Science of the Total Environment xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

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

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HIGHLIGHTS

- The air pollution effect in the United State stroke belt region was examined
- Winter $PM_{2.5}$ induced effects on cardiovascular and respiratory emergencies
- Effects were stronger for whites rather than Blacks/African-Americans

ARTICLE INFO

Article history:
Received 12 March 2015
Received in revised form 8 June 2015
Accepted 15 June 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Fine particles
Ozone
Heart disease
Asthma
Stroke
Nitrate particles
Biomass burning

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% (confidence interval) CI: −1.10%, 4.20%]; 1.45% [95%CI: −2.64%, 5.72%] per 10 μg/m^3) and O_3 (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 O_3 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.
Conclusion: Outdoor particulate pollution during winter had an effect on cardiovascular morbidity in central Arkansas, the region with high stroke and heart disease incidence rates.

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 (i.e., emergency visits and admissions) with outdoor fine particulate matter ($PM_{2.5}$: particles with diameter <2.5 μm) and ozone (O_3) 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; WHO, 2013; Wellenius et al., 2012). Furthermore, studies showed that risk for stroke may increase even at low PM_{10} 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 $PM_{2.5}$

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http://dx.doi.org/10.1016/j.scitotenv.2015.06.056
0048-9697/

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., 2007; 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 3083 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; U.S. average $28,051), with many counties being among the poorest in the U.S.. Before Affordable Care Act implementation, about 1-in-4 residents lacked health insurance due to cost.

$PM_{2.5}$ levels in Arkansas, U.S., 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 O_3, ambient levels were slightly higher than the 2008 NAAQS (the 98th percentile of the daily 8-h 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 O_3 did not follow the substantial decreases of SO_2 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 O_3 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 (i.e., 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 Blacks or African Americans. Residents of Hispanic or Latino origin accounted for 6.8% (5.8% in Pulaski County) of the population. $PM_{2.5}$ and O_3 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-h $PM_{2.5}$ mass concentrations and the daily 8-h maximum O_3 concentrations 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 bronchiolitis): 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 O_3 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). The lag structure was selected a-priori based on previous findings and indications of longer patters of associations with respiratory admissions (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 on 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 21 and 7, 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 Blacks or African-Americans (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 (6271). Most of the respiratory ER visits were due to acute respiratory infections (13,650) and COPD (12,511). The mean 24-h $PM_{2.5}$ and 8-h maximum O_3 concentrations were 12.4 $\mu g/m^3$ and 40.0 ppbv for the 2002–2012 period with less than 4% and 1% of missing measurements for $PM_{2.5}$ and O_3, respectively (Table 1). The mean ambient temperature and relative humidity were 17.6 °C and 56.3%, respectively.