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Caroline Olson Date

**The Effect of Ambient Air Pollution and Temperature on Acute Pediatric Mental Health Outcomes in Los Angeles, CA:
A Case-Crossover Study**

By

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Master of Public Health

Environmental Health

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The Effect of Ambient Air Pollution and Temperature on Acute Pediatric Mental Health Outcomes in Los Angeles, CA: A Case-Crossover Study

By

Caroline Ellis Olson
B.S., Emory University, 2020

Advisor: Noah Scovronick, Ph.D., M.S.

An abstract of
a thesis submitted to the Faculty of the
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2021

Abstract

The Effect of Ambient Air Pollution and Temperature on Acute Pediatric Mental Health Outcomes in Los Angeles, CA:
A Case-Crossover Study

By Caroline Olson

Purpose: Previous epidemiologic studies support an association between ambient air pollutants and mental health events. However, further research should be conducted to assess whether there is a measurable effect of pollutants on the mental health of children, who may be more vulnerable to the physiologic effects of pollutants. Similarly, little is known about the effect of temperature on children's mental health.

Methods: A case-crossover study was conducted using psychiatric emergency department visits from 2005 to 2014 in Los Angeles, California among children aged 5 to 17 (n=233,043). Concentrations of three air pollutants (NO_2, $PM_{2.5}$, and O_3) and ambient maximum temperature were derived from the U.S. EPA's *Community Multiscale Air Quality* (CMAQ) model. Odds ratios were calculated using conditional logistic regression for same-day and 3-day moving averages of daily pollutant concentrations and daily maximum temperature.

Results: Positive associations were only found between NO_2 and two categories of mental health disorder: all mental health disorders and affective disorders. No positive associations were detected between ozone or $PM_{2.5}$ and mental health outcomes. Strong positive associations were found between maximum temperature and pediatric mental health ED visits; associations were found across all categories and both single day and 3-day lag. No discernible differences were observed between those with public insurance and those with private insurance.

Conclusion: These findings provide mixed evidence to the emerging body of work documenting the association between air pollutants and mental health in children. This is one of the first reports of an association between temperature and children's mental health outcomes.

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Table of Contents

Introduction

Air pollution is nearly ubiquitous; the World Health Organization has estimated that approximately 9 out of every 10 people worldwide are exposed to polluted air, making it one of the most pressing, current environmental health issues (2019). Research has reported that exposure to high levels of ambient air pollution has been associated with many harmful physiological conditions in humans, ranging from respiratory to cardiovascular to neurovascular disease (Siponen et al., 2015; Block, Calderón-Garcidueñas, 2009). Decades of epidemiologic work has established that not only chronic exposure, but short-term exposure to ambient air pollutants has significant adverse health outcomes (Dockery et al., 1993; Samet et al., 2000; Peel et al., 2005). Specifically, the existing literature suggests that short-term exposure to ambient concentrations of ozone, nitrogen oxides, and fine particulate matter ($PM_{2.5}$)- which are among the most common of pollutants (U.S. Environmental Protection Agency, 2020)- is associated with increases in morbidity and mortality (Dockery et al.; Samet et al.; Peel et al.).

Inflammation and oxidative stress within the brain and central nervous system resulting from exposure to polluted air have been implicated in the etiology of a broad range of neurological and psychiatric disorders (Costa et al., 2015; Block, & Calderón-Garcidueñas, 2009). Inflammatory processes are associated with a variety of more specific mental disorders, ranging from aggression to anxiety to depression (Miller and Raison, 2016; Vogelzangs et al., 2013). For these reasons, it has been hypothesized that air pollution is associated with exacerbations of mental health disorders in adults (Khan et al., 2019). Despite the varying make-up of polluted air and the complex mechanisms driving its associated health effects, the general theorized mechanistic pathway is that air pollutants entering the respiratory tract can lead to acute systemic inflammation of the body (Block & Calderón-Garcidueñas, 2009). The resulting neuroinflammation may negatively influence cognition and behavior (Brokamp et al., 2019). Previous studies have shown that short-term exposure to pollutants can affect mental health conditions like sleep, anxiety, and suicide attempts and completions in adults (Kim et al., 2019; Szyszkowicz et al., 2020; Tang et al., 2020).

Though there are reported associations in adults, there is limited research on the psychiatric effects of air pollution in children and youth, despite their potentially elevated sensitivity to both air pollution and mental health impacts (Perera et al., 2016). Children may be more susceptible to air pollution due to both behavioral and developmental aspects (Brockmeyer, S., & D'Angiulli, 2016). They often spend more time outdoors playing and exercising, elevating their risk of exposure. Children also have higher respiration rates for their body size and more vulnerable neurologic and respiratory systems, all of which may put them at higher risk for the effects of pollutants (Brockmeyer, S., & D'Angiulli, 2016). Children may be especially susceptible to neurologic impacts because their brains are still in the process of developing (Brockmeyer, S., & D'Angiulli, 2016).

While recent research supports the biological plausibility of the link between air pollution and children's mental health, there is a paucity of epidemiologic research on the topic. Most epidemiologic studies to date have evaluated the effects of chronic exposure on mental health outcomes or examined neurologic development over time, but only a select number of studies have been conducted to investigate the association between short-term air pollutant exposure and acute psychiatric effects in children (Brokamp et al., 2019; Szyszkowicz et al., 2020; Thilakaratne et al., 2020).

The primary aim of this research is to investigate the association between short-term exposure to ambient air pollutants ($PM_{2.5}$, NO_2, and O_3) and acute mental health events in youth aged 5-17 – identified through emergency department utilization data - in Los Angeles County. We hypothesized that higher levels of pollutants would be associated with an elevated risk of pediatric acute mental health events.

In addition, we further explore the association between ambient temperature and child mental health outcomes. Significant gaps exist in our understanding of the impact of heat exposure on mental health, particularly in children. However, studies suggest that risk of hospital admission in adults for mental health-related reasons increases with higher temperatures, as does risk of suicide (Thompson et al., 2018). A recent statewide study conducted in California showed that increases in mean temperatures was associated with increased in emergency department visits for adult mental health disorders, suicide, and intentional injury, regardless of season (Basu et al., 2018).

As climate change continues to elevate temperatures, as well as contribute to the degradation of air quality worldwide (USGCRP, 2017), the health effects related to both need to be assessed and quantified. This study will be able to provide preliminary data on the association between air pollution and temperature on the mental health of children.

