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Source apportionment of fine particulate matter and risk of term low birth weight in California: Exploring modification by region and maternal characteristics

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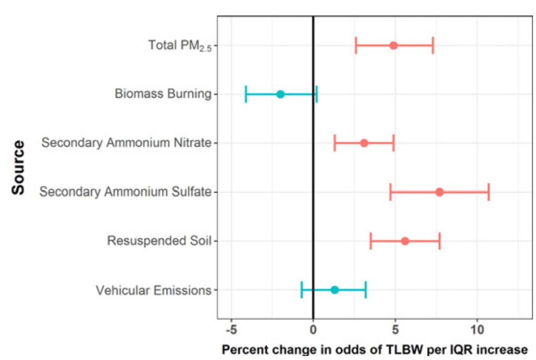
HIGHLIGHTS

- Explored associations between $PM_{2.5}$ sources and term low birth weight
- Source apportionment was performed using positive matrix factorization.
- Some $PM_{2.5}$ sources were more harmful than other sources.
- Associations were modified by region and maternal characteristics.

GRAPHICAL ABSTRACT



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ABSTRACT

Previous studies have demonstrated associations between fine particulate matter ($PM_{2.5}$) and risk of term low birth weight (TLBW; birth weight < 2500 g and gestational weeks ≥ 37 weeks). However, it remains unclear which $PM_{2.5}$ sources mainly contribute to these associations, and which subgroups (e.g. by residential region and maternal characteristics) may be more susceptible to these exposures. Using California birth records and $PM_{2.5}$ data from eight monitoring sites from 2002 to 2009, we examined the relationship between exposures to total $PM_{2.5}$ and $PM_{2.5}$ sources and risk of TLBW. Source apportionment was performed for each site using Positive Matrix Factorization, and five $PM_{2.5}$ sources (i.e., secondary ammonium sulfate, secondary ammonium nitrate, vehicular emissions, biomass burning, and resuspended soil) were included in our analysis. Mean gestational and trimester exposures were calculated for mothers with ZIP codes located within a 20 km radius of monitors (N = 1,050,330). Logistic regression was conducted and adjusted for maternal age, race/ethnicity, and education, as well as gestational age, year of birth, apparent temperature exposure during gestation, and neighborhood level percentage of households below poverty level. Increased risks of TLBW associated with each interquartile range increase in exposure were 4.9% (95% confidence interval: 2.6, 7.3) for total $PM_{2.5}$, 7.7% (4.7, 10.7) for secondary ammonium sulfate, 5.6% (3.5, 7.7) for resuspended soil, and 3.1% (1.3, 4.9) for secondary ammonium nitrate. Differences in associations were found between inland and coastal regions, and between northern and southern regions for several sources. Results also showed effect measure modification by maternal race/ethnicity and education, with the lowest risk of TLBW associated with $PM_{2.5}$ exposures found in mothers with at least a college education and Asian mothers. Some $PM_{2.5}$ sources may be more harmful than others,

Abbreviations: IQR, interquartile range; $PM_{2.5}$, particulate matter with an aerodynamic diameter < 2.5 μm; TLBW, term low birth weight; LBW, low birth weight.

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and a better understanding of the relative toxicity of $PM_{2.5}$ from each source could lead to more targeted and cost-effective regulations to protect public health.

1. Introduction

Low birth weight (LBW, birth weight < 2500 g) has been associated with increased neonatal morbidity and mortality, as well as increased risk of health issues and developmental delays later in life (Belbasis et al., 2016; Johnson and Schoeni, 2011; Kochanek et al., 2016). Approximately 8.0% of all babies born in the US in 2014 were LBW (~318,000) (Hamilton et al., 2015), constituting a significant public health problem. Although most cases of LBW are associated with premature birth (gestational age < 37 weeks), about 30% of LBW babies are born at full term (gestational age ≥ 37 weeks) (Hamilton et al., 2015). Factors that have been shown to contribute to LBW include air pollution exposure, smoking, alcohol and drug use during pregnancy, maternal body mass index and weight gain during pregnancy, high blood pressure and other chronic health conditions (de Bernabé et al., 2004). LBW disproportionately affects babies born to mothers who are non-Hispanic Black, of lower socioeconomic status, or are <20 or >35 years of age at the time of giving birth (Blumenshine et al., 2010; Hamilton et al., 2015).

