimated daily apparent temperature using monitored data in the same climate zone, weighting by distance from each monitor. These were combined to create an estimate for daily apparent temperature for each climate zone, while also weighting by the US Census population count associated with the zip-code tabulation area centroid. Distance calculations were completed with Geospatial Modeling Environment, with additional data manipulation done using SAS Version 9.4 (20). The final dataset consisted of variables for apparent temperature lags 0-30 days for mean, maximum, and minimum apparent temperature.

Data Analysis

We analyzed data using a two-stage time-series method with Poisson regression in R Version 3.2.2 (21) to estimate the effect of mean, maximum, or minimum daily apparent temperature on daily counts of emergency department visits, adjusting for holidays; day of the week, and seasonal/long-term trends using a natural spline smoothing function of time measured in days with two degrees of freedom per season for long-term temporal adjustment. Effect estimates were first calculated for each climate-zone, and then combined using random effects

models for meta-analyses to get an overall estimate (22). Daily temperature data was merged with ER daily count data and binomial (0/1) indicators for “holiday” days (New Year’s, Memorial, Independence, Labor, Thanksgiving, Christmas). Day of the week was included since homicides and suicides have been shown to vary by day of the week (11, 23). We did not include the last month to avoid the issue of counts declining from ER admissions in 2013 that were not discharged until 2014.

The final model was chosen based on Akaike’s Information Criterion (AIC) comparing models with mean, maximum, minimum apparent temperatures. Several lag times were considered, consisting of same-day (lag 0), previous day (lag 1), average of same and previous 6 days (lag 0-6), and average of same day and previous 29 days (lag 0-29), and the metric of apparent temperature with the best model fit was used. We tested an additional squared term for apparent temperature in the final model with the best lag fit. Results were further stratified by race/ethnicity, age group, sex, and region (coastal/non-coastal). Race/ethnicity of homicides/inflicted injury is typically for the victim(s), as they were admitted to the ER. All main results are reported as a percent increase in ER visits per 10°F increase in apparent temperature.

We also considered extreme apparent temperatures, defined as the bottom 10th percentile and the upper 90th percentile of the distribution for each climate zone using 0/1 as indicator variables. Additionally, we evaluated heat waves, which were defined as two or more consecutive days of apparent temperature above the 95th percentile of each climate zone.

Prior to beginning this study, IRB approval was obtained by the California’s Committee for the Protection of Human Subjects.

Results

Our study population consisted of 219,942 ER visits for mental health disorders with injuries of external cause, 62,812 of which were categorized as psychosis visits and 157,050 of which were neurotic visits (Table 1). Additionally, there were 322,478 suicide/self-injury visits and 1,041,433 homicide/inflicted injuries recorded, also in Table 1. White patients consisted of 56% of mental disorder visits, while 26% were Hispanic patients, 8% and 3% were Black and Asian patients, respectively. Most were 19-64 years old (74%), with a smaller percentage of cases 6-18 years old and 65+ years old (13% each). Less than 1% of mental disorder visits were under 6 years old, insufficient for analyses. The majority of all visits were male (61%).

Climate-zone specific mean apparent temperature distributions are listed in Table 2. Non-coastal climate zones had the majority of ER visits with 71-77%, while coastal climate zones had the remaining 23-29% of ER visits. The overall mean apparent temperature was 65.5°F during the warm season and 48.9°F during the cold season. During the warm season, individual zone mean apparent temperatures range from 51.9°F - 83.5°F, while mean apparent temperatures ranged from 37.3°F – 56.1°F during the cold season.

After analyzing several lag times, we found that same-day lags most frequently had the best model fit according to AICs (Figure 1). While some elevated risks were also observed for lag 1 and lag 06, lag 0-30 had all significant associations for the cold season (Web Figure 1).

After comparing associations between mean, minimum, and maximum apparent temperatures, mean apparent temperature was found to have the best model fit (Figure 2, Web Figure 2).

Squared terms were generally not statistically significant when stratified by warm and cold season, implying that the linear term was sufficient. Thus, our final model included mean apparent temperature for lag 0, and all results were stratified by warm and cold season.