Finally, many environmental health exposures are not distributed equally throughout the population. Most studies on environmental equity link lower socioeconomic status to higher exposures of air pollutants, especially traffic-related air pollution (Harvard, 2009). This has been documented with air pollution associated health outcomes like asthma and cardiovascular disease (Neidell, 2004; Brook et al., 2004). This study aimed to determine if the association between air pollution and mental health is modified by payor status (private insurance vs. state-sponsored insurance, in this case Medi-Cal), which can serve as an indicator for socioeconomic status. This study was conducted in Los Angeles County, CA, which is in the top 2% of least equitable counties by income in the United States (Price & Sommeiller, 2018).

Methods

Study Design

We conducted a time-stratified case-crossover study to explore the possible association between ambient air pollution and temperature with psychiatric Emergency Department (ED) visits in youth aged 5-17.

Exposure data

Daily ambient concentrations (24-hr averages) of three air pollutants (NO_2, O_3, and $PM_{2.5}$) were derived from the U.S. EPA's Community Multiscale Air Quality Modeling System (CMAQ) for each zip code located within Los Angeles County from January 1, 2005 to December 31, 2014. CMAQ is an open-source air quality model that simulates the emissions, chemistry, and physics of the atmosphere for studying air pollution from local to hemispheric scales (*CMAQ Output*, 2021). Daily maximum temperature and maximum dew point were obtained from the same data source.

Health Data

We examined daily counts of mental health-related ED visits of youth aged 5-17 within Los Angeles County, CA from January 1, 2005 to December 31, 2014. This included all emergency departments from all hospitals in Los Angeles County. Only cases with a mental health disorder listed as their primary reason for the ED visit were included. This data was obtained from the California Office of Statewide Health Planning and Development. Only patients with addresses within the limits of Los Angeles County and healthcare facilities within Los Angeles County were considered, as to match the spatiotemporal resolution between exposure and outcome.

We based our fourteen mental health outcome categories on a prior study of trends in ED mental health admission in youth (Lo et al., 2020). These fourteen categories were created using codes from the *International Classification of Diseases, Ninth Revision (ICD-9)* that aligned with groupings for mental health and behavioral disorders by the Healthcare Cost and Utilization Project Clinical Classification Software (CSS). The fourteen individual mental health outcome categories that we explored, and their included ICD-9 codes, are found below in Table 1. Additional information regarding ED visits can be found in *Appendix A* and *B*.

Table 1. Included ICD-9 Codes, adapted from *Lo et al. (2020)*

Outcome	ICD-9 Codes Included
Attention-Deficit	312.00-312.9, 313.81, 314.00-314.9
Adjustment	309.0-309.9
Alcohol	291.0-291.9, 303.00-303.93, 305.00-305.03, 357.5, 425.5, 535.3-535.31, 571.0-571.3, 760.71, 980.0
Anxiety	293.84, 300.00-300.9, 308.0-308.9, 309.81, 313.0-313.83
Cognitive	290.0-290.9, 293.0-293.1, 294.0-294.9, 310.0-310.9, 331.0-331.82, 797
Developmental	307.0-370.9, 315.0-315.9, 317, 318.0-318.2, 319, V40.0-V40.1
Impulse Control	312.3-312.39
Diagnosed in Childhood	299.00-299.91, 307.20-307.7, 309.21, 313.23-313.9
Miscellaneous	293.89-293.9, 300.11-300.82, 302.1-302.9, 306.0-306.9, 307.1-307.89, 310.1, 316, 648.40-648.44
Mood	293.83, 296.00-296.99, 300.4, 311
Personality	301-301.9
Psychotic	293.81-293.82, 295.00-295.95, 297.0-297.9, 298.0-298.9
Substance	292.0-292.9, 304.00-304.93, 305.20-305.93, 648.30-648.34, 655.50-655.53, 760.72-760.75, 779.5, 965.00-965.09, V65.42
Suicide or Intentional Self-Harm	E950.0-E959, V62.84

In our main analyses we consolidated the fourteen mental health outcomes into four larger groups: (1) *all disorders*, (2) *substance disorders*, which included both alcohol-related and substance-related admissions, (3) *affective disorders*, which included anxiety disorders, mood disorders, and suicide (Nepon et al., 2010 & Isometsa, 2014), and *other disorders*, which included all other types of mental health outcomes. In the Appendix, we report associations for all 14 outcomes individually.

Statistical Analyses

The case-crossover design is an appropriate epidemiological approach when both the exposure and the effect are transient, making it a useful tool in air pollution epidemiology (Jaakkola, 2003). In the case-crossover approach, each subject serves as his or her own control. This means that individual-level characteristics like age, sex, and zip code of residence are controlled for by design (Brokamp et al., 2019). However, it is also important to control for other potential time-varying confounders. Therefore, all our models control for dew point and federal holidays. In addition, our main results control for the other pollutants ("multi-pollutant models"), but we also report single-pollutant models in the Appendix. All hazard ratios were estimated using conditional logistic regression, and all effect sizes are reported per inter-quartile range of exposure. There was an assumed linearity in the exposure-response association; this study did not examine non-linear effects.

The effect of air pollution and temperature may have immediate, as well as delayed effects (Xue et al., 2019; Shin et al., 2018) Therefore, we investigated same-day associations (Lag 0) as well as a 3-day moving average (Lag 0-2).

In order to assess potential modification by socioeconomic status, the dataset was stratified by payor status, defined as either *public insurance* (self-pay or Medi-Cal) or *private insurance*. These analyses were conducted using the multi-pollutant models.

All analyses were conducted using the statistical software SAS Studio 3.8 (Gary, NC, 2014). This study was approved by the Institutional Review Board of Emory University.

Results

Pollutants

Descriptive characteristics for ambient pollutants and maximum temperature are shown in *Table 2* and depicted graphically in *Figure 1*. Daily time series for each pollutant and temperature are shown in *Figure 2.* There were strong seasonal effects for each pollutant and temperature. Both NO_2 and $PM_{2.5}$ concentrations were consistently higher in the winter than the summer. Ozone and maximum daily temperature showed seasonal highs during the summer.

Table 2: Statistics of daily values used to calculate environmental exposures. Los Angeles County, CA 2005-2014.