Several studies have found significant associations between exposure to fine particulate matter ($PM_{2.5}$, particulate matter with an aerodynamic diameter < 2.5 μm) and adverse health conditions, including cardiovascular diseases, respiratory diseases, and birth outcomes such as term birth weight and risk of LBW (Sun et al., 2016). The findings of these studies, however, have been inconsistent. For example, a multi-state study found associations between exposure to $PM_{2.5}$ mass and risk of LBW in Minnesota, New Jersey, New York, and Wisconsin, but not in Connecticut, Maine, and Utah (Harris et al., 2014). Although the US EPA regulates $PM_{2.5}$ based on total mass, $PM_{2.5}$ is composed of a heterogeneous mixture of chemical constituents originating from a variety of sources (Code of Federal Regulations, 2013; Sowlat et al., 2016). Differences in the toxicity and spatio-temporal distributions of constituents and sources of $PM_{2.5}$ could explain the heterogeneity of results across studies (Bell et al., 2010; Hao et al., 2016; Sun et al., 2016). Only a few studies have examined associations between different $PM_{2.5}$ sources and adverse birth outcomes and even fewer have explored whether these associations are modified by region or by demographic (e.g., maternal age, race, education), and socioeconomic factors (Bell et al., 2010; Laurent et al., 2014; Pereira et al., 2014).

Our study investigated whether prenatal exposure to ambient $PM_{2.5}$ and its sources were associated with birth outcomes (i.e., term birth weight and term LBW) in a 2002 to 2009 California birth cohort using source data obtained from a receptor-based source apportionment model. There are two principal approaches used for source apportionment of ambient PM: top-down receptor-based techniques and bottom-up chemical transport techniques (Johnson et al., 2011). The receptor-based Positive Matrix Factorization (PMF) source-apportionment technique used in this study provides better temporal resolution and identification of local sources compared to chemical transport modeling techniques used in other studies (Laurent et al., 2014; Laurent et al., 2016). We further examined whether the relationships between sources of $PM_{2.5}$ and outcomes differ by maternal race/ethnicity, education, and region to help identify high-risk subgroups. Investigating the relative toxicity of different sources of $PM_{2.5}$ may be useful from a regulatory standpoint by allowing targeting of emission sources that are most toxic to public health.

2. Material and methods

2.1. Study population

We obtained records of live singleton births in California between 2002 and 2009 from the California Department of Public Health (California Department of Health Services, 2012). These records included infant characteristics, such as birth date, birth weight, gestational age, and sex, as well as maternal characteristics, such as race/ethnicity, educational attainment, age, and residential ZIP Code at the time of delivery. Neighborhood socio-economic status was represented by the percentage of households with income below the poverty line in each ZIP Code Tabulation Area (ZCTA) as ascertained from the American Community Survey 5-year data (2007–2011) (United States Census Bureau/American FactFinder, 2011). We excluded births where gestational age was <37 weeks or >44 weeks, and births with implausible combinations of gestational age and birth weight (Alexander et al., 1996). IRB approval of the study protocol was obtained from the State of California Committee for the Protection of Human Subjects prior to beginning this study.

2.2. Source apportionment and exposure assessment

24-hour time-integrated $PM_{2.5}$ samples were collected between 2002 and 2009 every third day at monitoring sites in Sacramento (SAC), San Jose (SJO), Fresno (FRE), Bakersfield (BAK), Rubidoux (RUB), and El Cajon (ELC), and every sixth day at sites in Los Angeles (LAX) and Simi Valley (SVY). $PM_{2.5}$ samples were analyzed and the mass concentrations of fine PM, organic carbon (OC), elemental carbon (EC), ions, and metals were quantified. Source apportionment of $PM_{2.5}$ mass concentrations was then performed using PMF receptor model software (version 3.0) for each sampling site, separately (Hasheminassab et al., 2014a; Hasheminassab et al., 2014b; U.S. Environmental Protection Agency, 2014). Sources included in our analysis were biomass burning, secondary ammonium nitrate, secondary ammonium sulfate, resuspended soil, and vehicular emissions. These sources were used in our previous study (Ostro et al., 2016). Additional details regarding PMF and site-specific source characteristics are available elsewhere (Hasheminassab et al., 2014b).

To avoid exposure misclassification (Ebisu et al., 2014), we only included mothers whose population weighted ZCTA centroids were within 20 km of monitor locations. We calculated four different exposure metrics for each source, representing full gestational and trimester exposures (i.e. 1st, 2nd, and 3rd trimester). First, we took weekly averages of exposures to avoid bias due to different measurement frequency. Full gestational exposure was then estimated by averaging weekly exposures over the full gestational period (the time from last menstrual period to the delivery date) for each source. Trimester exposures were estimated by averaging weekly exposures for each source over each specific trimester (weeks 1–13 for the 1st trimester, weeks 14–26 for the 2nd trimester, and week 27 to delivery for the 3rd trimester). To avoid measurement error, we did not assign exposure levels for mothers whose weekly exposure data were missing for >25% of the total weeks during any trimester. These exposure estimations are similar to those used in other studies (Basu et al., 2014; Ebisu and Bell, 2012).

Apparent temperature, an index of overall temperature and humidity, was calculated from daily data obtained from the U.S. EPA, California