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Air pollution and cardiovascular and respiratory emergency visits in Central Arkansas: A time-series analysis

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Abstract

Background—Heart disease and stroke mortality and morbidity rates in Arkansas are among the highest in the U.S. While the effect of air pollution on cardiovascular health was identified in traffic-dominated metropolitan areas, there is a lack of studies for populations with variable exposure profiles, demographic and disease characteristics.

Objective—Determine the short-term effects of air pollution on cardiovascular and respiratory morbidity in the stroke and heart failure belt.

Methods—We investigated the associations of fine particles and ozone with respiratory and cardiovascular emergency room visits during the 2002–2012 period for adults in Central Arkansas using Poisson generalized models adjusted for temporal, seasonal and meteorological effects. We evaluated sensitivity of the associations to mutual pollutant adjustment and effect modification patterns by sex, age, race and season.

Results—We found effects on cardiovascular and respiratory emergencies for PM_{2.5} (1.52% [95%CI: −1.10, 4.20]; 1.45% [95%CI: −2.64, 5.72] per 10 µg/m³) and O₃ (0.93% [95%CI: −0.87, 2.76]; 0.76 [95%CI: −1.92, 3.52] per 10 ppbv) during the cold period (October–March). The effects were stronger among whites, except for the respiratory effects of O₃ that were higher among Blacks/African-Americans. Effect modification patterns by age and sex differed by association. Both pollutants were associated with increases in emergency room visits for hypertension, heart failure and asthma. Effects on cardiovascular and respiratory emergencies were observed during the cold period when particulate matter was dominated by secondary nitrate and wood burning.

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Competing interests
None declared.

Conclusion—Outdoor particulate pollution during winter had an effect of cardiovascular morbidity in central Arkansas, the region with high stroke and heart disease incidence rates.

Keywords

Fine particles; ozone; heart disease; asthma; stroke; nitrate particles; biomass burning

1 Introduction

The Southeast United States (U.S.), encompassing Alabama, Arkansas, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee and Virginia, has been characterized with high incidence rates of stroke and heart failure (Howard, 1999; Mujib et al., 2011). Several risk factors have been identified, including smoking, race, diet and hypertension; however, the causes have not yet been determined (Howard et al., 2006; Ostro et al., 2006; Cushman et al., 2008; Liao et al., 2009; Glymour et al., 2009). The associations of respiratory and cardiovascular morbidity (ie, emergency visits and admissions) with outdoor fine particulate matter (PM_{2.5}: particles with diameter < 2.5 µm) and ozone (O₃) have been recognized and provide the scientific basis for the enactment of national ambient air quality standards (NAAQS) for the protection of health in the U.S. and other countries (Zanobetti and Schwartz, 2005; Dominici et al., 2006; World Health Organization, 2008; Wellenius et al., 2012). Furthermore, studies showed that risk for stroke may increase even at low PM₁₀ and PM_{2.5} levels (Metzger et al., 2004; Lisabeth et al., 2008; Wellenius et al., 2012). Stroke incidence in urban areas was associated with PM_{2.5} mass concentration even though the effect could be underestimated due to uncertainties associated with the use of satellite-derived PM_{2.5} concentrations (Loop et al., 2013; Alexeef et al., 2014). Effects were also observed in Canada and Europe (Larrieu et al., 2004; Villeneuve et al., 2006). The variability of the effect on stroke morbidity indicators may be associated with the use of morbidity indicators (emergency room visit date as compared to stroke onset and severity) as well as the lag effect between PM exposure and stroke event which depends on stroke type (hemorrhagic, ischemic or transient ischemic) and patient characteristics (age, race).

Arkansas had the highest age-adjusted 2010 stroke mortality (53.8 deaths per 100,000) in the U.S. and is ranked among the top five states for coronary heart disease (CHD) mortality (143.9 deaths per 100,000 population) (CDC WONDER). Age-adjusted mortality rates were higher among African-Americans than for whites. CHD and stroke hospitalization rates were also 60.7 and 34.1 per 10,000 population in 2010 (Reeve et al., 2012). In addition, the prevalence of asthma in adults was 13% with higher rates among African-Americans and females as compared to whites and males, respectively (Maulden and Philips, 2012). In 2008, there were 3,083 hospital admissions with asthma as the principal diagnosis in Arkansas (100% increase from 2000) (Biddle et al., 2011). The prevalence of asthma, heart attack and stroke in the state are above the national averages. The per-capita income in Arkansas is among the lowest in the nation (\$22,007; US average \$28,051), with many counties being among the poorest in the US. Before Affordable Care Act implementation, about 1-in-4 residents lacked health insurance due to cost.