We observed significant associations between same-day mean apparent temperature and overall and specific categories of mental-health related ER visits. During the warm season, a 10°F increase in mean apparent temperature was associated with a 4.8% (95% confidence interval, 3.6-6.0%) increase in overall mental health events, a 2.9% (0.7-5.2%) increase in psychosis events, and a 5.7% (3.8-7.6%) increase in neurotic events. Increased temperatures during the cold season were associated with a 5.3% (4.0-6.7%), 3.9% (1.6-6.3%), and 6.0% (4.5-7.5%) increase in overall mental health events, psychosis events, and neurotic events, respectively. During the warm season, a 10°F increase in mean apparent temperatures was associated with a 5.8% (4.5-7.1%) increase in suicides/self-injury ER visits and a 7.9% (7.3-8.4%) increase in inflicted injury/homicides. During the cold season, mean apparent temperature increase was associated with a 7.2% (5.7-8.8%) increase in suicide/self-injury and a 10.6% (9.8-11.4%) increase in homicide/inflicted injury visits.

The results stratified by race/ethnic group, age, sex, and region are depicted for all mental health (Figure 3), psychosis (Web Figure 3a), neurotic disorders (Web Figure 3b), suicide (Web Figure 3c), and homicide (Web Figure 3d) subcategories, respectively. Since the results for warm and cold seasons were similar, only warm season results are shown in these figures. Per 10°F increase in mean apparent temperature, the greatest associations were observed for Whites and Hispanics for mental health during the warm season (Whites: 4.7% [3.1-6.4%] and Hispanics: 6.3% [3.7-9.1%]) (Figure 3). Similar results were observed during the cold season. For all

mental health, as well as psychosis and neurotic disorder visits, estimates for Black and Asian patients were not significantly associated with temperature increases.

When stratified, risk of self-injury/suicides (cold season) and inflicted injury/homicide (warm season) appeared to be highest for Hispanics. For self-injury/suicides, a 10°F increase in mean apparent temperature was associated with a 6.9% (4.3-9.6%) increase during the warm season and a 10.5% (7.3-13.7%) increase during the cold season. These risks were more increased compared to Whites during the warm season (5.1% [3.4-6.8%]) and cold season (6.1% [4.7-7.5%]). Blacks also had significantly elevated risk during both seasons, while Asians had greater risk for the cold season only. During the warm and cold seasons, risk of being a victim of homicide/inflicted injuries was also highest for Hispanics. During the warm season, a 9.9% (9.0-10.9%) increase in inflicted injury/homicides was found for Hispanics, compared to a 7.0% (6.0-7.9%) increase among Whites and a 6.0% (4.6-7.4%) increase among Blacks.

Risk was relatively the same across age categories during both the warm and cold seasons. During the warm season, mental health disorders had the highest association with apparent temperature for 6-18 year olds with a 7.3% (4.0-10.8%) increase per 10°F increase in mean apparent temperature. The association between temperature and suicide/self-inflicted injury was also highest in 6-18 year olds (6.7% [4.5-8.9%]). The increase in homicides/inflicted injury was highest in those aged 19-64 years (8.3% [7.7-9.0%]). Cold season estimates followed a similar pattern, with all mental health and suicide/self-inflicted injury associations being highest for 6-18 year olds. During the cold season, however, homicide/inflicted injury had the highest association with temperature for the 6-18 year old group at 15.4% (13.7-17.2%) risk.

Effect modification by region was not found, except for psychosis, which had a greater association in non-coastal areas during the warm season (Web Figure 3a). Homicides/inflicted

injury showed fairly similar associations with apparent temperature by regions. During the cold season, significant associations were found for coastal and non-coastal populations for neurotic disorders, suicides/self-inflicted injury, and homicides /inflicted injury, but no significant differences between regions were observed.

In analyses that considered extreme temperatures, the upper 90th percentile and heat wave exposure results were similar to our estimates including temperatures per 10°F (Figure 4). Most estimates had slightly less magnitude for the 90th percentile, but a slightly higher association with heat wave for inflicted injury/homicides, overall mental health, and neurotic outcomes. The lowest 10th percentile had all negative associations.

