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Sophie Lockwood Date

The Association between Ambient Heat Exposure and Pediatric Mental Health, Modified by Individual Socioeconomic Status

By

Sophie Lockwood

MSPH

Department of Epidemiology

_____

Stefanie Ebelt

Committee Chair

The Association between Ambient Heat Exposure and Pediatric Mental Health, Modified by Individual Socioeconomic Status

By

Sophie Lockwood

B.S.
Georgetown University
2020

Thesis Committee Chair: Stefanie Ebelt, ScD

An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

The Association between Ambient Heat Exposure and Pediatric Mental Health, Modified by Individual Socioeconomic Status

By Sophie Lockwood

Purpose: This study examined the association between ambient heat exposure and acute mental health events among children aged 5-17 years in Los Angeles County, California between 2005 and 2019, and evaluated individual socioeconomic status as an effect measure modifier.

Methods: Patient-level data of mental health-related emergency department (ED) visits was obtained from the California Office of Statewide Health Planning and Development and meteorological data recorded at the Los Angeles International Airport Weather Station was obtained from the National Oceanic and Atmospheric Administration's National Center for Environmental Information Integrated Surface Database. A case-crossover study design was used where control days were selected from the same day, week, and calendar year as the observed case day. Distributed lag non-linear models were fit to assess the cumulative effect of mean and maximum daily temperature on the odds of ED visit for nine categories of mental health outcomes. Stratification on payor status was used to evaluate effect measure modification by individual socioeconomic status.

Results: The findings suggest that the cumulative effect of increasing mean daily temperature was associated with increased odds of ED visits for anxiety, cognitive, mood, and suicide and self-harm disorders and that this association is slightly stronger among children covered by California's Medicaid program compared to those covered by private insurance for anxiety disorders and suicide and self-harm. Effect measure modification was not consistently identified among other mental health outcomes or by considering exposure to daily maximum temperature.

Conclusions: This study provides evidence that increasing ambient temperature is associated increased risk of suicide and self-harm and anxiety, cognitive, and mood disorders among children and that these effects are stronger among Medicaid-covered patients for several outcomes. Future work in this field should address additional methods of measuring socioeconomic status and mental health burden.

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For Melanie.

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Background

Rising global temperatures are projected throughout the next century and extreme heat events are expected to increase in frequency and intensity as a result of global climate change (Pachauri et al., 2014). Increasing temperatures have been shown to be associated with increased risk of emergency care for any cause (Sun et al., 2021), and a number of heat-sensitive disorders, including cardiovascular diseases, stroke, and renal diseases have been identified (Fuhrmann et al., 2016; Sun et al., 2021).

An emerging body of literature suggests that mental health disorders are likewise heat sensitive. Previous epidemiologic work has identified a positive association between heat exposure and acute mental health disorders (Thompson et al., 2018; Yoo et al., 2021; Vida et al., 2012). In California specifically, increasing temperature was associated with an increased risk of mental health related emergency department (ED) visits (Basu et al., 2018). The magnitude of observed associations has varied across studies and by population subgroups in some studies, including by age, sex, and race or ethnicity (Deng et al., 2022; Sun et al., 2021), while no evidence of effect modification by demographic characteristics was found in others (Yoo et al., 2021). Overall, however, the effect of increased temperatures on mental health outcomes has been most pronounced in older populations and youth (Liu et al., 2021; Basu et al., 2018; Sun et al., 2021).

Studies that have disaggregated mental health events into categories with shared etiologies or specific diagnoses have identified variability in heat susceptibility, although findings are not consistent. While mental health-related hospital visits increased following a heat wave, individuals with schizophrenia were most likely to experience hospitalization and mortality, compared to those with other mental, behavioral, or cognitive disorders (Hansen et al., 2008). When models allowed non-linear temperature-outcome relationships, exposure to both lower and higher than referent temperatures resulted in elevated risks of depressive disorders, anxiety disorders, and schizophrenia in some study populations (Zhang et al., 2020),

while only exposure to higher than referent temperatures was associated with elevated risks of these mental health events as well as substance use disorders and dementia in others (Yoo et al., 2021). Other research did not find evidence of non-linear associations between ambient temperature and mental health outcomes and suggested that the highest risks associated with higher temperatures were for developmental disorders and schizophrenia (Bundo et al., 2021). Not only are individuals at increased risk of mental health events following extreme temperatures, but people with mental health disorders are at higher risk of heat-related mortality (Cusack et al., 2010; Stafoggia et al., 2008).

Several potential mechanisms through which ambient temperature affects mental health have been hypothesized. Löhmus (2018) suggests that heat stress is associated with increased secretion and circulation of hormones such as adrenaline, noradrenaline, cortisol, serotonin, and dopamine and highlights the involvement of mood-related hormones in thermoregulatory processes in the body. Other work suggests that increasing temperatures result in disrupted sleep, leading to mental health effects (Mullins & White, 2019). Increasing body temperature may also have direct physiological influence on the brain via oxygen delivery and an increased risk of edema and swollen nerve cells (Löhmus, 2018).

The role of socioeconomic status in mental health disorders has been well studied from the perspective of social-psychological theory. Past work has demonstrated that vulnerability to heat exposure varies regionally based on adaptation measures, population density, socioeconomic status, and access to health services (Löhmus, 2018). Mullins & White (2019) propose several mechanisms through which socioeconomic status may influence the association between heat exposure and mental health outcomes, including accessibility of air conditioning, availability of mental health care providers, varying insurance coverage of mental health services, and income. Evaluation of effect modification by socioeconomic status at the city level has indicated that lower income cities experience stronger associations between heat and certain heat-sensitive conditions (Xu et al., 2020). However, the role of socioeconomic status in the epidemiologic association between heat exposure and acute mental health events remains understudied.