PM_{2.5} levels in Arkansas, USA, were consistently below the 2005 NAAQS but comparable to the revised PM_{2.5} standards (Chalbot et al., 2014a). Secondary sulfate and nitrate and biomass burning emissions (both from wildfires and residential wood burning) accounted for at least 65% of measured PM_{2.5} mass (Chalbot et al., 2013). For O₃, ambient levels were slightly higher than the 2008 NAAQS (the 98th percentile of the daily 8-hr maximum concentration over a 3-year period should not exceed 70 ppbv) in at least one site in the Little Rock metropolitan urban area. The annual trends of PM_{2.5} and O₃ did not follow the substantial decreases of SO₂ and NO_x emissions (Guerra et al., 2014; Jhun et al., 2014). In this study, we assessed the short-term associations between exposures to ambient PM_{2.5} and O₃ levels and respiratory and cardiovascular emergency visits in the Little Rock region. To the best of our knowledge, this is the first study examining the short-term effects of air pollution on cardiovascular and respiratory morbidity in the core region (ie, Deep South: Alabama, Arkansas, Louisiana and Mississippi) of the stroke and heart failure belt.

2 Methods

2.1 Air pollution and health data

Little Rock is the capital city of Arkansas with a population of 197,357 in 2013 (391,284 residents in Pulaski County). 48.9% of population (57.5% in Pulaski County) was white, followed by 42.3% (35.0% in Pulaski County) for Black or African American. Residents of Hispanic or Latino origin accounted for 6.8% (5.8% in Pulaski County) of the population. PM_{2.5} and O₃ measurements in Little Rock during 2002–2012 were retrieved from the U.S. Environmental Protection Agency Air Quality System (AQS) NCore site (AQS # 05-119-0007). The 24-hr PM_{2.5} mass concentrations and the daily 8-hr maximum O₃ concentration were used as metrics of exposures. Meteorological data at the Little Rock Airport (GHCND: USW00013963) were obtained from National Oceanic and Atmospheric Administration's National Climatic Data Center Local Climatological Data.

We obtained data from the UAMS Medical Center in Little Rock, Arkansas, the only state-owned medical center in Arkansas that serves uninsured and Medicare/Medicaid patients. Daily emergency room visits (ER) during the period from 2002 to 2012 for the adult population (≥ 15 years of age) were retrieved from the UAMS Enterprise Data Warehouse that included data on the date of visit, age, gender and race/ethnicity. ER visits were selected for the following diagnoses: cardiovascular: International Classification of Disease (ICD) -9 401–459; hypertension ICD-9 401; hypertensive heart disease and heart failure: ICD-9: 402 and 428; conduction disorders and cardiac dysrhythmias: ICD-9: 426 and 427; cerebrovascular disease and stroke: ICD-9 430–438; respiratory: ICD-9 460–519; acute respiratory infections (except acute bronchiolitis and bronchitis): ICD-9: 460–465; pneumonia: ICD-9: 480–486; asthma: ICD-9: 493; chronic obstructive pulmonary disease (COPD): ICD-9: 490, 491, 492 and 496. Demographic and economic characteristics, including age, sex, race, family, income and benefits and health insurance for each zone improvement plan (ZIP) area code (ZCTA), were obtained from the U.S. Census Bureau's American Community Survey for the 2008–2012 period.

2.2 Time series analysis

The daily hospital emergency counts were linked to daily levels of PM_{2.5} and O₃ on the previous day (lag1) for visits from cardiovascular causes and on the two preceding days (lag2) for visits from respiratory causes using overdispersed generalized linear Poisson regression models (Katsouyanni et al., 2009; Rodopoulou et al., 2014). Natural spline smooth functions were applied to include the effect of time-varying covariates and calendar time on daily visits (Touloumi et al., 2004). The lag structure was selected *a-priori* based on previous findings and indications of longer patterns of associations with respiratory admissions (Touloumi et al., 2006; Dominici et al., 2006; Peng et al., 2009). Natural spline smooth functions were applied to include the effect to time-varying covariates and calendar time on daily visits (Katsouyanni et al., 2009; Zanobetti and Schwartz, 2009). Following previous time series analysis of US admissions data, we used a natural cubic regression splint with 1.5 degrees of freedom (*df*) for each season and year (Zanobetti and Schwartz, 2009). For meteorological variables, we applied a natural spline with three *df* for temperature on the day of the visit (lag0) and a natural spline with three *df* for the average temperature of two previous days (lag1 and 2), based on the minimization of the Akaike Information Criteria and of the partial autocorrelation function of the model residuals. A linear term for average relative humidity of the day of visit and the two preceding days (lags0–2) was also included, while dummy variables were used for the day of the week and holidays effect. We tested the sensitivity of our findings to mutual exposure by applying two pollutant models and to the choice of lag by investigating effects on lags 0,1,2 as well as the average exposure during lags 0–2. Given the strong seasonal variability of atmospheric transport pattern, we also examined effect modification patterns by season for the cold (October–March) and warm (April–September) period. Finally, we investigated effect modification by age, gender and race in order to address the higher CVD rates found in the region. We used R statistical package for the analysis (version 2.15.0, Vienna, Austria).