	NO_2 (ppb)	O_3 (ppb)	$PM_{2.5}$ (μg/m³)	Maximum Temp.(C°)
Mean	32.5	41.4	11.1	21.2
Median	31.5	42.2	10.4	21.1
Standard Deviation	10.5	13.1	4.49	4.11
Minimum	6.79	8.11	2.73	11.1
Maximum	76.8	85.9	46.9	40.6

Figure 1. Distributions of atmospheric pollutants and maximum temperature

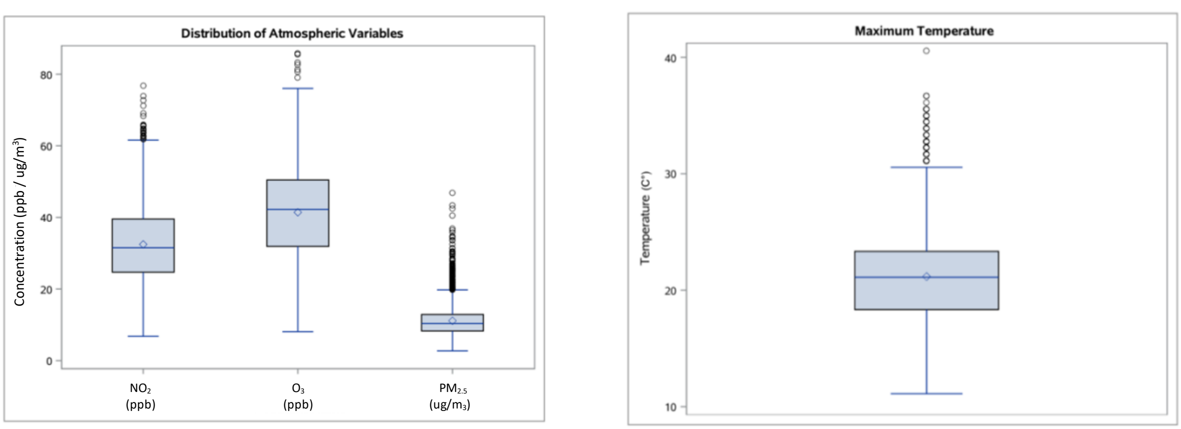
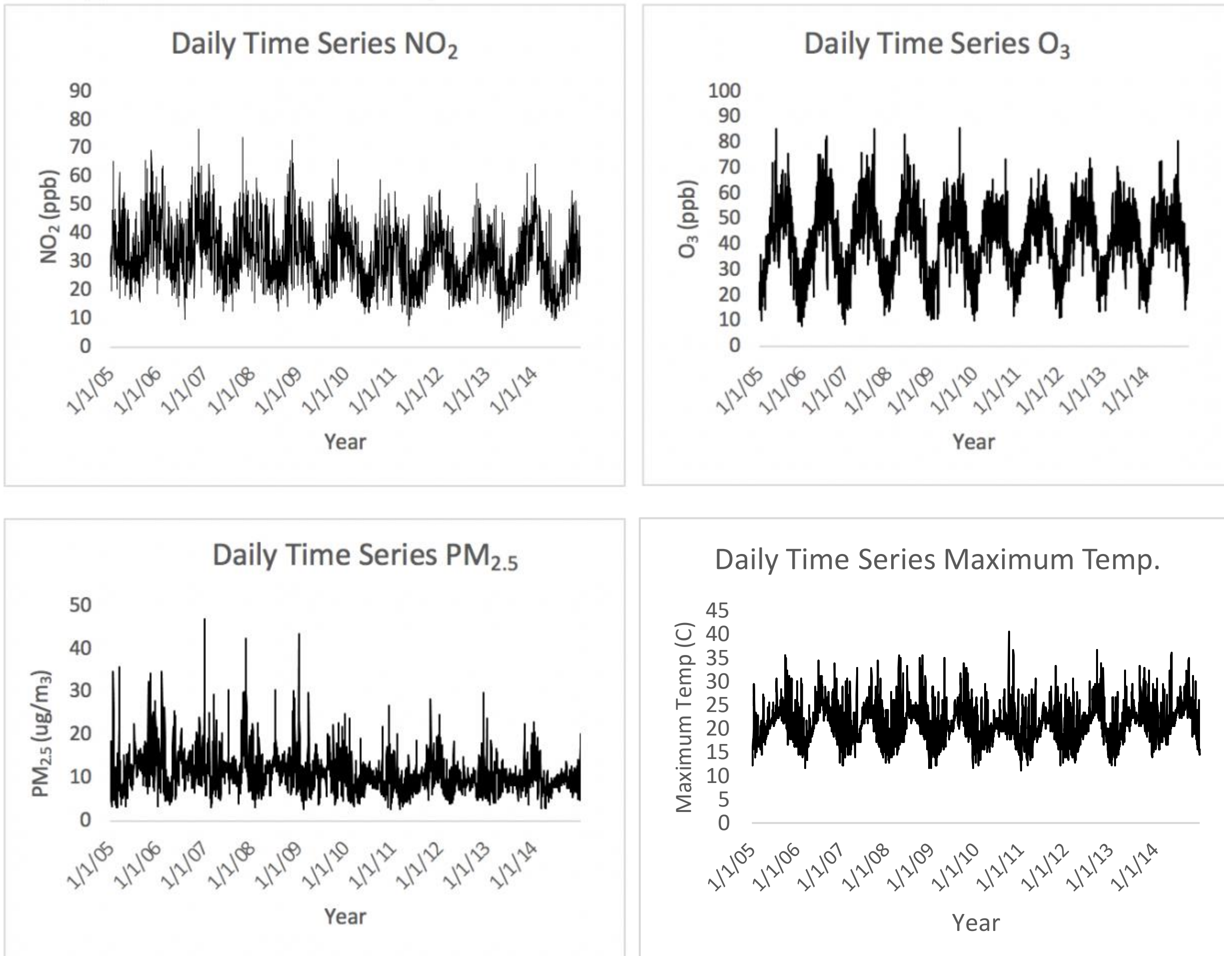


Figure 2. Daily time series of each pollutant and temperature as an average over all zip codes.



During the 9 year study period, there were 233,043 psychiatric ED encounters in children aged 5-17 (*Table* 3). The median age at encounter was 15 y (IQR: 12y, 16y). Among all encounters, 48% were female, 55% were white, and 54.2% were publicly insured.