Much of the existing work examining the linkage of temperature and mental health focuses on adult populations; the effects of ambient heat on pediatric mental health outcomes have received comparatively little focus. Some evidence suggests a positive effect of increasing temperature and humidity on mental health events among youth (Vida et al., 2018), although effects are inconsistent across other studies (Uibel et al., 2022). The burden of mental health disorders among youth is increasing in the US; mental health events resulting in emergency room visits, hours spent in the ED due to mental health-related visits, costs associated with mental health ED usage, and the proportion of emergency room visits attributable to mental health are increasing in the US (Abrams et al., 2022; Hoffmann et al., 2019; Sheridan et al., 2015). Furthermore, while previous work has shown that increases in mental health emergency room visits is disproportionately higher among children belonging to racialized minority groups, less research has focused on the role of socioeconomic status in pediatric mental health burden (Abrams et al., 2022).

This study aimed to estimate the association between exposure to ambient temperature and acute mental health outcomes in children aged 5 to 17 in Los Angeles County, California during 2005-2019 and to further assess whether associations were modified by socioeconomic status. We hypothesized that increasing ambient temperature is associated with an increased risk of acute mental health events and that this effect is stronger among individuals with lower socioeconomic status.

Methods

Study Design

A time-stratified case-crossover study was used to explore the association between ambient temperature and acute mental health events, as measured by visits to pediatric emergency rooms.

Data Sources

Mental health-related emergency room visit records by patients aged 5-17 years between January 1, 2005 and December 31, 2019 were obtained from the California Office of Statewide Health Planning and Development. Records included the following variables relevant to the current study: admit date, ZIP code of patient residence, hospital name, ZIP code of hospital location, primary and secondary International Classification of Disease (ICD) diagnosis codes, and method of payment for the visit. Visits were included if both the ZIP code of the patient and the hospital where they sought care were located in LA County, California.

Daily mean, maximum, and minimum temperature and daily mean, maximum, and minimum relative humidity values at the Los Angeles International Airport weather station were obtained from the National Oceanic and Atmospheric Administration's (NOAA) National Center for Environmental Information (NCEI) Integrated Surface Database (NCEI, 2022).

Mental Health Outcomes

Mental health outcomes were defined by ICD Ninth Revision (ICD-9) and ICD Tenth Revision (ICD-10) codes (CMS, 2022) into nine categories: attention deficit disorders, anxiety disorders, cognitive disorders, developmental disorders, impulse control disorders, mood disorders, psychotic disorders, substance use disorders, and suicide and self-harm (see specific definitions in Appendix 1). These categories were modified from the Child and Adolescent Mental Health Disorders Classification System

published by the Children's Hospital Association and follow categories of mental health ED visits adapted from Yoo et al. (2021) and Thilakaratne et al. (2020).

Mental health visits for each category were identified by presence of a primary ICD code of interest ('primary diagnosis'), meaning that the diagnosing physician indicated the diagnosis as the primary reason for the visit, and by presence of a primary or secondary ICD code of interest ('any diagnosis'). In October of 2015, US hospitals transitioned from ICD-9 codes to ICD-10 codes, a change intended to provide improved accuracy and detail in diagnoses. To determine if the updated ICD codes substantially varied outcome ascertainment, time series plots of the daily counts for each category were generated and evaluated for substantial deviations from expected trends.

Statistical Analysis

The case-crossover design allows the comparison of the likelihood of an emergency department visit on the reported day with the likelihood on selected control days and inherently controls for individual-level confounders, such as age, sex, and socioeconomic status, by design. For each visit, control days were selected from the same day of week, month, and calendar year as the observed case day; as such, all days in seven-day intervals of the case day within the same month were considered control days. Stratified analyses were conducted to evaluate effect measure modification by payor status. Payor status was assessed using a binary categorization, to compare Medicaid-insured patients and those covered by private insurance. Medi-Cal, the state of California's Medicaid program, covers emergency and mental health services for children whose family income would be classified as low or very low. Other payor status, including self-pay, were not included in the stratified analysis.

Conditional logistic regression models were fit to estimate associations between mean and maximum daily temperatures and the nine categories of mental health ED visits. Temperature terms were modeled flexibly using a natural cubic spline with three degrees of freedom. The effects of 0-, 1-, 2-, and 3-day moving average temperature lags and multilag cumulative effects were explored. Mean daily relative

humidity, a time-varying potential confounder of the association between temperature and health outcomes, was modeled (Ding et al., 2016). For each model with lagged exposure, a corresponding 0-, 1-, 2- and 3-day moving average lag was applied to relative humidity. Odds ratios reflecting the cumulative effect of exposure to the 90^{th} percentile of daily mean and maximum temperature compared to the referent, defined as the median daily mean and maximum temperature, were obtained using the dlnm package (Gasparrini, 2011).

Results

Temperature, both daily mean and maximum, and relative humidity exhibited clear seasonal oscillations over the study period, peaking in summer months and lowest in winter months (Figure 1). Daily mean temperatures ranged from 7.2 to 30.3 degrees Celsius, and the average daily mean temperature was 17.3 degrees (standard deviation = 3.4). Daily maximum temperatures ranged from 11.1 to 39.4 degrees Celsius, and the average maximum temperature was 21.0 degrees C (standard deviation = 4.1) (Table 1).