3 Results

3.1 Study population and air pollution characteristics

The total number of emergency visits for adults for cardiovascular (CVD) and respiratory diseases were 84,269 and 29,402 in 2002–2012 (daily mean of 7.32 and 20.97, respectively) with less than 2% of them for elderly (65+ years) adults (Table 1). ER visits were higher for females (CVD: 48,469; respiratory: 17,658) and for Black or African-American (CVD: 46,809; respiratory: 16,110). The vast majority of CVD ER visits were associated with hypertension (64,206) followed by conduction disorders and cardiac arrhythmias (6,271). Most of the respiratory ER visits were due to acute respiratory infections (13,650) and chronic obstructive pulmonary disease (COPD) (12,511). The mean 24-hr PM_{2.5} and 8-hr maximum O₃ concentrations were 12.4 µg/m³ and 40.0 ppbv for the 2002–2012 period with less than 4% and 1% of missing measurements for PM_{2.5} and O₃, respectively (Table 1). The mean ambient temperature and relative humidity were 17.6°C and 56.3%, respectively.

Figure 1 shows the variability of total CVD and respiratory emergency visits and air pollution parameters. Hospital CVD emergency visits presented an increasing trend during the 2002–2012 period that was attributed to the increase in hypertension diagnosis. A

seasonal pattern with increased counts in winter and lower counts in the summer was observed for respiratory emergencies due to moderate seasonal variability of acute respiratory infections and COPD visits. A seasonal pattern was observed for PM_{2.5} and O₃ with higher concentrations being measured in the summer. A moderate correlation was only calculated between O₃ and ambient temperature (See Table S1 in Supplemental Information).

Table 2 shows the demographic, economic and health insurance data for the communities (identified by seven ZIP codes) totaling 50% of the emergency visits at the UAMS Medical Center (the remaining visits were associated with communities in 2,421 ZIP codes) in comparison to the Little Rock/North Little Rock MSA, Arkansas and the U.S. More than 50% of the emergency visits originated from communities dominated by Blacks/African Americans (2–4 times that the MSA, state and national percentages) with median family and per capita incomes substantially lower than state and national averages and most of the residents with public (Medicare/Medicaid) or no insurance coverage (53.4%), which was higher than the state and national averages. Table 2 shows the age-adjusted hospitalization rates for heart disease and stroke in the U.S., Arkansas and Pulaski County (accounts for most of the population within the Little Rock/North Little Rock MSA and encompasses the ZIP codes with 50% of emergency visits). The age-adjusted hospitalization rate for blacks in Pulaski County was comparable to that observed for Arkansas and up to 40% higher than the national rate. The same rate for whites in Pulaski County was increased by 25% compared to the national rate. For all heart diseases, the age-adjusted hospitalization rates for blacks and whites were comparable to the national rates, albeit lower for whites.

3.2 Respiratory and cardiovascular effects

Table 3 shows the percent increase (and 95% confidence intervals) of emergency visits for CVD and respiratory diseases overall and per age group (15–64 and 65+ years), per sex and race for an increase of 10 µg/m³ of PM_{2.5} and 10 ppbv of O₃. For CVD emergency visits, an increase was estimated for males (0.86% [95% CI:–1.76, 3.55]) and whites (0.47% [95% CI: –2.10–3.12]) for PM_{2.5} during the 2002–2012. Regarding respiratory ER visits, positive effects were estimated for associations, except for respiratory visits, among 15–64 years old and Blacks/African-Americans. Effects of PM_{2.5} for both CVD and respiratory emergencies were higher in the cold period, reaching statistical significance for CVD visits among males (5.41% [95% CI: 1.32, 9.66]) and whites (4.40% [95% CI: 0.45, 8.51]). The effects of O₃ on CVD and respiratory emergency visits were effectively null for the entire period as well as for the warm period, when O₃ formation is favored, except for the association of CVD visits among those aged 65+ years and respiratory admissions of white adults. The effect estimates of most of the associations with O₃ under investigation in the cold period were positive.