Table 3. Demographic Summary

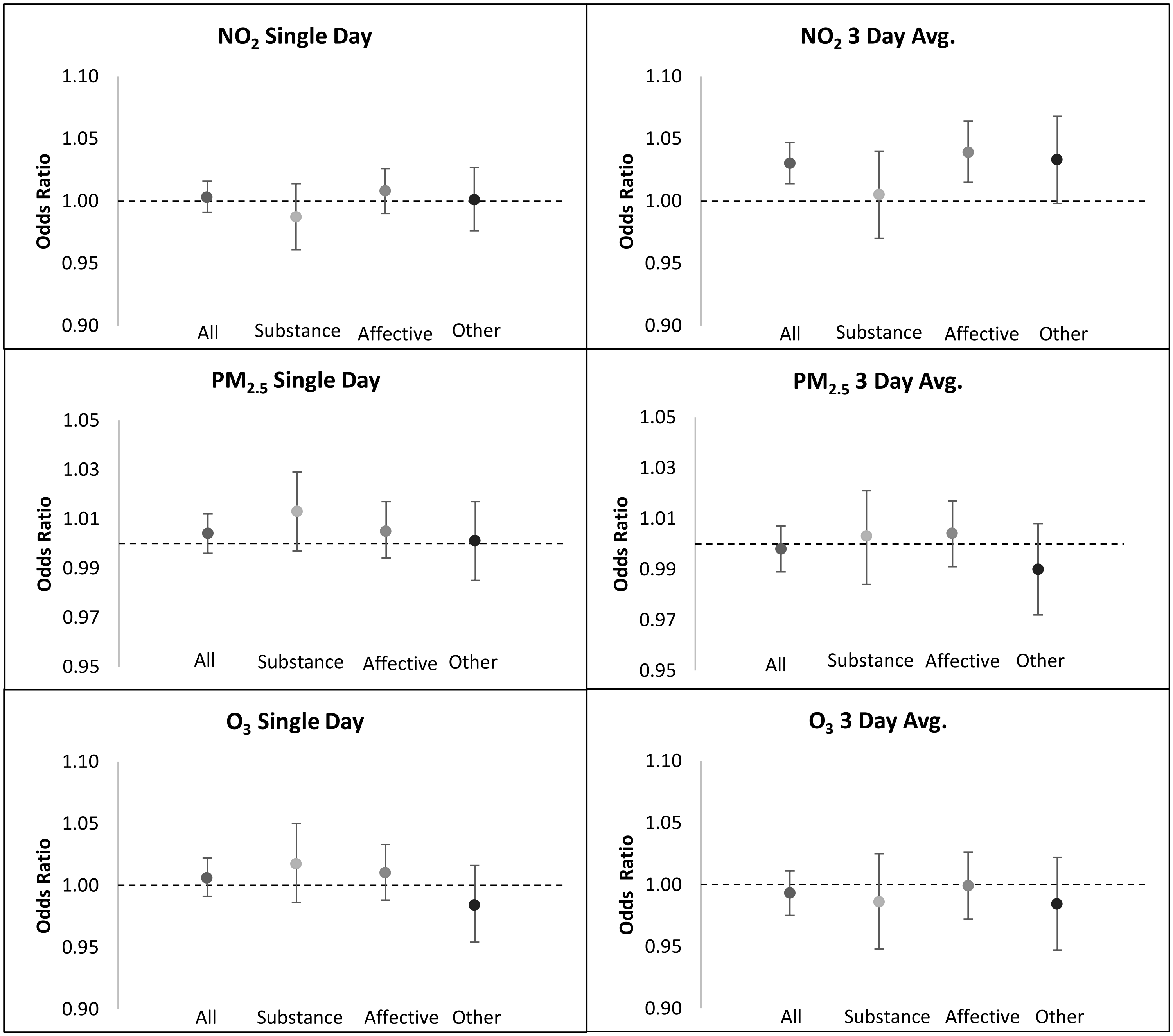
ED Visit Category	n	Avg. Daily ED Visits	Median Age (y)	% Female	% White	% Public Insurance
All	233043	33.4	15 (12, 16)	47.9	54.8	54.2
Substance	53040	7.54	16 (15, 17)	41.1	59.3	50.3
Affective	106585	16.2	15 (13, 16)	61.2	57.5	51.5
Other	108405	9.65	13 (9, 15)	37.3	52.0	56.8

For the same day lag, no pollutants were significantly associated with increased risk of a mental health outcome at the 5% level (Table 4). Most effect sizes were elevated, but not significantly associated. For the three-day moving average, NO_2 was significantly associated with both the *all* and *affective* groups. Ozone and $PM_{2.5}$ were not significantly associated with any of the outcomes at either lag.

Table 4. Results for multi-pollutant model for all mental health outcomes and mental health outcomes by grouping. Odds ratios from conditional logistic regression models are adjusted for temperature, humidity, holidays, and other pollutants and are reported per interquartile range of exposure.

Grouping	**Pollutant**	**Lag**	**OR**	**Lower**	**Upper**	**Lag**	**OR**	**Lower**	**Upper**
All	NO_2	0	1.003	0.991	1.016	**3 Day Avg.**	**1.030**	**1.014**	**1.047**
All	$PM_{2.5}$	0	1.004	0.996	1.012	3 Day Avg.	0.998	0.989	1.007
All	O_3	0	1.006	0.991	1.022	3 Day Avg.	0.993	0.975	1.011
Substance	NO_2	0	0.987	0.961	1.014	3 Day Avg.	1.005	0.970	1.040
Substance	$PM_{2.5}$	0	1.013	0.997	1.029	3 Day Avg.	1.003	0.984	1.021
Substance	O_3	0	1.017	0.986	1.050	3 Day Avg.	0.986	0.948	1.025
Affective	NO_2	0	1.008	0.990	1.026	**3 Day Avg.**	**1.039**	**1.015**	**1.064**
Affective	$PM_{2.5}$	0	1.005	0.994	1.017	3 Day Avg.	1.004	0.991	1.017
Affective	O_3	0	1.010	0.988	1.033	3 Day Avg.	0.999	0.972	1.026
Other	NO_2	0	1.001	0.976	1.027	3 Day Avg.	1.033	0.998	1.068
Other	$PM_{2.5}$	0	1.001	0.985	1.017	3 Day Avg.	0.990	0.972	1.008
Other	O_3	0	0.984	0.954	1.016	3 Day Avg.	0.984	0.947	1.022