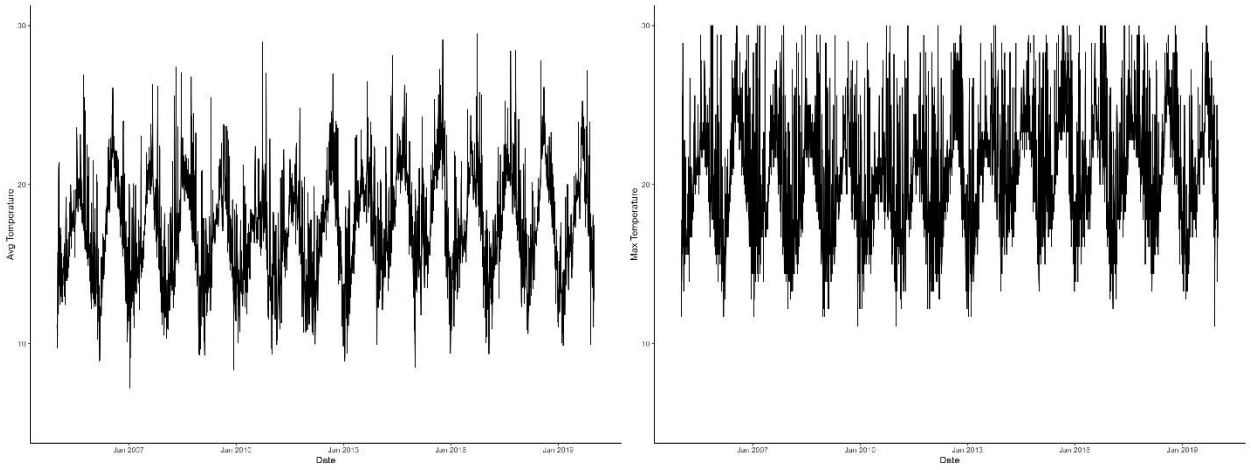

Figure 1. Time series plots of daily mean temperature and maximum temperature measurements

Table 1. Summary statistics for meteorological covariates

Meteorological data	**Mean (SD)**	**Percentile**		
		25th	**50th**	**75th**
Mean temperature (˚C)	17.3 (3.4)	14.9	17.2	19.7
Maximum temperature (˚C)	21.0 (4.1)	18.3	20.6	23.3
Relative humidity (%)	68.3 (15.7)	63.4	72.7	78.4

There were 536,446 total pediatric mental health emergency department visits over the study period, with an average of 146.1 visits per day. Total visit counts increased between 2005 and 2019 but oscillated seasonally within each year (Figure 2). In October 2015, hospital systems switched from ICD-9

to ICD-10 diagnosis codes, resulting in notably disrupted trends in ED visits over the study period for developmental disorders and psychotic disorders. Relatively less perturbation was observed in longitudinally increasing ED visit counts for attention deficit, anxiety, impulse control, and substance use disorders.

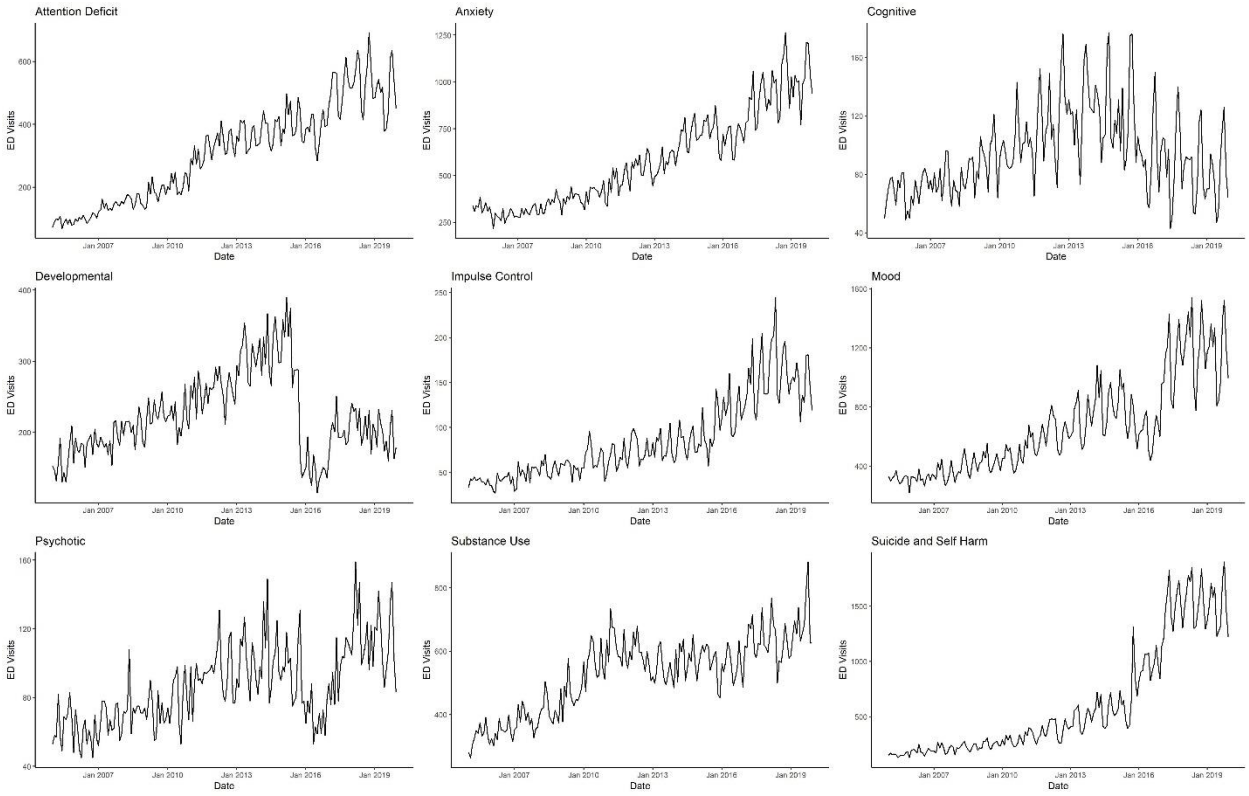

Figure 2. Time series plots of monthly emergency room visit counts by mental health diagnosis in ED.