Discussion

We found associations between increasing temperature and all mental health disorders in California, as well as for the subcategories of psychosis and neurotic events as well as inflicted injury/homicides and self-injury/suicides. While very few prior studies showed increased associations with mental health-related outcomes primarily during the warm season or following heat waves (6, 7), we observed both warm and cold seasons had greater risk for the mental health outcomes examined with increasing temperature. Because temperatures in California are relatively mild, particularly in the more densely populated coastal areas, there was not a drastic difference between mean cold and warm season temperatures. Extremes in hotter temperatures or heat waves were similar to the magnitude of the effect estimates for temperature per 10°F.

Higher associations were observed in non-coastal areas for psychosis only, while other outcomes had similar risk by region. Poor mental health-related outcomes in non-coastal areas

could be related to lower socioeconomic status (SES) compared to coastal areas. For example, air conditioning (AC) use is typically correlated with SES, but in California, coastal regions have higher SES but lower AC ownership due to relatively milder temperatures. Furthermore, low SES is also a risk factor for the mental disorder itself, particularly for children and adolescents(24), as well as being a victim of a violent crime, chronic stress, crowding, noise pollution, and discrimination (25).

ER visits in our study are often for the victims of the violence, not necessarily the perpetrators unless they are also admitted to the ER. For homicides, victims' race/ethnicity may be good predictors of the perpetrators' (26). Temperature may have also impacted the mental state and aggressiveness of both the perpetrator and the victim, resulting in the higher likelihood of physical altercation and injury. Our results support the hypothesis that higher temperatures may lead to more violence, including suicides and homicides, particularly for Hispanics and Whites during both seasons. During the warm season, Hispanics displayed greatest risks for all mental-health related outcomes except for psychosis, where Whites had a higher association. However, sample sizes were small for some outcomes for Asians and Blacks, so we may not have captured accurate risk estimates for these race/ethnic groups. There may be a cultural stigma for some communities regarding mental illness, so they may be underreported from lack of diagnoses. Some populations may be more likely to use the ER for primary care (27), and they would have received better coverage in this study. Prior studies did not examine disparities among race/ethnic groups specifically for temperature and mental health-related outcomes.

Although risks were similar by age, the greatest risk was observed for 6 to 18 year olds, except for inflicted injury/homicides where the greatest risk was for adults 19 to 64 year olds. Previous studies found elevated risk for psychological emergency calls for those 15-44 years

(28) and ER admissions due to mental and behavioral disorders (8). Unlike the majority of prior studies that focused on medication use in the elderly, we were able to evaluate overall as well as specific mental health outcomes for all age groups. In a previous Australian study(6), the elderly were also found to be at increased risk during heat waves for mortality, but not hospitalizations (except for those 75+ years). We did not observe increased risk for the elderly, partly because we examined ER visits rather than mortality or hospital visits. The elderly with mental health disorders in California typically reside in medical care facilities where they spend most time indoors under supervision and in climate-controlled environments with lower risk of morbidity/mortality following heat waves compared to younger age groups (29).

Apart from homicides, females had greater or similar risk as males during both the warm and cold seasons. In an Australian study, (6) adult males had greater risk for dementia and schizophrenic disorders, but females had greater risk for disorders due to psychoactive substance use following heat waves. In Vietnam, males 60+ years were more sensitive to seasonal fluctuations for mental disorder hospital admissions (30). Suicides also had slightly greater risk for males than females in Korea, although not statistically significant (12).

The biological mechanisms for temperature-related increases in mental-health related outcomes are multi-factorial. As temperatures rise, stresses from everyday life in the home, social networks, and workplace are likely to be exacerbated, particularly for those with acute or chronic mental problems. With extended periods of heat, irritability and psychological distress, including risky behaviors, such as alcohol consumption, violence, and aggression are more common (31). In one study, daytime temperature was found to be a risk factor for episodes related to schizophrenia (32), possibly because of increased stress on the nervous system (33). Medications such as beta-blockers (34), benzodiazepines (35), and anti-depressants (36) used to