Figure 3. Odds ratios for multi-pollutant models organized by pollutant



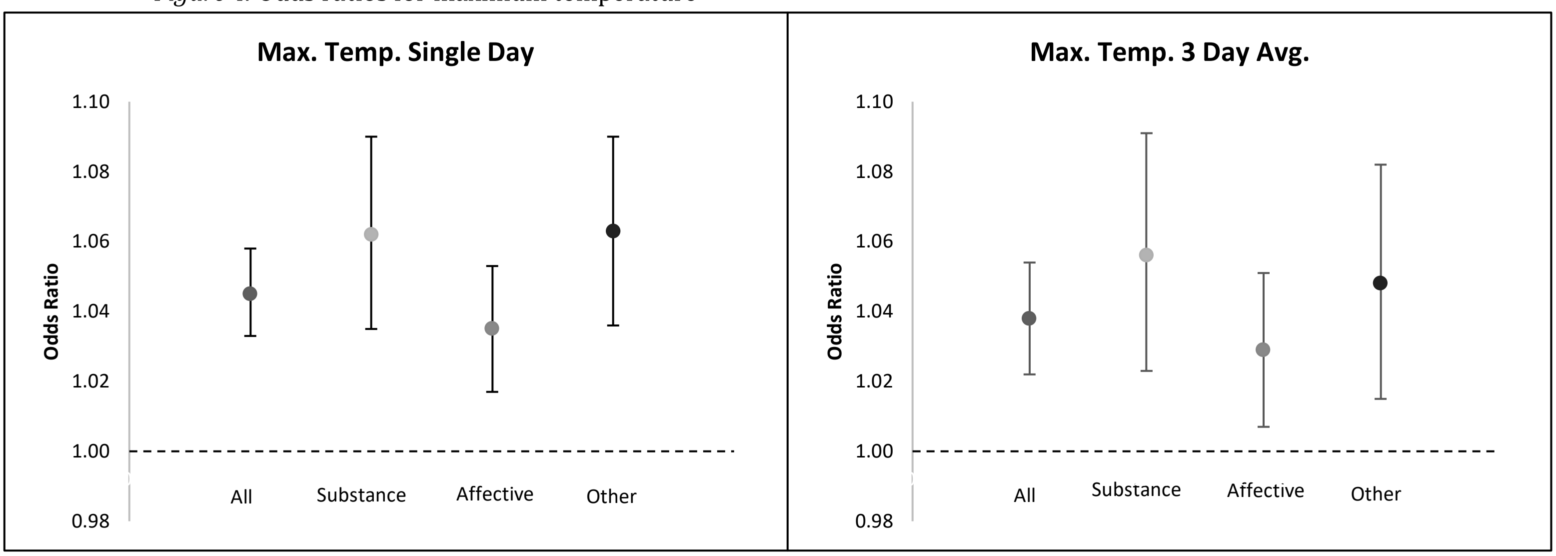
Temperature

Ambient temperature was significantly linearly associated with all four outcome groupings at both lags, as seen in *Table 5* (see *Appendix F* for single-pollutant model results). Odds ratios were relatively similar between single-day and 3-day lag scenarios, though consistently reduced for 3-day lag when compared to single-day exposure. *Figure 4* shows the odds ratios for each mental health grouping and lag.

Table 5. Association between temperature and mental health outcomes reported per interquartile range of exposure. Models control for all three air pollutants.

Grouping	Variable	Lag	OR	Lower	Upper	Lag	OR	Lower	Upper
All	Max. Temp.	0	1.045	1.033	1.058	3 Day Avg.	1.038	1.022	1.054
Substance	Max. Temp.	0	1.062	1.035	1.090	3 Day Avg.	1.056	1.023	1.091
Affective	Max. Temp.	0	1.035	1.017	1.053	3 Day Avg.	1.029	1.007	1.051
Other	Max. Temp.	0	1.063	1.036	1.090	3 Day Avg.	1.048	1.015	1.082

Figure 4. Odds ratios for maximum temperature



Results for single-pollutant models and for the 14 specific mental health outcomes can be found in *Appendix D, E, F,* and *G*.

Payor Status

The patterns of association between air pollution and mental health outcome by insurance type is largely the same between the two groups. As seen in the previous analyses, most significant associations are found with NO_2. With public insurance this includes *all* disorders and *affective* disorders, and for those with private insurance in the *other* category (all 3-day lag). In addition, a significant association was observed between $PM_{2.5}$ and *affective* disorders with a 3-day lag in those with public insurance. Ozone was not associated with any mental health outcome in either group.

Table 6. Effect Modification on each mental health grouping

Grouping	Lag	Pollutant	Public Insurance			Private Insurance		
			RR	Lower	Upper	RR	Lower	Upper
All	0	NO_2	1.007	0.992	1.022	1.005	0.988	1.023
All	0	$PM_{2.5}$	1.004	0.994	1.013	1.006	0.996	1.018
All	0	O_3	1.008	0.988	1.028	1.009	0.986	1.032
All	3 Day Avg.	NO_2	**1.032**	**1.012**	**1.052**	1.023	1.000	1.046
All	3 Day Avg.	$PM_{2.5}$	1.005	0.996	1.014	1.005	0.992	1.017
All	3 Day Avg.	O_3	0.998	0.974	1.022	1.001	0.974	1.029

Grouping	Lag	Pollutant	Public Insurance			Private Insurance		
			RR	Lower	Upper	RR	Lower	Upper
Affective	0	NO_2	1.015	0.993	1.037	1.008	0.984	1.034
Affective	0	$PM_{2.5}$	1.010	0.996	1.025	1.005	0.989	1.021
Affective	0	O_3	1.007	0.979	1.037	1.020	0.987	1.055
Affective	3 Day Avg.	NO_2	**1.060**	**1.031**	**1.090**	1.018	0.985	1.052
Affective	3 Day Avg.	$PM_{2.5}$	**1.019**	**1.003**	**1.036**	1.004	0.986	1.023
Affective	3 Day Avg.	O_3	0.999	0.965	1.035	1.021	0.982	1.063

Grouping	Lag	Pollutant	Public Insurance			Private Insurance		
			RR	Lower	Upper	RR	Lower	Upper
Substance	0	NO_2	1.009	0.976	1.043	0.982	0.947	1.018
Substance	0	$PM_{2.5}$	1.016	0.996	1.037	1.005	0.987	1.023
Substance	0	O_3	1.031	0.987	1.077	1.005	0.961	1.052
Substance	3 Day Avg.	NO_2	1.003	0.961	1.047	1.007	0.962	1.054
Substance	3 Day Avg.	$PM_{2.5}$	1.001	0.979	1.025	1.004	0.980	1.029
Substance	3 Day Avg.	O_3	1.007	0.956	1.062	0.966	0.914	1.022

Grouping	Lag	Pollutant	Public Insurance			Private Insurance		
			RR	Lower	Upper	RR	Lower	Upper
Other	0	NO_2	0.988	0.958	1.019	1.018	0.988	1.048
Other	0	$PM_{2.5}$	0.984	0.965	1.003	1.023	1.000	1.046
Other	0	O_3	0.985	0.945	1.027	0.985	0.939	1.033
Other	3 Day Avg.	NO_2	1.001	0.962	1.042	**1.049**	**1.001**	**1.100**
Other	3 Day Avg.	$PM_{2.5}$	0.984	0.962	1.006	1.012	0.987	1.039
Other	3 Day Avg.	O_3	0.979	0.932	1.029	0.997	0.942	1.055

Discussion

This study utilized a case-crossover design to examine the association between ambient pollutants and temperature and daily pediatric mental health emergency department visits. Additionally, we examined whether there were patterns of effect modification on this association by stratifying the dataset by payor status. Positive associations between mental health outcomes were indicated for NO_2 with a 3-day lag and maximum temperature under both a single day and 3-day lag. No clear differences by payor status were detected.