Considering specific CVD and respiratory diseases, effect increases of visits for hypertension (2.03% [95% CI:–0.57, 4.69]), hypertensive heart disease and heart failure (7.79 [95% CI:–2.01, 18.57]), and cerebrovascular disease (7.54% [95% CI:–10.34, 28.99]) were estimated for PM_{2.5} during the cold period (Table 4). Interestingly, positive associations were also computed for hypertension (0.63% [95% CI:–1.15, 2.43]), hypertensive heart disease and heart failure (3.96% [95% CI: –2.67, 11.03]) and conduction

disorders and cardiac dysrhythmias (5.20% [95% CI: -1.43, 12.27]) with O₃ during the cold period (Table 4). For respiratory diseases, PM_{2.5} and O₃ exposure was not associated with infections (acute respiratory infections and pneumonia); however, adverse effects were estimated for asthma and COPD. Results from two-pollutant models revealed that effect estimates were robust to mutual adjustment of PM_{2.5} and O₃, except for the association of O₃ with asthma and COPD that decreased by more than half after controlling for particles, but nevertheless remained adverse (Table 4). Moreover, the effects identified during the cold period for both pollutants remained after mutual control (see Supplemental Table S2 and S3). Although the effect estimates were variable depending on lag choice, largely attributed to the large random variation, remained consistent in direction during the cold period of the year (see Supplemental Table S4).

4 Discussion

We estimated the effects of ambient PM_{2.5} and O₃ on hospital emergency visits at the UAMS Medical Center, the only state hospital serving the residents of Little Rock area, including those with public insurance and without health insurance. CVD and respiratory emergency visits of females and Blacks/African-Americans exceeded those of males and whites by 28 and 48%, respectively. This pattern was consistent with the demographic profiles of the low-income and predominantly minority communities served by the public hospital. Hypertension and acute respiratory infections dominated CVD and respiratory emergency visits. Hypertension is a risk factor for stroke and heart disease (O'Donnell et al., 2010); for both of them, Arkansas has one of the highest mortality and incidence rates in the nation, with Blacks/African Americans having higher risks than whites (Reeve et al., 2012). The increasing trend of CVD emergency visits over the 2002–2012 period may be contributed to earlier diagnoses of specific risk factors (eg, hypertension) and subsequent treatment, which, in turn, may have contributed to the declining trends of mortality (Crimmins and Beltran-Sanchez, 2014; Koton et al., 2014).

We found indications of short-term effects of PM_{2.5} and O₃ on respiratory and cardiovascular hospital emergency visits during the cold period; especially for particles, this finding may be attributed to their seasonally varying contribution of PM_{2.5} sources (Peng et al., 2009). The observed seasonal trends for air pollution variables were consistent with differences in sources and meteorological transport for PM_{2.5}. Wood burning was identified as the dominant source of fine particles in the winter (Chalbot et al., 2013, 2014b).^{19,30} In addition, secondary nitrate, formed from the oxidation of NO_x, neutralization by NH₃ and low temperature-induced condensation, was an important contributor of wintertime fine particles. The gas-to-particle partitioning of NO₂ to particulate NO₃⁻ typically takes place within 1–2 days. During summer, secondary sulfate (~4.8 µg/m³) followed by biomass burning from wildfires/woodburning (3.0 µg/m³) and mineral dust (1.0 µg/m³) were the predominant sources of fine particles. In previous studies, calculation of the percent increases for CVD and respiratory risks of individual aerosol species demonstrated positive percent increases of emergency admissions for elemental carbon and nitrate, positive increases in respiratory risks for organic aerosol and no effect for secondary sulfate (Bell et al., 2009).

The finding of effects during the cold period is consistent to previous studies reporting the effect of fine particle mass on hospital admissions in major U.S. urban areas (Dominici et al., 2006; Bell et al., 2008). The strongest effects between PM_{2.5} and cardiovascular and respiratory hospital admissions were reported for winter in the Northwest U.S. and to a lesser extend in the Southeast, the Northwest and the Southwest. Winter PM_{2.5} in the Northwest was primarily associated with secondary nitrate particles. In the study area, the average contribution of nitrate to PM_{2.5} mass was $1.1 \pm 0.1 \mu\text{g}/\text{m}^3$, accounting for 10% of PM_{2.5} mass (Chalbot et al., 2013). At the same time, the associations between cardiovascular emergencies and PM_{2.5} during winter in Central Arkansas were different to previous results that reported possible associations between CVD emergency visits and PM_{2.5} and O₃ during the warm period in Doña Ana County along the central U.S.-Mexico border region (Rodopoulou et al., 2014). In both studies, the air pollution and time-series analysis methods were similar. While there are many differences between these two US regions albeit dominated by minorities, the differences in the seasonality may be related to the magnitude and timing of biomass burning influence on PM_{2.5} mass (Kavouras et al., 2007). The abundance of sulfate and nitrate in the Southwest US was substantially lower than that regularly measured in the Midwest and Eastern U.S. (Hand et al., 2012). On the other hand, the contribution of biomass burning particles was almost entirely due to wildfires in the summer. Thus, in both studies, stronger effects were computed for periods with the most intense contributions of wood/biomass burning, albeit at different seasons.