Patients were on average 13.7 years old (standard deviation: 3.2) at ED visit and 51.2% were female. 46.7% of visits were covered by public insurance, compared to 8.6% using self-pay or 44.6% by other insurance, including private insurance coverage. Total numbers of patient visits and proportions of payor status varied among outcome groups (Table 2).

Table 2. Study population of children aged 5-17 in LA County between 2005 and 2019

	Primary diagnosis	**Any diagnosis**
Attention deficit disorders	n = 2,575	n = 55,535
Age (mean, std)	11.0, 3.3	12.3, 3.3
Medi-Cal (n, %)	1,488 (47.8%)	27,044 (48.7%)
Private Insurance (n, %)	856 (33.2%)	26,544 (47.8%)
Daily Visit Count (mean)	0.47	10.1
Anxiety	n = 42,890	n = 104,329
Age (mean, std)	14.3, 2.6	14.4, 2.6
Medi-Cal (n, %)	19,832 (46.2%)	47,604 (45.6%)
Private Insurance (n, %)	18,507 (43.1%)	48,727 (46.7%)
Daily Visit Count (mean)	7.8	19.0
Cognitive disorders	n = 7,862	n = 17,054
Age (mean, std)	13.1, 3.3	12.5, 3.6
Medi-Cal (n, %)	2,595 (33.0%)	7,025 (41.2%)
Private Insurance (n, %)	4,720 (60.0%)	9,074 (53.2%)
Daily Visit Count (mean)	1.4	3.1
Developmental disorders	n = 5,047	n = 40,237
Age (mean, std)	13.0, 3.5	11.2, 3.9
Medi-Cal (n, %)	2.459 (48.7%)	27,118 (67.4%)
Private Insurance (n, %)	2.031 (40.2%)	11,416 (28.4%)
Daily Visit Count (mean)	0.9	7.3
Impulse control disorders	n = 7,638	n = 15,500
Age (mean, std)	12.2 (3.4)	12.6 (3.3)
Medi-Cal (n, %)	4,106 (53.8%)	8,363 (54.0%)
Private Insurance (n, %)	2,837 (37.1%)	6,043 (39.0%)
Daily Visit Count (mean)	0.6	1.4
Mood disorders	n = 60,765	n = 118,989
Age (mean, std)	14.5, 2.1	14.7, 2.1
Medi-Cal (n, %)	27,971 (46.0%)	55,215 (46.4%)
Private Insurance (n, %)	27,272 (44.9%)	55,204 (46.4%)
Daily Visit Count (mean)	11.3	22.2
Psychotic disorders	n = 9,185	n = 15,573
Age (mean, std)	14.9, 2.4	14.8, 2.5
Medi-Cal (n, %)	4,352 (47.4%)	7,748 (49.8%)
Private Insurance (n, %)	3,332 (36.3%)	5,850 (37.6%)
Daily Visit Count (mean)	1.7	2.8
Substance use disorders	n = 39,689	n = 94,740
Age (mean, std)	15.6, 1.4	15.7, 1.5
Medi-Cal (n, %)	14,367 (36.2%)	37,959 (40.1%)
Private Insurance (n, %)	18,554 (46.7%)	42,791 (45.2%)
Daily Visit Count (mean)	7.2	17.3
Suicide or self-harm	n = 41,440	n = 110,884
Age (mean, std)	13.5, 3.2	14.0, 2.9
Medi-Cal (n, %)	19,521 (47.1%)	51,409 (46.4%)
Private Insurance (n, %)	19,758 (47.7%)	53,477 (48.2%)
Daily Visit Count (mean)	5.4	14.6

The effect of exposure to the 90th percentile of daily mean temperature compared to the median increased the odds of ED visits for all studied outcomes, although the magnitude of the effect varied across outcomes (Table 3). The cumulative effect of daily mean temperatures across lag days 0, 1, and 2 was most pronounced for suicide and self-harm and cognitive disorders and only statistically significant for anxiety (OR: 1.08 CI: 1.01, 1.16), cognitive (OR: 1.25, CI: 1.09, 1.45), mood (OR: 1.13, CI: 1.06, 1.21), and suicide and self-harm (OR: 1.19, CI: 1.11, 1.27) disorders. There was no evidence that effects differed across 0, 1, or 2-day individual lags (Table 3).

Table 3. Effect estimates comparing the odds of ED visit at the 90th percentile of maximum daily temperature to the median recorded maximum temperature. Temperature exposure is examined at same-day temperature (Lag 0), 1 day of lag, 2 days of lag, the average of 0, 1, and 2 days of lag, and for the cumulative effect of a 3-day lag.