This study yielded differing results from the two previous studies characterizing the effects of air pollution on children's psychiatric health events through emergency department utilization. In Brokamp et al. (2019), $PM_{2.5}$ was associated with an increase in ED utilization for all mental health outcomes; our study found no association between $PM_{2.5}$ and mental health outcomes of any grouping. This may be due to differences in climate or study population, as it was conducted in Ohio. In Thilakaratne et al. (2020), which was conducted on adults and children in California over much of the same study period, found that violent behavior emergency department visits of children and NO_2 concentrations were positively correlated. We did not test for a particular mental health outcome relating to violence, though we did find that NO_2 was positively associated with affective and all disorders. To our knowledge, this study may be the first to demonstrate the acute effects of heat on the mental health of youth. The paucity of research on this topic, as well as the urgent need to better understand the risks posed to children's mental health presents an opportunity for an emerging field. Further work on the relationship between ambient environmental exposures and mental health is critical, especially as our climate continues to change, making exposure to higher temperatures and concentrations of pollutants more common for some populations.

Our study did share several similarities with Szyszkowicz et al. (2020); both found that NO_2 and $PM_{2.5}$ were positively associated with mental health outcomes in some scenarios depending on lag and subset of the population, whereas ozone was not significantly associated under any scenario. A fundamental similarity between our research and prior research is that the effects of air pollution for acute events are often most prominent with a 3-to-5 day lag time (Sinclair & Tolsma, 2004). The appropriate time frame for assessing the relationship between acute mental health events and air pollution is still being established due to lack of research. This study supports the body of work that shows more prominent associations with air pollution with a 3-day lag than on the same day as the health event.

The major strengths of this study include the large sample size (n= 233,043) and a long study period (Jan 1, 2005 - Dec 31, 2014), which can aid in detecting small effect sizes on health like those often associated with ambient air pollution. Additionally, a large range of mental health disorders were considered. Another strength of this study is the high degree of spatiotemporal resolution of air pollutants. We also were able to control for the effects of other pollutants, as well as for temperature. We attempted to control for the movement of patients within the study by restricting to only those who live within Los Angeles County, as well as restricting the hospitals within Los Angeles.

The results of this study should be considered within the context of several limitations. First, there were several limiting factors relating to our data. Temperature data was collected and applied as an average for all of L.A. county and was not distinguishable by zip code as the pollutant data was. Effects of temperature could be more localized than this study was able to account for. Also, there may not have been enough case counts per day to identify effects on each individual mental health outcome. Though our models were scaled by IQR, they were not scaled by the IQR of each pollutant within a zip code, which would have produced more exact results. Finally, our study used the same ICD-9 codes throughout the study period, however, almost all mental health outcomes increased over time. This may be due to differences in diagnoses over time and the broadening recognition of the signs of poor mental health in children. This could affect the true prevalence of mental health outcomes among children over the time period.

There were several methodological limitations to our data as well. ED visits may not be the best way to gauge mental health within a population. Though it gives useful information about the acute mental health needs of an area, it does not necessarily supply information about chronic mental health effects. Furthermore, many parents may not think to bring their children to a public emergency department for treatment during a mental health crisis. They may either not seek treatment or visit a specialized mental health rehabilitation facility instead. This study did not include scheduled visits to clinicians. Another consideration should be that we did not compare time during the school year vs. outside of the school year, which may impact the mental health of children. Also, we did not examine the differences in mental health outcome among age group. Our age requirements (5y-17y) were quite broad; it is possible that there would be differences in mental health disorders between age groupings. This characteristic should be further researched. Finally, no significant associations were found between ozone or $PM_{2.5}$ and mental health events, but both pollutant levels are highly seasonal. Perhaps an association would be found if examined during warm vs. cold months; a linear relationship was assumed during analyses.

Further work should investigate the relationship between mental health and environmental factors like air pollution and temperature through means other than emergency department visits. Though the emphasis of this study was not on demographic or socioeconomic disparities, future studies should attempt to characterize these effect modifiers so clinical and public health resources can be equitably distributed. These data reinforce the importance of local and regional efforts to reduce ambient air pollutants; perhaps more resources can be allocated to the reduction and control of anthropogenic sources that emit NO_2. Also, this study further highlights the need for an adequate and robust health infrastructure to respond to the broad health effects of elevated temperatures, particularly in youth.

Conclusion

In this study, we explored the relationship between short-term exposure to concentrations of NO_2, O_3, and $PM_{2.5}$(same day and 3-day average) and daily counts of general and grouped pediatric mental health-related emergency department visits in Los Angeles County, CA from 2005 to 2015. For the same day lag, no associations were detected. For the three-day moving average, NO_2 was significantly associated with both *all* and *affective* disorders. Ozone and $PM_{2.5}$ were not associated with any of the outcomes at either lag.

This study also explored the relationship between daily maximum temperature and daily counts of mental health-related emergency department visits in children. Maximum temperature was associated with all types of mental health outcome (all, affective, substance, and other), occurring on the same day and as a three-day average. Though temperature has been previously associated with mental health of adults, this may be the first empirical evidence of the risk temperature poses to the acute mental health of children as determined through emergency department utilization.