We found indications of associations between emergency visits for hypertension, hypertensive heart disease and heart failure, stroke, asthma and COPD and PM_{2.5} in the cold period. This finding was consistent with the increased prevalence of heart failure and stroke mortality and hospitalization in the winter. Different biological mechanisms have been suggested including systemic inflammation and oxidative stress. The translocation of individual particles of chemical species into the blood stream may also trigger several responses including ANS-mediated changes and pro-coagulant and thrombotic alterations (Brook et al., 2010). These outcomes may be augmented by low temperatures that may induce acute changes in blood pressure and may increase blood viscosity, red blood cell counts, heart rate and peripheral vascular resistance (Hanna, 1999).

Despite the higher cardiovascular incidence and mortality rates for Blacks/African-Americans as compared to whites in the study area, the effect of air pollution on hospital emergencies was absent. Analysis of the Arkansas Behavioral Risk Factor Surveillance System (BRFSS) survey showed that the prevalence of self-reported obesity and high blood pressure was higher in Blacks/African-Americans (73.5% and 39.5%, respectively) as compared to whites (63.7% and 36.4%), while no differences in the prevalence of high cholesterol and smoking were observed. Both obesity and high blood pressure are significant risk factors for cardiovascular diseases that may obscure the potential effect of particulate pollution. As health insurance coverage is increasing due to the implementation of the Affordable Care Act, the prevalence of undiagnosed/untreated hypertension may decrease, particularly for Blacks/African-Americans who transition faster from pre-hypertension to hypertension as compared to whites (Selassie et al., 2011).

There have been a limited number of studies examining the long-term effects of air pollution on respiratory, cardiovascular and stroke mortality in the Southeast US; however, this study examined the short-term effects of air pollution in the stroke/heart disease belt region of the US. The analysis of emergency visits allowed for the determination of the actual short-term effect of air pollution reducing the possible bias due the lack of health insurance using hospital admissions and medication use. By law, emergency room incidents must be treated and stabilized regardless of health insurance coverage. On the other hand, proof of health insurance coverage is requested during registration for hospital admissions. Traditionally, PM_{2.5} and O₃ measurements from fixed monitoring sites may misrepresent exposures of residents living on the edge/outside of the urban area; however, in this study most (60 %) of the emergency visits were from residents within 10 km of the monitoring site. In addition, a spatially uniform profile was previously observed for PM_{2.5} in the region (Chalbot et al., 2014a). Lastly, it was possible to analyze the effects on specific diagnoses (such as hypertension, asthma, stroke and heart failure) in the region with the highest incidences of cardiovascular and cerebrovascular diseases.

There were several limitations to this study, including exposure misclassification inherent to the study design that utilizes ambient air PM_{2.5} and O₃ measurements. The effect of exposures to indoor air in residences could not be assessed. Fireplaces and conventional woodstoves are among the primary modes of domestic heating during winter in Arkansas, especially for low income households such as those in the neighborhoods with the most emergency visits in this study. The small sample size over a 10 year period for cause-specific visits limited our power to detect strong associations for specific diseases. Finally, we used emergency visits from one of the three hospitals serving the Little Rock urban area; however, the UAMS Medical Center has the most emergency visits, accounting for 40% of all visits at the three hospitals. The largest fraction of emergency visits to the hospital was from neighborhoods with the largest percentages of minorities, low-income and uninsured rates in the state that sought medical care in the state-owned hospital.

In large scale multi-sites epidemiological investigations in metropolitan areas with continuous traffic-related pollution, the statistical significance of the effect estimates due to the large underlying populations and the statistical power gained through meta-analytic techniques has strengthened the relative findings. However, consistency of findings rather than the statistical significance guides conclusions of analyses in smaller settings including smaller population groups (e.g. minorities) and more rare types of exposures such as smoke and dust. In this study, positive associations between emergency visits and outdoor air pollution were observed during winter. We previously identified that winter pollution was influenced by domestic wood burning and regional transports; both pollution types were variable and episodic (Chalbot et al., 2013). In addition, behavioral characteristics may also influence the effect estimates (Rodopoulou et al., 2014). Overall, the positive effect estimates, albeit statistically insignificant, provide indications of a potential association that merits further investigation.

5 Conclusion

Overall, air pollution is an important risk factor for cardiovascular and respiratory morbidity. Our analysis in the U.S. region with the highest heart disease incidence supported the evidence of effects on both CVD and respiratory emergencies due mainly to outdoor PM_{2.5}, especially for hypertension, heart failure and COPD during the cold period. No effects were estimated during the warm period. This disparity suggested the modification of the effect, perhaps due to the difference in particle sources types and origin. These findings call for further research into the associations between cardiovascular outcomes and outdoor PM_{2.5} in a region characterized by high rates of CVD, with a high percentage of minorities demographically and with air having particulate properties that are unique, having temporally variable fine particle chemical properties predominated by particulate matter from wood burning. This study suggests that biomass burning smoke may induce adverse health effects in the stroke and heart disease belt.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- ▶ The role of air pollution in the region with the highest stroke incidence rate was examined
- ▶ Winter PM_{2.5} induced effects on cardiovascular and respiratory emergencies
- ▶ Effects were stronger for whites rather than Blacks/African-Americans

Figure 1. Daily Cardiovascular (a) and Respiratory (b) Emergency Room Visits (a) and 24-hr $PM_{2.5}$ (c) and max 8-hr O_3 (d) in Central Arkansas.

