

Title: Power Outages: An Underappreciated Risk Factor for Children’s Carbon Monoxide Poisoning

Alexander J. Northrop^{a,b,c}, Vivian Do^d, Nina M. Flores^d, Lauren Blair Wilner^e, Perry E. Sheffield^{b,f}, Joan A. Casey^{d,g}

Affiliations:

^aVagelos College of Physicians and Surgeons, Columbia University, New York, NY

^bDepartment of Environmental Medicine and Climate Science, Icahn School of Medicine at Mount Sinai, New York City, NY

^cDepartment of Pediatrics, The Children’s Hospital of Philadelphia, Philadelphia, PA

^dDepartment of Environmental Health Sciences, Mailman School of Public Health, Columbia University, New York, NY

^eDepartment of Epidemiology, University of Washington School of Public Health, Seattle, WA

^fDepartment of Pediatrics, Icahn School of Medicine at Mount Sinai, New York City, NY

^gDepartment of Environmental and Occupational Health Sciences, University of Washington School of Public Health, Seattle, WA

Address correspondence to: Alexander J. Northrop, The Children’s Hospital of Philadelphia, 3401 Civic Center Boulevard, Philadelphia, PA, 19104, northropa@chop.edu

Conflict of Interest Disclosures (includes financial disclosures):

None declared

Funding: This work was supported by grant R01ES030717 from the National Institute of Environmental Health Sciences. This work was also supported by grant T32ES007322, 2T32ES007322, P30ES009089, and R00ES027023 of the National Institute of Environmental Health Sciences.

Data Availability: Power outage data and related code are available upon request. The meteorological data used in the analyses are publicly available (<https://ldas.gsfc.nasa.gov/nldas>). Health data from the analyses may be available upon SPARCS approval (<https://www.health.ny.gov/statistics/sparcs/access/>).

Role of Funder (if any): The NIH had no role in the design and conduct of the study.

Abbreviations:

CO: Carbon monoxide

ED: Emergency department

ICD-10: *International Classification of Diseases-10*

NH: Non-Hispanic

NYS: New York State

Contributors Statement Page

Dr Alex Northrop conceived and designed the study, conducted the statistical analyses, wrote the initial manuscript, and critically reviewed and revised the manuscript.

Vivian Do and Nina Flores assisted in data aggregation, data cleaning, code review, statistical analyses, data interpretation, and critically reviewed and revised the manuscript.

Lauren Blair Wilner assisted in data cleaning, conducted code review, and critically reviewed and revised the manuscript.

Dr Joan Casey and Dr Perry Sheffield conceived and designed the study, coordinated data access, and critically reviewed and revised the manuscript.

All authors discussed the results and approved the final manuscript as submitted.

ABSTRACT

Children's risk of exposure to carbon monoxide (CO) increases after disasters, likely due to improper generator use during power outages. Here, we evaluate the impact of outages on children's CO-related emergency department (ED) visits in New York State (NYS). We leveraged power outage data spanning 2017-2020 from the NYS Department of Public Service for 1,865 power operating localities (i.e., communities) and defined all-size and large-scale power outage hours. All-size outage hours affected $\geq 1\%$ of customers, and large-scale outage hours affected $\geq 20\%$. We identified CO poisoning using diagnostic codes among those aged <18 between 2017 and 2020 using the Statewide Planning and Research Cooperative System (SPARCS), an all-payer reporting system in NYS. We linked community power outage exposure to patients using the population-weighted centroid of their block group of residence. We estimated the impact of power outages on CO poisoning using a time-stratified case-crossover study design with conditional logistic regression, controlling for daily relative humidity, mean temperature, and total precipitation. Analyses were stratified by urban and rural communities. From 2017-2020, there were 917 pediatric CO poisoning ED visits in NYS. Most cases (83%) occurred in urban region of the state. We observed an association statewide between all-size and large-scale outages and CO ED visits on the index day and the following two days before a return to baseline on lag day 3. Four hours without power increased the odds of a pediatric CO poisoning ED visit by $\geq 50\%$ for small-scale and $\geq 150\%$ for large-scale outages, and associations were stronger in urban versus rural areas. While CO poisoning is a relatively rare cause of pediatric ED visits in NYS, it can be deadly and is also preventable. Expanded analyses of the health impacts of outages and advocacy for reliable energy access are needed to support children's health in a changing climate

INTRODUCTION

Carbon monoxide (CO) is a colorless, odorless gas that binds to hemoglobin more avidly than oxygen, which can result in health impacts from mild headaches to death. Major exposure sources include the incomplete combustion of hydrocarbons from vehicle exhaust, gas stoves, and furnaces.¹ Children may be uniquely vulnerable to CO poisoning due to higher minute ventilation and metabolic demands compared to adults.² Moreover, children's risk of CO exposure increases after disasters, likely due to improper generator use during power outages.^{3,4} As climate change drives more severe weather events⁵ causing additional outages, we must understand their impact on pediatric CO poisoning. Prior studies evaluated single large-scale outages, which do not represent more frequent, smaller outage exposures nationwide.⁶ Here, we evaluate the impact of outages on children's CO-related emergency department (ED) visits in New York State (NYS) from 2017-2020.