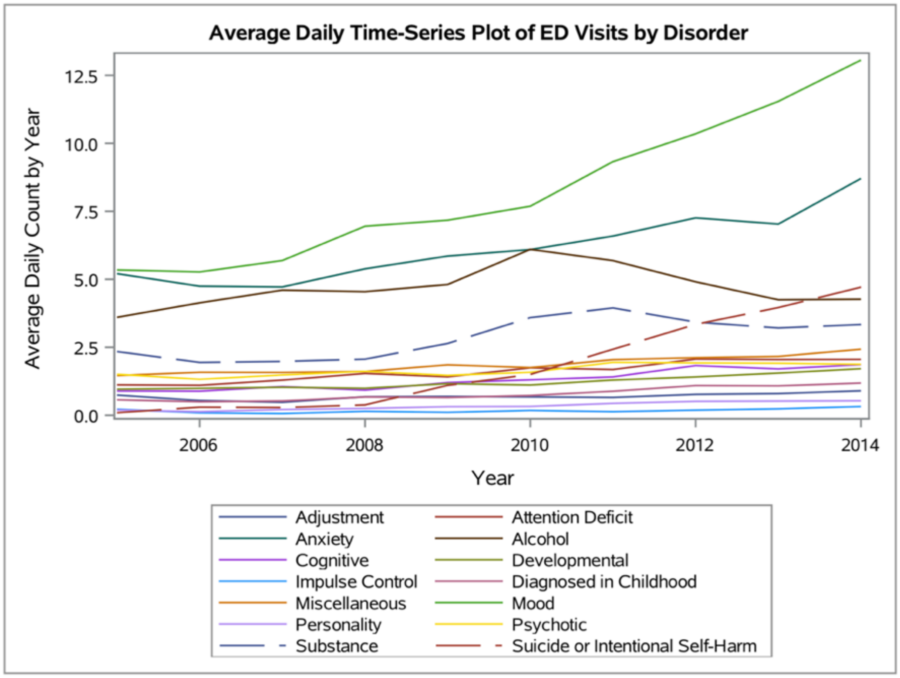
Finally, our study investigated the role payor status may play in the modification of the association between pollutants and mental health outcomes. This risks between those with public insurance compared to those with private insurance were largely the same between the two groups. In the future, further research is required.

The literature surrounding short-term mental health in children and air pollution or temperature is extremely limited. This study was able to contribute to this lack of information, but uncertainty clearly remains. More research is necessary to elucidate the role of elevated air pollutants and temperature on the acute mental health of children, especially as climate change continues to make these factors more common and challenging.

Appendix

Appendix A. Average daily counts and daily time series by mental health outcome

Mental Health Outcome	Avg. Daily Count
Mood	8.24
Anxiety	6.16
Alcohol-Related	4.69
Substance-Related	2.85
Miscellaneous	1.86
Suicide and Self-inflicted Injury	1.81
Psychotic	1.66
Attention-Deficit	1.61
Cognitive	1.31
Developmental	1.22
Diagnosed in Childhood	0.789
Adjustment	0.694
Personality	0.343
Impulse Control	0.168



Appendix B. Descriptive statistics by ED visit category

ED Visit Category	n	Avg. Daily n	Median Age (years)	% Female	% White	% Public Insurance
Attention-Deficit	34468	1.61	13 (10, 15)	29.3	59.3	44.5
Adjustment	5805	0.694	15 (13, 16)	62.5	48.5	45.4
Alcohol	26930	4.69	16 (15, 17)	48.5	61.2	30.0
Anxiety	48688	6.16	15 (13, 16)	61.5	58.0	39.1
Cognitive	10691	1.31	13 (9, 15)	38.85	56.5	38.5
Developmental	27826	1.22	12 (8, 15)	43.0	40.2	65.6
Impulse Control	1242	0.168	14 (12, 16)	35.8	52.8	49.2
Diagnosed in Childhood	26163	0.789	10 (7, 14)	24.1	52.8	52.8
Miscellaneous	14293	1.86	15 (12, 16)	61.1	56.0	38.6
Mood	60584	8.24	15 (14, 16)	62.0	58.2	40.9
Personality	2451	0.343	14 (11, 16)	41.5	62.9	39.6
Psychotic	9689	1.66	16 (14, 17)	41.6	48.5	43.7
Substance	31928	2.85	16 (15, 17)	41.3	57.5	34.0
Suicide or Intentional Self-Harm	20434	1.81	15 (13, 16)	63.1	60.9	35.8

Appendix C. Example SAS codes: case-crossover models

```
* single pollutant, single outcome model;
proc phreg data=indiv.add_cc nosummary;
class season;
model time*outcome_add (0) =O3
        holiday_fo holiday_dac holiday_datg
        TMX TMX2 TMX3 TDMX TDMX2 TDMX3 /ties=discrete
        risklimits;
strata group;


*single outcome, single pollutant temperature;
proc phreg data=indiv.add_cc nosummary;
class season;
model time*outcome_add (0) = TMX TMX2 TMX3
        holiday_fo holiday_dac holiday_datg
        TDMX TDMX2 TDMX3 /ties=discrete
        risklimits;
strata group;
*multi-pollutant model;
proc phreg data=indiv.allmhaq_cc nosummary;
class season;
model time*outcome_all (0) =O3
        holiday_fo holiday_dac holiday_datg
        NO21 PM251 TMX TMX2 TMX3 TDMX TDMX2 TDMX3  /ties=discrete
        risklimits;
strata group;
run;
```

Appendix D. Single-Variable Model Results

Table 7. Results for Single Pollutant Model for All Mental Health Outcomes

Grouping	Pollutant	Lag	OR	Lower	Upper	Lag	OR	Lower	Upper
All	NO_2	**0**	**1.006**	**1.005**	**1.007**	**3 Day Avg.**	**1.030**	**1.015**	**1.045**
All	$PM_{2.5}$	0	1.005	0.998	1.011	**3 Day Avg.**	**1.005**	**1.004**	**1.006**
All	O_3	0	1.008	0.993	1.023	3 Day Avg.	0.999	0.981	1.017

Table 8. Results for Single Pollutant Models by Mental Health Grouping

Grouping	Pollutant	Lag	OR	Lower	Upper	Lag	OR	Lower	Upper
Substance	NO_2	0	1.000	0.977	1.023	3 Day Avg.	1.004	0.999	1.010
Substance	$PM_{2.5}$	0	1.009	0.991	1.028	3 Day Avg.	1.003	0.985	1.021
Substance	O_3	0	1.019	0.987	1.051	3 Day Avg.	0.987	0.950	1.026
Affective	NO_2	0	1.003	0.985	1.021	**3 Day Avg.**	**1.046**	**1.025**	**1.067**
Affective	$PM_{2.5}$	0	1.009	1.000	1.018	**3 Day Avg.**	**1.014**	**1.005**	**1.023**
Affective	O_3	0	1.013	0.991	1.035	3 Day Avg.	1.009	0.983	1.036
Other	NO_2	0	1.000	0.977	1.024	3 Day Avg.	1.015	0.986	1.045
Other	$PM_{2.5}$	0	1.000	0.986	1.015	3 Day Avg.	0.996	0.978	1.014
Other	O_3	0	0.985	0.955	1.016	3 Day Avg.	0.987	0.951	1.025