Table 1

Daily frequency of hospital emergency visits, air pollution and meteorological data for the period 2002–2012.

Variable	Mean (SD)	Median (25 th –75 th percentile)	Total
Cardiovascular visits			
All	21 (11)	18 (12–28)	84,269
Per age group			
15–64 years	17 (9)	15 (10–23)	68,240
65+ years	4 (3)	3 (2–5)	16,023
Per gender			
Female	12 (7)	11 (7–16)	48,469
Male	9 (6)	8 (5–12)	35,797
Per race			
White	9 (6)	8 (5–12)	36,036
Black or African-American	12 (7)	10 (7–15)	46,809
Other	0 (0)	0 (0–0)	686
Cause specific			
Hypertension	16 (8)	14 (10–21)	64,206
Hypertensive heart disease and heart failure	1 (1)	1 (0–2)	4,461
Conduction disorders and cardiac dysrhythmias	2 (2)	1 (0–2)	6,271
Cerebrovascular	0 (1)	0 (0–1)	1,388
Respiratory visits			
All	7 (4)	7 (4–10)	29,402
Per age group			
15–64 years	7 (4)	6 (4–9)	27,104
65+ years	1 (1)	0 (0–1)	2,167
Per gender			
Female	4 (3)	4 (2–6)	17,568
Male	3 (2)	3 (1–4)	11,833
Per race			
White	3 (2)	3 (1–4)	12,577
Black or African-American	4 (3)	3 (2–6)	16,110
Other	0 (0)	0 (0–0)	398
Cause specific			
Acute Respiratory Infections	3 (2)	3 (2–5)	13,650
Pneumonia	1 (1)	0 (0–1)	2,412
Asthma	0 (1)	0 (0–0)	829
Chronic obstructive pulmonary disease	3 (2)	3 (1–4)	12,511
Air pollution and meteorology			Missing (%)
PM _{2.5} (µg/m ³)	12.4 (5.9)	11.3 (8.0–15.6)	3.68
O ₃ (ppbv)	40.0 (14.6)	39.0 (29.0–50.0)	0.07
Temperature (°C)	17.6 (9.2)	18.3 (10.0–25.6)	0.47
Relative Humidity (%)	56.3 (15.5)	56.0 (45.0–67.0)	0.72

Table 2

Demographic, Income and Health Insurance Characteristics on US, Arkansas, Little Rock/North Little Rock Metropolitan Statistical Area and The Communities (ZIP Codes) Totalling 50% of Emergency Room Visits at UAMS Medical Center.

Population characteristic	United States	Arkansas	Little Rock/North Little Rock MSA	ZIP codes with 50% of ER visits at UAMS Medical Center
White (%)	74.8	78.8	73.2	43.1
Black or African-American (%)	13.6	16.1	23	51.8
Other (%)	11.6	5.1	3.8	6.6
Per capita income (US \$)	27,334	21,274	26,103	20,994
Median family income (US \$)	62,982	48,491	30,183	34,042
% People living below the poverty level (%)	13.8	18	14.8	16.3
Private health insurance (%)	66.9	59.6	66.6	46.6
Public health insurance (%)	18.2	23.6	19.1	34.8
No insurance (%)	14.9	16.9	14.3	18.6
Heart diseases (age-adjusted hospitalization rate)				
<i>White</i>	360.3	435.7		
<i>Black</i>	461.3	534.0		
Stroke (age-adjusted hospitalization rate)				
<i>White</i>	75.6	103.9		
<i>Black</i>	109.8	144.8		
			Pulaski County	
			340.0	
			457.8	
			94.1	
			144.7	

Table 3

Percent Increase (and 95% Confidence Intervals (CIs)) in Cardiovascular And Respiratory Emergency Room Visits Overall, per Age Group, Gender and Race Associated with 10 $\mu\text{g}/\text{m}^3$ Increase in $\text{PM}_{2.5}$ and 10 ppbv Increase in O_3 for the Whole Study Period, for Cold Period (October to March) and Warm Period (April to September).