METHODS

Power outage data spanning 2017-2020 was obtained through the NYS Department of Public Service for 1,865 power operating localities (i.e., communities), areal units approximately the size of zip codes. We determined the number and percent of customers without power every hour in each community. We defined an hour when $\geq 1\%$ of customers lacked power as an all-size outage-hour and when $\geq 20\%$ of customers lacked power as a large-scale outage-hour. The daily sum of outage hours in a community represented the exposure. We stratified communities as urban and rural for subgroup analyses due to differential exposure patterns and characteristics between these groups.⁷

We leveraged block group level outcome data from the Statewide Planning and Research Cooperative System (SPARCS), an all-payer reporting system in NYS. Included cases were

CO poisoning among those aged <18 between 2017 and 2020 using a T58 *International Classification of Diseases-10 (ICD-10)* primary diagnosis (Toxic effects of carbon monoxide).⁸ We linked community power outage exposure to patients using the population-weighted centroid of their block group of residence. An individual is considered exposed if they experienced ≥ 1 outage-hour on either the day of their healthcare encounter or during the two days prior.

We used a time-stratified case-crossover study design with a conditional logistic regression, matching on the day of week, month, and year to control for variables not expected to significantly change during the study period. The models controlled flexibly for daily relative humidity, mean temperature, and total precipitation. These rasterized weather data were obtained from the North American Land Data Assimilation System Phase 2⁹ and aggregated to the community level. We calculated the population attributable fraction (PAF), the proportion of children's CO ED visits due to all-size and large-scale outages.¹⁰ All analyses were conducted on R (version 3.6.3; version 4.3.2).

An institutional review board approved the study (#19-00355).

RESULTS

From 2017-2020, there were 917 pediatric CO poisoning ED room visits in NYS. Most cases (83%) occurred in urban regions (**Table 1**). Most exposed and unexposed cases were non-Hispanic (NH) white children. Among those with a CO ED visit, there was a higher percentage (16%) of Hispanic children who were exposed to outages than NH Black (9%) or (14%) NH white children.

We observed an association statewide between all-size and large-scale outages and CO ED visits (**Figure 1**). Four hours without power increased the odds of a pediatric CO poisoning ED visit by $\geq 50\%$ for all-size and $\geq 150\%$ for large-scale outages. Associations were stronger in urban versus rural areas. The population attributable fraction of these outages was 4.8 and 2.6 percent of statewide CO ED visits using the all-size and large-scale thresholds, respectively.

DISCUSSION

While CO poisoning is a rare cause of pediatric ED visits in NYS, it is both frequently deadly and preventable. Our findings leverage exposure data with high spatiotemporal resolution to demonstrate that even smaller-scale outages, captured by our all-size metric, contribute to pediatric CO poisoning ED visits, building upon prior work identifying large-scale outages as a risk factor for CO poisoning.³

Outage data was an aggregate community exposure, so we cannot determine if an individual case was truly exposed, potentially biasing our results to the null. Due to low power, we could not evaluate response disparities by social determinants of health.

Expanded analyses of the health impacts of outages and advocacy for reliable energy access is needed to support children's health in a changing climate.

DISCLAIMER

This publication was produced from raw data provided by the New York State Department of Health (NYSDOH). However, the conclusions derived and views expressed herein are those of the authors and do not reflect the conclusions or views of NYSDOH. NYSDOH, its employees, officers, and agents make no representation, warranty, or guarantee as to the accuracy, completeness, currency, or suitability of the information provided here.