treat hypertension, schizophrenia and depression, respectively, have been shown to increase risk of suicides, while anti-psychotic medications for schizophrenics (37) as well as psychoactive substances (38) have been related to increased violence and homicides. Impaired thermoregulation and suppressed thirst, noted side-effects of medications associated with treating mental health disorders, may contribute to greater mental health admissions during periods of increased heat (39). Mental health illness is also a predominant risk factor for illnesses such as heat-related illnesses. In animal models, specific neurotransmitters that may be involved with thermoregulation may be compromised, particularly for schizophrenic patients (40). Some anti-psychotic medications may disrupt normal thermoregulation due to their particular pharmacological properties (4), especially those commonly prescribed to patients with dementia (41). Furthermore, specific conditions such as dementia as well as those who take particular medications may lack the awareness or cognitive function to avoid going outdoors or wear appropriate clothing during periods of heat exposure (6).

There are several limitations in this study. The most severe visits would not have been captured because they resulted in deaths before reaching the ER. On the other hand, other visits may not have been severe enough to make it to the ER and may have been treated at the scene or at other treatment facilities. In either scenario, ER visits capture a specific subset of mental health morbidity. While we were able to evaluate some specific mental health-related outcomes, we could not look at several others in more detail because of inadequate numbers. We relied on information provided by the databases and could not consider changes in individual factors that may be on the non-causal pathway, such as medication use, SES, activity patterns, trends in seeking care for mental health issues, or co-morbidities that may have contributed to false spurious positive associations. Since we used time-series, these confounders should not affect

our results, unless they change on a daily level, and other time-variant sources of confounding may exist. Race/ethnicity may be a valid measure of SES effect modification and could not account for the other factors. However, the results are generally consistent by lag period, outcome, and geographic region, providing further credibility to our study results. We also relied on ecologic exposure data, but tried to minimize misclassification by weighting climate zone temperature estimates based on population and temperature monitor proximity. It is not feasible to conduct personal temperature exposure assessment for each individual (42) in studies with large populations, given the large amount of time and expense involved, and monitored data provided a good proxy for population-weighted exposure.

As global temperatures continue to rise and heat waves are predicted to become more intense and frequent in the future (43), it is necessary to consider all outcomes rather than mortality from all causes or cardiovascular and/or respiratory diseases (44) to target high-risk populations and prevent heat-associated deaths and illnesses. This study is among the first to quantify the association between temperature and mental health-related outcomes, and the first to do so in California. We examined both warm and cold seasons and considered extreme temperatures. By identifying subgroups that are most vulnerable, morbidity related to temperature exposure can be alleviated. The results of this study could be invaluable to mental health patients and their caretakers as well as policymakers. The results of this study focus on short-term exposures, with the longest lag of 30 days. In future studies, longer exposure averages should also be examined for temperature and mental-health related outcomes.

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Table 1. Descriptive Characteristics of the Study Population (%) in California, 2005-2013.

Characteristic	All Mental Disorders (n = 219,942), %	Psychosis (n = 62,812), %	Neurotic Disorders (n = 157,050), %	Suicide/ Self-Injury (n = 322,478), %	Homicide/ Inflicted Injury (n = 1,041,433), %
Race/ethnic group					
White	56	63	53	55	34
Black	8	8	8	8	18
Asian	3	3	3	4	3
Hispanic	26	20	28	25	36
Age (years)					
0-5	<1	<1	1	<1	1
6-18	13	7	16	21	18
19-64	74	67	76	75	79
65+	13	26	7	3	2
Region					
Coastal	28	28	29	23	25
Non-coastal	72	72	71	77	75
Sex					
Male	56	54	56	41	68
Female	44	46	44	59	32

Table 2. Mean apparent temperature exposure (°F) by region, climate zone, and season in California, 2005-2013.