Outcome	**Lag 0**	**Lag 1**	**Lag 2**	**3-Day Average Lag**	**Cumulative Effect**
Attention Deficit Disorders	1.05 (1.01, 1.09)	1.06 (1.03, 1.11)	1.07 (1.03, 1.11)	1.07 (1.03, 1.11)	1.07 (0.97, 1.17)
Anxiety Disorders	1.08 (1.05, 1.11)	1.08 (1.05, 1.11)	1.08 (1.05, 1.11)	1.08 (1.05, 1.11)	1.08 (1.01, 1.16)
Cognitive Disorders	1.07 (1.00, 1.15)	1.09 (1.01, 1.16)	1.08 (1.01, 1.16)	1.09 (1.01, 1.16)	1.25 (1.09, 1.45)
Developmental Disorders	1.03 (0.98, 1.08)	1.05 (1.00, 1.10)	1.05 (1.00, 1.10)	1.05 (1.00, 1.10)	1.01 (0.92, 1.12)
Impulse Control Disorders	1.02 (0.95, 1.10)	1.01 (0.94, 1.08)	1.01 (0.94, 1.08)	1.01 (0.94, 1.08)	1.01 (0.86, 1.18)
Mood Disorders	1.07 (1.04, 1.09)	1.06 (1.04, 1.09)	1.06 (1.04, 1.09)	1.06 (1.04, 1.09)	1.13 (1.06, 1.21)
Psychotic Disorders	1.06 (0.99, 1.14)	1.07 (0.99, 1.14)	1.07 (0.99, 1.14)	1.07 (0.99, 1.14)	1.07 (0.92, 1.24)
Substance Use Disorders	1.01 (0.98, 1.04)	1.01 (0.98, 1.04)	1.01 (0.98, 1.04)	1.01 (0.98, 1.04)	1.01 (0.94, 1.09)
Suicide and Self Harm	1.08 (1.05, 1.11)	1.07 (1.04, 1.10)	1.07 (1.04, 1.10)	1.07 (1.04, 1.10)	1.19 (1.11, 1.27)

Overall, positive associations between temperature exposure and mental health outcomes were observed when considering the full exposure-response curve from the models (Figure 3, showing 3-day cumulative effects). Some associations appeared linear. For example, for suicide and self-harm, higher than referent temperatures were associated with an increased odds of ED visits and lower than referent temperatures were similarly associated with reduced odds of ED visits. There was some evidence of nonlinear associations between temperature exposure and other mental health outcomes. For example, for cognitive disorders, the increasing odds of ED visits with increasing temperatures appeared to plateau at higher temperatures (e.g. >20 C). Some evidence of non-linear associations held when outcomes were stratified by payor status (Figure 4).