REFERENCES

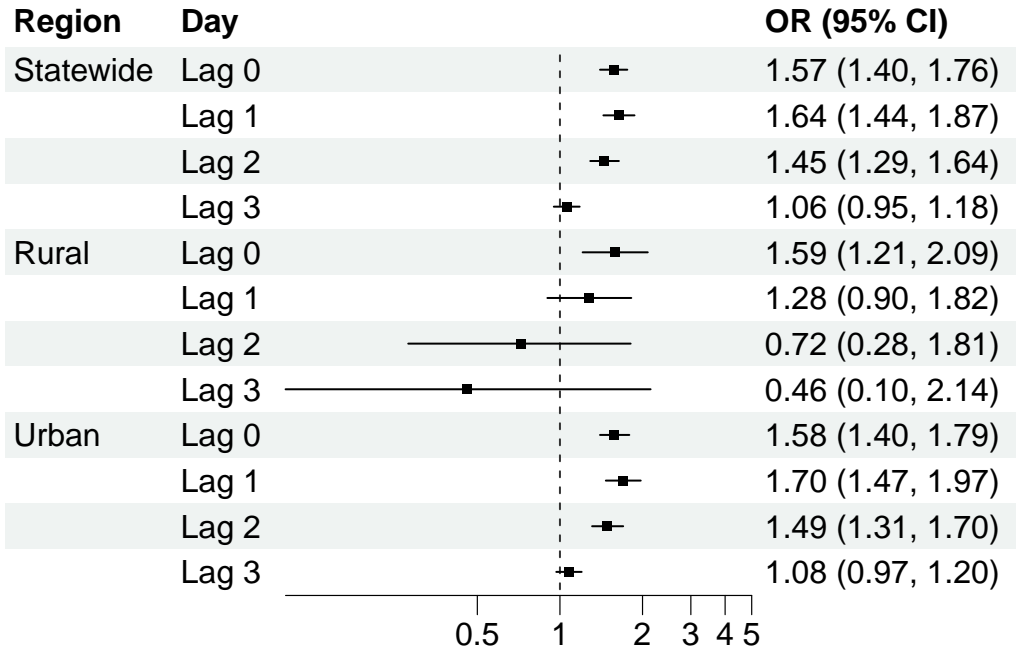
1. Rose JJ, Wang L, Xu Q, et al. Carbon Monoxide Poisoning: Pathogenesis, Management, and Future Directions of Therapy. *Am J Respir Crit Care Med*. 2017;195(5):596-606. doi:10.1164/rccm.201606-1275CI
2. Macnow TE, Waltzman ML. Carbon Monoxide Poisoning In Children: Diagnosis And Management In The Emergency Department. *Pediatr Emerg Med Pract*. 2016;13(9):1-24.
3. Worsham CM, Woo J, Kearney MJ, Bray CF, Jena AB. Carbon Monoxide Poisoning during Major U.S. Power Outages. *N Engl J Med*. 2022;386(2):191-192. doi:10.1056/NEJMc2113554
4. Fife CE, Smith LA, Maus EA, et al. Dying to play video games: carbon monoxide poisoning from electrical generators used after hurricane Ike. *Pediatrics*. 2009;123(6):e1035-1038. doi:10.1542/peds.2008-3273
5. Intergovernmental Panel On Climate Change (Ippc). *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. 1st ed. Cambridge University Press; 2023. doi:10.1017/9781009157896
6. Do V, McBrien H, Flores NM, et al. Spatiotemporal distribution of power outages with climate events and social vulnerability in the USA. *Nat Commun*. 2023;14(1):2470. doi:10.1038/s41467-023-38084-6
7. Northrop AJ, Flores NM, Do V, Sheffield PE, Casey JA. Power outages and pediatric unintentional injury hospitalizations in New York State. *Environ Epidemiol*. 2024;8(1):e287. doi:10.1097/EE9.0000000000000287
8. Chiang MY, Shao SC, Liao SC. Validation of Diagnostic Codes to Identify Carbon Monoxide Poisoning in Taiwan’s Claims Data. *Front Pharmacol*. 2022;13:882632. doi:10.3389/fphar.2022.882632
9. Xia Y, Et Al., NCEP/EMC. NLDAS Primary Forcing Data L4 Hourly 0.125 x 0.125 degree, Version 002. Published online 2009. doi:10.5067/6J5LHHOHZHN4
10. Lin CK, Chen ST. Estimation and application of population attributable fraction in ecological studies. *Environ Health*. 2019;18(1):52. doi:10.1186/s12940-019-0492-4

Table 1: Demographics Information of Carbon Monoxide Emergency Department Visits in New York State Among Children (<18 years old) Exposed and Unexposed to Power Outages. “Exposed” refers to children residing in a community with $\geq 1\%$ of customers without power on lag day 0-2 of their presentation to the emergency department for carbon monoxide poisoning. Race and ethnicity data was restricted to three categories due to low counts of other identities, and thus, do not sum to the total number of cases. Race and ethnicity categories represent a social construct without a biological basis. Abbreviations – NH: Non-Hispanic.

	Exposed Cases	Unexposed Cases	Total Cases
No. (%)	No. (%)	No. (%)	No.
Total Cases	124 (14)	793 (86)	917
Region			
Rural	14 (9)	145 (91)	159
Urban	110 (15)	648 (85)	758
Age			
Age <1	11 (12)	80 (88)	91
Age 1-5	37 (13)	256 (87)	293
Age 6-10	37 (17)	176 (83)	213
Age 11-17	39 (12)	281 (88)	320
Sex			
Female	59 (13)	390 (87)	449
Male	65 (14)	403 (86)	468
Race/Ethnicity			
NH Black	19 (9)	193 (91)	212
Hispanic	29 (16)	147 (84)	176
NH White	58 (14)	348 (86)	406

Figure 1: Odds Ratios: Outages and Carbon Monoxide Emergency Department Visits by Thresholds and Urbanicity. *Adjusted odds ratios represent the odds of a carbon monoxide emergency department visit for a four-hour increase in community outages at the **A**) all-size outage threshold ($\geq 1\%$ of the community without power) and **B**) large-scale outage threshold ($\geq 20\%$ of the community without power).*

A.



B.