Table 9 Results for Single-Variable Model with Temperature as Variable

Grouping	Variable	Lag	OR	Lower	Upper	Lag	OR	Lower	Upper
All	Max. Temp.	0	1.248	0.853	1.827	**3 Day Avg.**	**1.055**	**1.043**	**1.068**
Substance	Max. Temp.	0	1.242	0.580	2.657	**3 Day Avg.**	**1.057**	**1.031**	**1.084**
Affective	Max. Temp.	0	0.973	0.559	1.693	**3 Day Avg.**	**1.051**	**1.033**	**1.069**
Other	Max. Temp.	0	1.492	0.705	3.159	**3 Day Avg.**	**1.066**	**1.040**	**1.093**

Appendix E. Single-Day, Single-Variable Maximum Temperature Raw Data

MH Outcome	Odds Ratio	Lower	Upper
Attention-Deficit	0.363	0.040	3.328
Adjustment	1.029	0.372	2.846
Alcohol	1.332	0.533	3.331
Anxiety	0.982	0.149	6.467
Cognitive	2.822	0.455	17.509
Developmental	47.721	0.138	16512.187
Impulse Control	12.719	0.955	169.328
Diagnosed in Childhood	0.716	0.156	3.288
Miscellaneous	0.847	0.389	1.840
Mood	10.353	0.241	444.437
Personality	2.145	0.401	11.484
Psychotic	1.621	0.444	5.924
Substance	0.541	0.091	3.222
Suicide or Intentional Self-Harm	0.363	0.040	3.328

Appendix F. Single-day, single-pollutant data for each mental health outcome

Outcome	Pollutant	Odds Ratio	Lower	Upper
Attention-Deficit	NO_2	0.977	0.928	1.028
	O_3	0.965	0.901	1.034
	$PM_{2.5}$	0.992	0.961	1.024
Adjustment	NO_2	0.983	0.912	1.059
	O_3	1.060	0.958	1.173
	$PM_{2.5}$	0.998	0.954	1.043
Alcohol	**NO_2**	**3.921**	**3.800**	**4.045**
	O_3	1.021	0.982	1.063
	$PM_{2.5}$	1.009	0.990	1.027
Anxiety	NO_2	1.006	0.980	1.033
	O_3	**1.043**	**1.007**	**1.079**
	$PM_{2.5}$	1.007	0.990	1.024
Cognitive	NO_2	1.025	0.966	1.089
	O_3	1.038	0.959	1.124
	$PM_{2.5}$	1.020	0.981	1.061
Developmental	NO_2	0.988	0.933	1.047
	O_3	0.966	0.894	1.044
	$PM_{2.5}$	1.006	0.970	1.042
Impulse Control	NO_2	1.093	0.937	1.276
	O_3	0.973	0.790	1.198
	$PM_{2.5}$	0.933	0.827	1.051
Diagnosed in Childhood	NO_2	1.004	0.933	1.081
	O_3	0.969	0.877	1.070
	$PM_{2.5}$	0.998	0.952	1.046
Miscellaneous	NO_2	1.013	0.966	1.061
	O_3	0.962	0.904	1.024
	$PM_{2.5}$	1.010	0.981	1.040
Mood	NO_2	1.024	0.817	1.284
	O_3	0.984	0.954	1.015
	$PM_{2.5}$	1.011	0.997	1.026
Personality	NO_2	1.058	0.939	1.192
	O_3	0.974	0.829	1.143
	$PM_{2.5}$	1.017	0.941	1.099
Psychotic	NO_2	1.012	0.965	1.062
	O_3	1.016	0.953	1.084

	$PM_{2.5}$	0.978	0.949	1.008
Substance	NO_2	0.991	0.953	1.030
	O_3	1.015	0.964	1.069
	$PM_{2.5}$	1.014	0.990	1.038
Suicide or Intentional Self-Harm	NO_2	1.019	0.966	1.074
	O_3	1.046	0.972	1.125
	$PM_{2.5}$	0.992	0.954	1.031

Appendix G. 3-Day Average Single Pollutant Raw Data

Outcome	Pollutant	Odds Ratio	Lower	Upper
Attention-Deficit	NO_2	1.004	0.939	1.074
	O_3	0.995	0.916	1.081
	$PM_{2.5}$	0.997	0.962	1.033
Adjustment	NO_2	0.979	0.889	1.078
	O_3	1.112	0.985	1.257
	$PM_{2.5}$	1.013	0.961	1.067
Alcohol	NO_2	1.018	0.978	1.059
	O_3	1.017	0.969	1.067
	$PM_{2.5}$	0.997	0.976	1.018
Anxiety	**NO_2**	**1.037**	**1.002**	**1.073**
	O_3	1.031	0.989	1.074
	$PM_{2.5}$	1.012	0.993	1.032
Cognitive	NO_2	1.039	0.962	1.123
	O_3	0.996	0.906	1.096
	$PM_{2.5}$	1.000	0.956	1.046
Developmental	NO_2	1.025	0.951	1.105
	O_3	0.938	0.856	1.027
	$PM_{2.5}$	1.002	0.962	1.044
Impulse Control	NO_2	1.012	0.829	1.236
	O_3	1.108	0.860	1.428
	$PM_{2.5}$	0.919	0.825	1.024
Diagnosed in Childhood	NO_2	1.044	0.948	1.151
	O_3	0.970	0.862	1.091
	$PM_{2.5}$	0.991	0.940	1.045
Miscellaneous	NO_2	1.034	0.973	1.099
	O_3	0.964	0.895	1.038
	$PM_{2.5}$	0.993	0.960	1.026
Mood	**NO_2**	**1.044**	**1.014**	**1.075**
	O_3	0.975	0.940	1.011
	$PM_{2.5}$	**1.019**	**1.002**	**1.036**
Personality	NO_2	1.131	0.971	1.318

	O_3	0.892	0.738	1.078
	$PM_{2.5}$	1.064	0.976	1.160
Psychotic	NO_2	1.013	0.952	1.077
	O_3	1.024	0.948	1.106
	$PM_{2.5}$	0.979	0.946	1.013
Substance	NO_2	0.984	0.935	1.035
	O_3	0.942	0.885	1.003
	$PM_{2.5}$	1.010	0.983	1.039
Suicide or Intentional Self-Harm	NO_2	1.006	0.937	1.079
	O_3	**1.111**	**1.019**	**1.212**
	$PM_{2.5}$	0.972	0.930	1.016

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