Emergency room visits	Annual	Cold period	Warm period
$\text{PM}_{2.5}$			
Cardiovascular visits			
All	-0.95 (-2.65, 0.77)	1.52 (-1.10, 4.20)	-2.86 (-5.11, -0.55)
Per age group			
15-64 years	-0.66 (-2.47, 1.19)	1.54 (-1.23, 4.40)	-2.27 (-4.70, 0.22)
65+ years	-2.22 (-6.28, 2.01)	1.43 (-4.77, 8.03)	-5.43 (-10.79, 0.25)
Per gender			
Female	-2.26 (-4.36, -0.11)	-1.28 (-4.48, 2.03)	-2.84 (-5.66, 0.07)
Male	0.86 (-1.76, 3.55)	5.41 (1.32, 9.66)	-2.88 (-6.30, 0.67)
Per race			
White	0.47 (-2.10, 3.12)	4.40 (0.45, 8.51)	-2.71 (-6.14, 0.85)
Black or African American	-1.90 (-4.04, 0.29)	-0.16 (-3.47, 3.26)	-3.14 (-5.97, -0.23)
Respiratory visits			
All	0.68 (-2.18, 3.63)	1.45 (-2.64, 5.72)	-0.78 (-4.80, 3.41)
Per age group			
15-64 years	-0.13 (-3.07, 2.91)	0.54 (-3.69, 4.95)	-1.39 (-5.53, 2.93)
65+ years	10.07 (-0.29, 21.51)	13.04 (-1.14, 29.67)	4.12 (-10.03, 20.51)
Per gender			
Female	0.36 (-3.31, 4.17)	2.18 (-3.00, 7.63)	-1.74 (-6.98, 3.80)
Male	1.16 (-3.03, 5.52)	0.35 (-5.47, 6.54)	0.59 (-5.36, 6.92)
Per race			
White	3.31 (-0.90, 7.69)	4.53 (-1.34, 10.75)	0.68 (-5.24, 6.98)
Black or African-American	-1.08 (-4.83, 2.82)	-0.57 (-5.85, 5.01)	-1.61 (-6.97, 4.05)
O_3			
Cardiovascular visits			
All	-0.68 (-1.61, 0.27)	0.93 (-0.87, 2.76)	-0.85 (-1.99, 0.29)
Per age group			
15-64 years	-0.75 (-1.75, 0.26)	1.24 (-0.67, 3.19)	-1.10 (-2.30, 0.13)
65+ years	-0.43 (-2.74, 1.94)	-0.34 (-4.58, 4.09)	0.12 (-2.75, 3.08)
Per gender			
Female	-1.11 (-2.28, 0.07)	0.74 (-1.50, 3.03)	-1.43 (-2.85, 0.02)
Male	-0.08 (-1.52, 1.37)	1.17 (-1.57, 3.99)	-0.07 (-1.81, 1.70)
Per race			
White	-0.36 (-1.77, 1.08)	2.35 (-0.37, 5.15)	-1.07 (-2.79, 0.68)
Black or African American	-0.99 (-2.18, 0.22)	-0.16 (-2.44, 2.16)	-0.78 (-2.22, 0.68)
Respiratory visits			

Emergency room visits	Annual	Cold period	Warm period
All	-0.14 (-1.68, 1.43)	0.76 (-1.92, 3.52)	-0.81 (-2.73, 1.15)
Per age group			
15–64 years	-0.11 (-1.71, 1.52)	1.05 (-1.73, 3.92)	-0.94 (-2.93, 1.10)
65+ years	-0.76 (-6.00, 4.77)	-2.12 (-10.81, 7.42)	-0.15 (-6.80, 6.97)
Per gender			
Female	0.56 (-1.45, 2.61)	2.10 (-1.32, 5.63)	-1.04 (-3.57, 1.55)
Male	-1.16 (-3.40, 1.15)	-1.24 (-5.04, 2.72)	-0.46 (-3.35, 2.51)
Per race			
White	0.76 (-1.50, 3.07)	0.20 (-3.59, 4.13)	1.15 (-1.74, 4.13)
Black or African-American	-0.88 (-2.93, 1.21)	1.20 (-2.31, 4.83)	-2.44 (-5.00, 0.18)

Table 4

Percent Increase (and 95% Confidence Intervals (CIs)) in Emergency Room Visits for Indicated Cardiovascular and Respiratory Causes Associated with 10 Units ($\mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$ and ppbv for O_3) Increase in Corresponding Pollutant for the Whole Study Period, for Cold Period (October to March) and Warm Period (April to September).