	Climate Zone #	Mean (SD)		Lower 5 th %		Lower 10 th %		Upper 90 th %		Upper 95 th %	
		Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold	Warm	Cold
Coastal		59.9 (7.2)	49.6 (6.4)	48.7	38.8	50.9	41.1	69.6	57.6	72.7	59.7
Eureka	1	51.9 (4.3)	43.5 (5.5)	45.0	34.8	46.4	36.6	57.5	50.6	59.4	52.5
San Francisco	3	57.5 (4.1)	48.0 (5.0)	50.7	39.7	52.1	41.4	62.7	54.3	64.3	56.3
Santa Maria	5	58.7 (4.7)	48.9 (5.4)	51.1	40.4	52.5	42.0	64.0	55.3	66.7	57.7
LA Airport	6	64.0 (4.8)	53.3 (4.9)	56.6	45.3	58.2	46.8	70.3	59.2	71.9	61.2
San Diego	7	67.3 (5.9)	54.0 (4.9)	58.7	45.9	60.3	47.4	75.6	60.0	77.8	61.7
Non-coastal		68.0 (10.4)	48.6 (8.7)	52.2	34.5	55.4	37.4	81.3	59.5	86.5	62.8
Napa	2	59.9 (6.3)	44.2 (6.3)	49.6	34.0	51.4	36.1	67.4	52.3	70.2	54.9
San Jose	4	61.5 (5.6)	47.9 (5.9)	52.4	38.1	54.2	40.3	68.8	55.3	71.0	57.7
Long Beach	8	68.8 (5.9)	55.2 (5.3)	59.9	47.0	61.7	48.4	76.9	61.6	78.7	63.5
LA Civic	9	67.8 (7.2)	53.8 (6.8)	56.5	43.3	58.6	45.1	77.4	62.7	80.1	65.4
Riverside	10	69.5 (8.3)	52.1 (6.5)	56.3	41.8	58.8	43.5	80.5	60.4	83.2	62.8
Red Bluff	11	69.9 (9.4)	47.2 (7.5)	54.0	35.7	57.1	37.9	81.4	57.0	84.5	60.0
Stockton	12	66.7 (7.7)	47.0 (7.1)	54.0	36.2	56.3	38.0	76.2	56.0	79.4	58.8
Fresno	13	71.5 (9.3)	48.0 (7.8)	55.8	35.9	58.3	37.9	82.4	58.0	85.6	61.3
Barstow	14	69.7 (9.7)	45.7 (7.6)	52.4	34.6	55.5	36.5	81.3	55.5	83.2	59.1
Brawley	15	83.5 (10.9)	56.1 (7.9)	64.8	43.8	67.3	46.3	97.1	66.7	98.9	69.5
Bishop	16	59.5 (9.0)	37.3 (6.8)	43.9	26.9	46.8	28.8	70.0	46.3	72.1	49.3

SD, standard deviation

Table 3. Results per 10°F increase in mean apparent temperature by season in California, 2005-2013.

Outcome	<u>Warm Season</u>			<u>Cold Season</u>		
	N	% change	95% CI	N	% change	(95% CI)
All Mental Disorders	115,962	4.8	3.6, 6.0	103,980	5.3	4.0, 6.7
Psychosis	32,959	2.9	0.7, 5.2	29,853	3.9	1.6, 6.3
Neurotic disorders	82,962	5.7	3.8, 7.6	74,088	6.0	4.5, 7.5
Suicides	168,596	5.8	4.5, 7.1	153,882	7.2	5.7, 8.8
Homicides	561,891	7.9	7.3, 8.4	479,542	10.6	9.8, 11.4

CI, confidence interval

Figure Legend

Figure 1: Percent change in odds (with 95% CI) for mean apparent temperature per 10°F (5.6°C) increase and emergency room visits for all mental health by lag period in California by season, 2005-2013.

Figure 2: Percent change in odds (with 95% CI) for minimum, mean, and maximum apparent temperature per 10°F (5.6°C) increase for emergency room visits for all mental health for lag 0 by season in California, 2005-2013.

Figure 3: Percent change in odds (with 95% CI) per 10°F (5.6°C) increase in mean apparent temperature for emergency room visits for all mental health during the warm season by A) race/ethnicity, B) age, C) sex and D) region groups in California, 2005-2013.

Figure 4: Percent change in odds (with 95% CI) for A) bottom 10th percentile in temperature, B) upper 90th percentile and C) heat waves (2+ days 95th percentile for climate zone) for emergency room visits for mental health-related outcomes in California, 2005-2013.