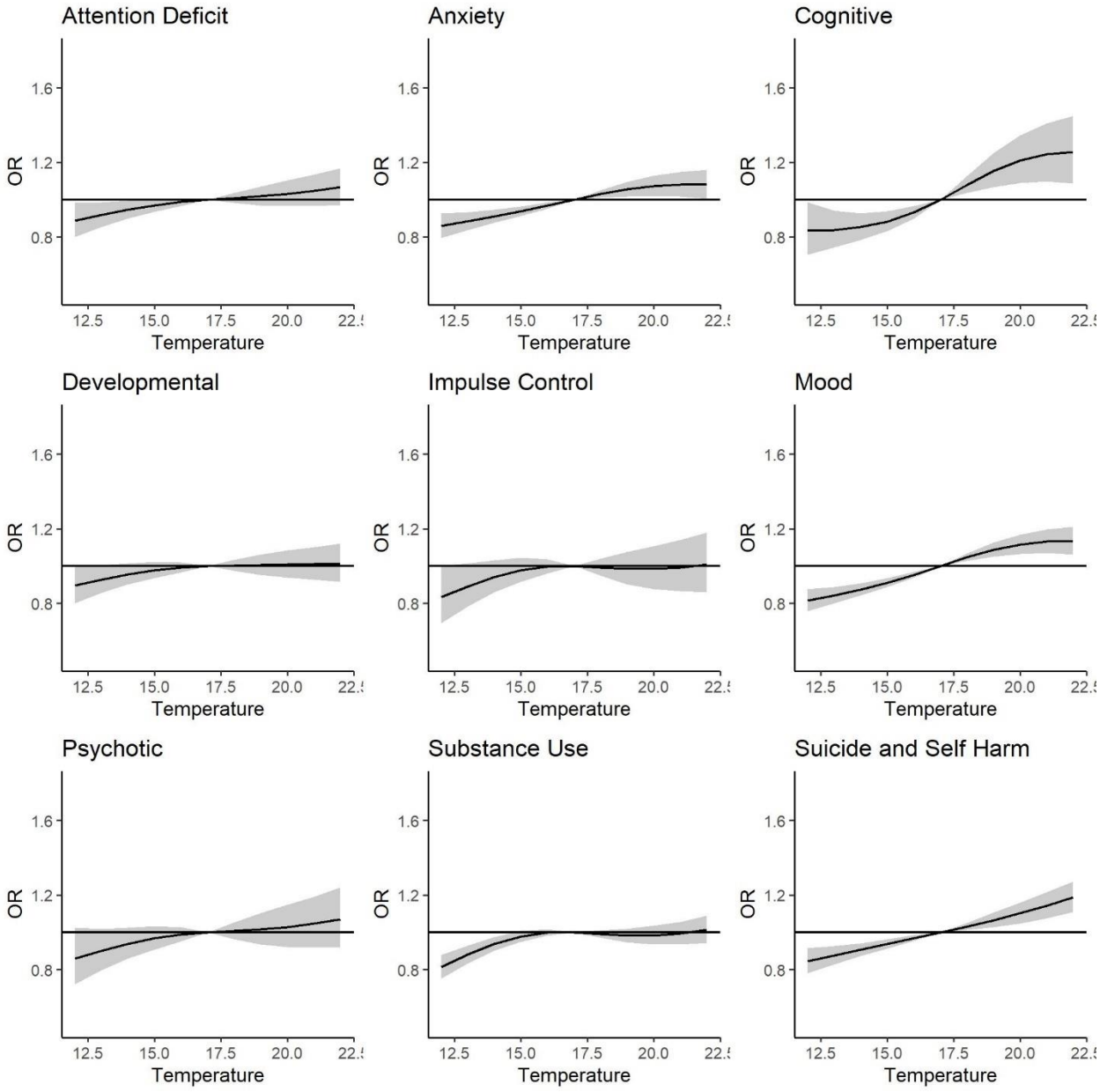

Figure 3. Estimated 3-day cumulative exposure-outcome curve for mean daily temperature and mental health outcomes. The referent is 17 degrees, the median value of mean daily temperature and the range displayed is the 5th – 95th percentile of mean daily temperature.

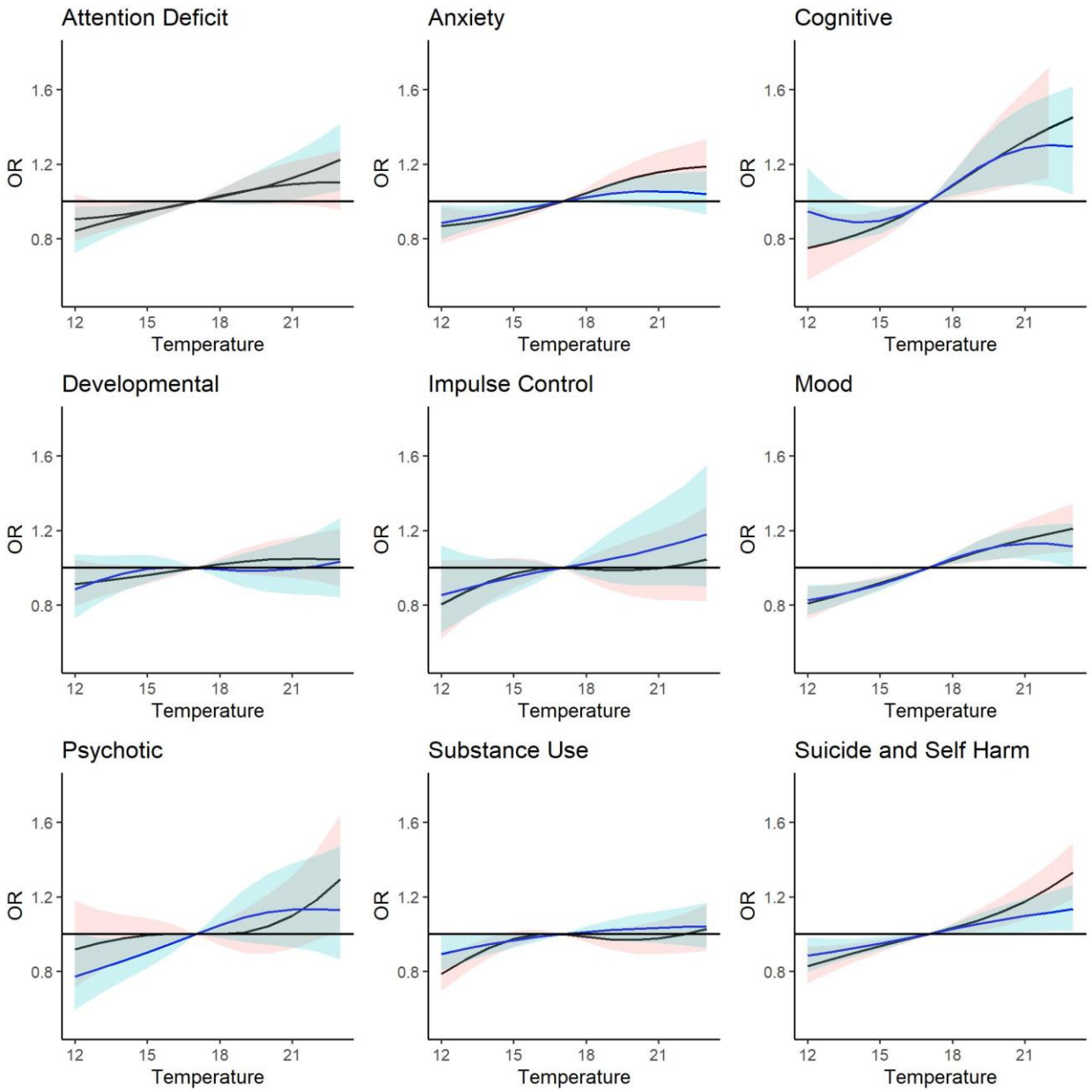

Figure 4. Estimated 3-day cumulative exposure-outcome curve for mean daily temperature and mental health outcomes, stratified by insurance type: Medi-Cal (red) or private (blue). The referent is 17 degrees, the median value of mean daily temperature and the range displayed is the 5^{th} – 95^{th} percentile of mean daily temperature.

Stratification by payor-status indicated some effect measure modification among the outcomes. When evaluating mean daily temperature, there was no considerable difference in effect estimates between Medi-Cal and private insurance strata for some outcomes, whereas for attention deficit, anxiety,

cognitive, mood, and suicide and self-harm disorders, the cumulative effect of 90th compared to 50th percentile mean daily temperature was slightly stronger for patient visits covered by Medi-Cal (Figure 5). These differences were not observed when using daily maximum temperature as the exposure, for which payor status-stratified effect estimates were more similar for each outcome.