Association under investigation	2002–2012	Cold period	Warm period
Cardiovascular causes			
Hypertension			
$\text{PM}_{2.5}$	−1.03 (−2.69, 0.67)	2.03 (−0.57, 4.69)	−3.17 (−5.36, −0.92)
O_3	−0.96 (−1.88, −0.02)	0.63 (−1.15, 2.43)	−1.02 (−2.14, 0.12)
Hypertensive heart disease & Heart failure			
$\text{PM}_{2.5}$	−1.30 (−7.38, 5.18)	7.79 (−2.01, 18.57)	−7.92 (−15.63, 0.49)
O_3	−1.26 (−4.65, 2.25)	3.96 (−2.67, 11.03)	−2.62 (−6.73, 1.68)
Conduction disorders and cardiac dysrhythmias			
$\text{PM}_{2.5}$	−0.73 (−6.71, 5.63)	−3.50 (−12.26, 6.15)	1.98 (−6.30, 11.00)
O_3	2.60 (−0.73, 6.04)	5.20 (−1.43, 12.27)	0.39 (−3.42, 4.36)
Cerebrovascular			
$\text{PM}_{2.5}$	−3.47 (−14.53, 9.02)	7.54 (−10.34, 28.99)	−14.95 (−28.12, 0.64)
O_3	−6.45 (−12.45, −0.04)	−4.44 (−15.41, 7.96)	−8.74 (−16.02, −0.82)
Respiratory causes			
Acute Respiratory Infections			
$\text{PM}_{2.5}$	−1.34 (−5.31, 2.79)	−0.58 (−6.21, 5.38)	−1.10 (−6.78, 4.92)
O_3	−0.75 (−2.94, 1.49)	2.00 (−1.74, 5.88)	−2.38 (−5.12, 0.44)
Pneumonia			
$\text{PM}_{2.5}$	−2.91 (−11.07, 6.01)	2.70 (−8.72, 15.54)	−8.14 (−19.49, 4.80)
O_3	−4.18 (−8.70, 0.58)	−1.41 (−8.76, 6.53)	−5.99 (−11.79, 0.18)
Asthma			
$\text{PM}_{2.5}$	13.75 (−1.44, 31.28)	2.39 (−16.65, 25.78)	20.09 (−3.11, 48.86)
O_3	2.78 (−4.89, 11.06)	2.95 (−10.88, 18.92)	0.44 (−8.79, 10.59)
Chronic obstructive pulmonary disease			
$\text{PM}_{2.5}$	3.08 (−0.98, 7.30)	3.48 (−2.12, 9.40)	−0.11 (−5.88, 6.02)
O_3	1.14 (−1.04, 3.37)	−0.38 (−4.03, 3.40)	1.68 (−1.14, 4.58)

Table 6

Percent Increase (95% Confidence Intervals (CIs)) in Emergency Room Visits Associated with 10 Units ($\mu\text{g}/\text{m}^3$ for $\text{PM}_{2.5}$ and ppbv for O_3) Increase in Pollutants. Results from Two – Pollutant Models.

Emergency room visits	$\text{PM}_{2.5}$		O_3	
	Single pollutant	O_3 adjusted	Single pollutant	$\text{PM}_{2.5}$ adjusted
Cardiovascular visits				
All	−0.95 (−2.65, 0.77)	−0.66 (−2.45, 1.16)	−0.68 (−1.61, 0.27)	−0.52 (−1.53, 0.49)
Cause-specific				
Hypertension	−1.03 (−2.69, 0.67)	−0.58 (−2.34, 1.21)	−0.96 (−1.88, −0.02)	−0.80 (−1.79, 0.21)
Hypertensive heart disease and heart failure	−1.30 (−7.38, 5.18)	−0.50 (−6.95, 6.40)	−1.26 (−4.65, 2.25)	−1.47 (−5.09, 2.30)
Conduction disorders and cardiac dysrhythmias	−0.73 (−6.71, 5.63)	−2.19 (−8.33, 4.36)	2.60 (−0.73, 6.04)	2.82 (−0.69, 6.46)
Cerebrovascular	−3.47 (−14.53, 9.02)	0.79 (−11.30, 14.53)	−6.45 (−12.45, −0.04)	−7.53 (−13.91, −0.66)
Respiratory visits				
All	0.68 (−2.18, 3.63)	1.01 (−1.97, 4.09)	−0.14 (−1.68, 1.43)	−0.63 (−2.26, 1.04)
Cause-specific				
Acute respiratory infections	−1.34 (−5.31, 2.79)	−0.82 (−4.96, 3.50)	−0.75 (−2.94, 1.49)	−1.08 (−3.41, 1.30)
Pneumonia	−2.91 (−11.07, 6.01)	−0.59 (−9.26, 8.90)	−4.18 (−8.70, 0.58)	−4.48 (−9.25, 0.54)
Asthma	13.75 (−1.44, 31.28)	12.94 (−2.99, 31.50)	2.78 (−4.89, 11.06)	1.19 (−6.62, 9.64)
COPD	3.08 (−0.98, 7.30)	2.86 (−1.35, 7.24)	1.14 (−1.04, 3.37)	0.46 (−1.82, 2.79)