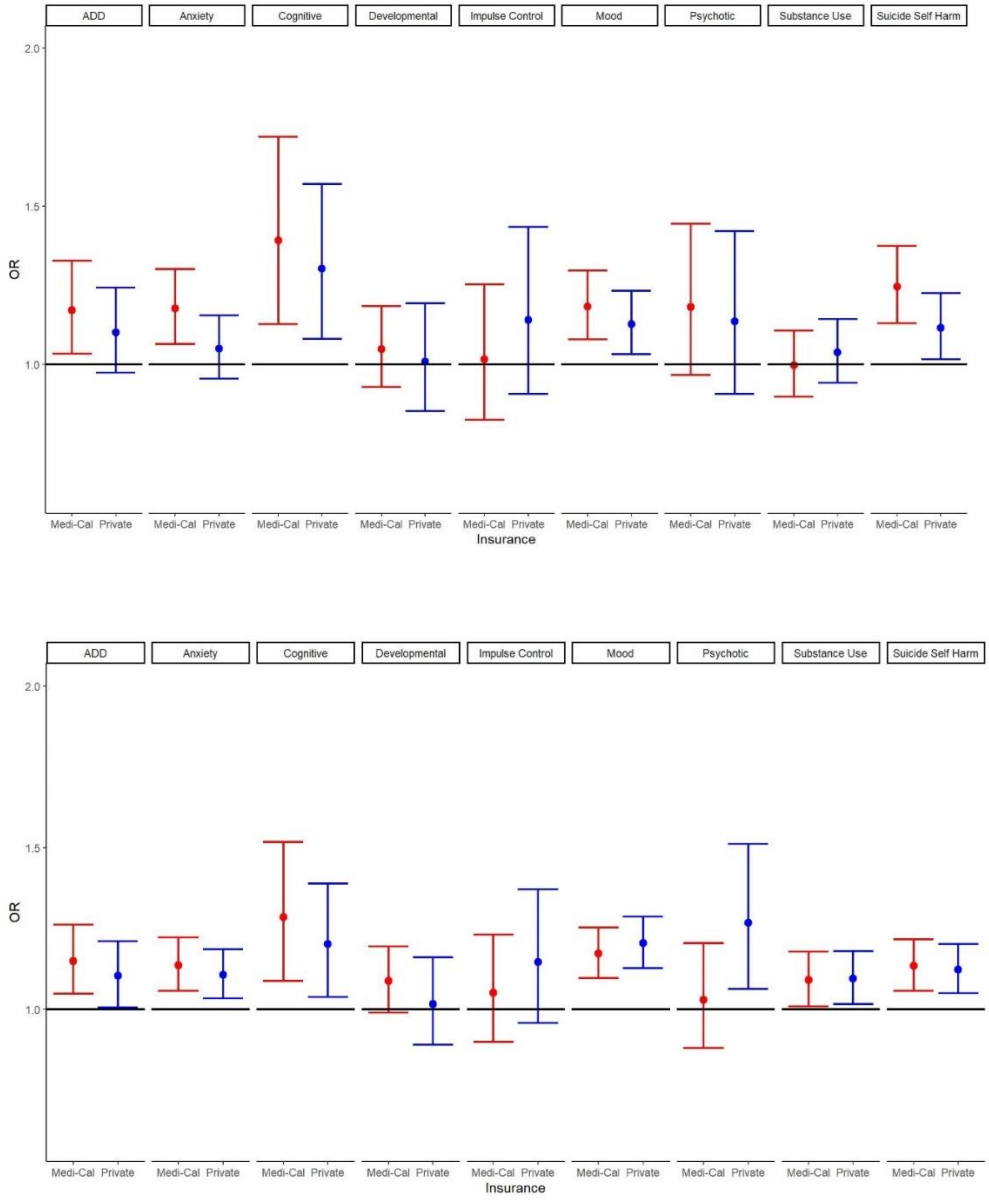

Figure 5. (upper) Odds ratio and 95% confidence interval estimates for the 3-day cumulative effect of mean daily temperature on the odds of ED visit by mental health outcome. (lower) Odds ratio and 95% confidence interval estimates for the 3-day cumulative effect of maximum daily temperature on the odds of ED visit by mental health outcome.

Discussion

This study explored the relationship between temperature and pediatric mental health outcomes, adding evidence of association between ambient heat and emergency room visits for suicide and self-harm, anxiety, cognitive, and mood disorders among youth, and finding inconclusive evidence of association between temperature and attention deficit, developmental, and substance use disorders. Mental health related ED visits in LA County, CA increased in number over the interval 2005 to 2019. There was some evidence of effect measure modification by individual-level socioeconomic status as indicated by payor status, with slightly higher cumulative effects of mean daily temperature among those covered by Medi-Cal compared to those covered by private insurance for attention deficit, anxiety, cognitive, mood, and suicide and self-harm disorders. However, effect measure modification was not consistently identified among mental health outcomes when daily maximum temperature was the exposure.

The result that suicide and self-harm emergency room visits increased following exposure to higher ambient temperature is consistent with previous findings. In a study of the California population above 6 years old, an increased risk of self-injury and suicide was associated 90^{th} percentile heat exposure (Basu et al., 2018). The trend of positive association between heat exposure and mood and anxiety disorders is also consistent with previous findings. In a study of mental health-related emergency room visits in New York State, exposure to extreme heat (defined as 27.1 degrees Celsius) was associated with increased risk of emergency room visits for mood and anxiety disorders (Yoo et al., 2021). However, while Yoo et al. (2021) also concluded transient extreme heat exposures increased the risk of substance abuse, this study did not find strong evidence of increased visits for substance use. Furthermore, while previous research has also identified increased risk of developmental disorder ED visits in response to high temperatures (Bundo et al., 2021), this study found little evidence that developmental disorders were heat sensitive. It is possible that outcome ascertainment for developmental disorders was hindered by the transition between ICD-9 and ICD-10 during the study period. Time-series plots of ED visits for developmental disorders

indicate an alteration from expected increases in visit counts, potentially influencing the effect estimates obtained in this study.

We did not find strong evidence of effect differences for up to a 3-day lag in temperature exposure, which is consistent with previous studies in adult populations; Nori-Sarma et al. (2022) did not find evidence of lagged exposure in an analysis of ambient heat exposure on mental health-related ED visits in insured US adults and Basu et al. (2018) found that same-day lags resulted in best model fits in a study of mental health emergency room visits in California. Although not specific to mental health, one analysis of pediatric emergency room visits found that most visits occurred later in the day, after 5pm, reducing the potential for a same-day lag to misclassify exposure as it would if an early-morning emergency room visit reflected a 1-day lagged exposure (Ali et al., 2012).

This study adds evidence of the cumulative effect of temperature on acute pediatric mental health events. Where previous research explored associations between ambient temperature and mental health outcomes, the specific effects in youth populations remained understudied. This study's strengths include its 14-year study period. Furthermore, modeling temperature and relative humidity nonlinearly allows flexibility in the association, accounting for the potential effect differences at extreme temperatures relative to the median. Additionally, the case-crossover study design addressed concerns of individual confounding by design as cases are considered their own controls.

This study also had several important limitations. First, LA County, California covers approximately 4,000 square miles and ranges from coastal landscape inland. Meteorologic data in this study were obtained from a single measurement facility located within LA County. However, there is concern that this mechanism of exposure assignment may result in misclassification if there is spatial heterogeneity in temperature and relative humidity experienced by the study population. Further, the interaction between characteristics of the built environment and exposure to heat such as the urban heat island effect, may also contribute to varying exposures.

Second, this study controlled for relative humidity as an *a priori* confounder. Other studies have incorporated additional meteorological factors, including sun radiation, heat index, and daily precipitation, in addition to temperature and relative humidity and ambient air pollutants, including carbon monoxide and nitrogen dioxide, in analyses of mental health events (Deng et al., 2016; Yoo et al., 2021; Thilakaratne et al., 2020).

Third, socioeconomic status as a construct is difficult to measure and payor status may be an incomplete indicator of the individual effects. As the outcome data here were derived from emergency care seeking, there is the possibility of selection bias, in that only a subset of children attended the ED for an acute mental health event and differential selection bias if ED entry varied by income, health knowledge, immigration status, or other variable that may be related to payor status. Vulnerability to temperature-sensitive illnesses is modified by housing in a study of cardiovascular mortality (Saucy et al., 2021). Furthermore, there are numerous ways to conceptualize socioeconomic status at a household- or neighborhood-level, which may also influence the association between temperature exposure and mental health events. LA County is the largest county in the US by population and whose population is divided by income inequality, levels of unemployment and educational attainment (US Census, 2018).

It is also important to note that emergency department visits reflect relatively severe outcomes; there is likely underrepresentation of pediatric mental health burden among emergency room visits as many mental health events may not require emergency care. Previous work exploring self-reported mental health found increasing risk of reporting poor mental health associated with increasing temperatures (Li et al., 2020). Future work should explore the frequency of visits to multiple mental health services, in addition to hospital-based emergency departments.

Conclusion

This study examined the association between ambient heat exposure and acute mental health events among children aged 5-17 in LA County, California and evaluated individual socioeconomic status as an effect measure modifier. The findings suggest that the cumulative effect of increasing mean temperature on mental health-related emergency department visits is positive for suicide and self-harm and anxiety, cognitive, and mood disorders. Furthermore, assessment of individual socioeconomic status suggests that these associations for attention deficit, anxiety, cognitive, mood, and suicide and self-harm disorders are stronger among children covered by California's Medicaid program compared to those covered by private insurance. Effect measure modification was not consistently identified among other mental health outcomes.

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Appendix

Appendix 1. ICD-9 and ICD-10 codes used for exposure specification.

Category	**ICD-9 Codes**	**ICD-10 Codes**
Attention Deficit Disorders	314	F90.0 – F90.2 F90.8 – F90.9
Anxiety Disorders	300 308 – 309 313.0-313.83	F40 – F43 F93.0 F94.0
Cognitive Disorders	290 293 – 294 310 331	F01.5 F02.8 F03.9 F04 – F06 F07.8 G30 – G31
Developmental Disorders	307 315 V40 317 – 319	F78 – F81 F98.5 F88 – F89 F70 – F73
Impulse Control Disorders	312	F63 F91
Mood Disorders	296 311 300.4	F30 – F34 F53.0 O90.6
Psychotic Disorders	295 297 298	F53.1 F06 F20 F22 – F25 F29
Substance Use Disorders	779.5 655.4 655.5 760.7 648.3 649.0 291 – 292 303 – 305	F10 – F19 O35.4XX O35.5XX P04.1 P04.3 – P04.4 P96.1 O99.310-O99.315 O99.320-O99.325 O99.330-O99.333 O99.34
Suicide/Self-Harm	E950-E959 V62.84	T1491 T36 – T50 T51 – T60 T71.112, T71.122, T71.133, T71.152, T71.162, T71.192, T71.222, T71.232 X71-X83 R45.851