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Relationship Between Birth Weight and Exposure to Airborne Fine Particulate Potassium and Titanium During Gestation

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Abstract

Airborne particles are linked to numerous health impacts, including adverse pregnancy outcomes. Most studies of particles examined total mass, although the chemical structure of particles varies widely. We investigated whether mother's exposure to potassium (K) and titanium (Ti) components of airborne fine particulate matter ($PM_{2.5}$) during pregnancy was associated with birth weight or risk of low birth weight (<2500 gm) for term infants. The study population was 76,788 infants born in four counties in Connecticut and Massachusetts, US, for August 2000-February 2004. Both K and Ti were associated with birth weight. An interquartile range (IQR) increase K was associated with an 8.75% (95% confidence interval (CI): 1.24–16.8%) increase in risk of low birth weight. An IQR increase in Ti was associated with a 12.1% (95% CI: 3.55–21.4%) increase in risk of low birth weight, with an estimate of 6.41% (95% CI: −5.80–20.2%) for males and 16.4% (95% CI: 5.13–28.9%) for females. Results were robust to sensitivity analysis of first births only, but not adjustment by co-pollutants. Disentangling the effects of various chemical components is challenging because of the covariance among some components due to similar sources. Central effect estimates for infants of African-American mothers were higher than those of white mothers, although the confidence intervals overlapped. Our results indicate that exposure to airborne potassium and titanium during pregnancy is associated with lower birth weight. Associations may relate to chemical components of sources producing K and Ti.

Keywords

air pollution; pregnancy; $PM_{2.5}$; low birth weight; titanium; potassium

1. Introduction

Airborne particulate matter of various size ranges have been linked to numerous human health endpoints, especially for fine particles, those with aerodynamic diameter ≤2.5 μm

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($PM_{2.5}$) (Pope and Dockery, 2006). The chemical structure of $PM_{2.5}$ exhibits strong spatial and temporal heterogeneity (Bell et al., 2007a); however, this pollutant is regulated by total mass and size only, without regard to chemical form. A growing body of scientific evidence suggests that the toxicity of particles differs according to their source and chemical composition, including recent studies of $PM_{2.5}$ sources and components for mortality in Santiago, Chile (Cakmak et al., 2009); and Detroit and Seattle, US (Zhou et al., 2011); and for hospital admissions in New York, US (Ito et al., 2011; Lall et al., 2011); and multi-city US studies (Peng et al., 2009b; Zanobetti et al., 2009). Understanding which characteristics of particles are most harmful was identified as a critical research need by the US Environmental Protection Agency and National Resource Council committees (NRC Committee on Research Priorities for Airborne Particulate Matter Board on Environmental Studies and Toxicology, 2004; U.S. EPA, 2009).

Associations between exposure to particles during pregnancy and adverse pregnancy outcomes has been observed in several studies, although results are inconsistent across studies and comparisons are hindered by differences in exposure assessment, statistical methods, and pollution characteristics (Maisonet et al., 2004; Slama et al., 2008; Woodruff et al., 2009). The International Collaboration on Air Pollution and Pregnancy Outcomes applied a uniform methodology to 14 datasets in 9 countries, finding that a 10 μg/m^3 increase in PM_{10} over pregnancy, adjusted for socio-economic status, was associated with increased risk of low birth weight from 0.63% for the Netherlands to 1.15% in Vancouver, with statistically significant results for 6 of the 14 datasets (Parker et al., 2011). The differences in effects across regions may relate to differences in the particles' chemical composition. A recent meta-analysis found that a 10 μg/m^3 increase in $PM_{2.5}$ over the gestational period was associated with a 9% (−10, 32%) increase in risk of low birth weight, but noted that future epidemiological studies should consider issues relating to particulate's chemical composition and source (Sapkota et al., in press).

To date, few studies have investigated $PM_{2.5}$ sources or chemical components in relation to pregnancy outcomes. Studies in Los Angeles Co., California related $PM_{2.5}$ from traffic and from road dust to increased risk of low birth weight (Wilhelm et al., In press) and specific $PM_{2.5}$ components (e.g., organic carbon, elemental carbon, ammonium nitrate) to risk of preterm delivery (Wilhelm et al., 2011). Our earlier work in Connecticut and Massachusetts, US, found that higher exposures to $PM_{2.5}$ from oil combustion and $PM_{2.5}$ components of elemental carbon, zinc, vanadium, and nickel were associated with increased risk of low birth weight (Bell et al., 2010).

In our previous work on $PM_{2.5}$ chemical components we used a hypothesis driven approach to select the components for study by choosing those that contribute 1% or more to $PM_{2.5}$ total mass (Bell et al., 2007a) and/or that exhibited potential associations based on a review of epidemiological and toxicological literature (Bell et al., 2011; Bell et al., 2009; Peng and Bell, 2010; Peng et al., 2009a). At the time of those studies, potassium (K) and titanium (Ti) were not chosen for analysis; however, recent work has found associations between exposures to these $PM_{2.5}$ components and health effects other than birth outcomes. Potassium has been linked to increased risk for respiratory hospital admissions for children (Ostro et al., 2009) and cardiovascular mortality (Ostro et al., 2008) in six California counties and total mortality in Seattle, US (Zhou et al., 2011). Also in California, Ti was associated with cardiovascular mortality (Ostro et al., 2008).

We investigated the relationship between these chemical components of $PM_{2.5}$ and birth weight. This work expands our earlier analysis to include new exposures of interest (K and Ti). We also examined potential differences in effects of air pollution by sex and race. A recent review of how sex modifies air pollution's health impacts noted that additional work in this area is needed, and differences in effects may relate to biological factors, occupational exposure, and activity patterns (Clougherty, 2010). Our previous work found higher effects for $PM_{2.5}$ on birth weight for infants of African-American mothers than infants of white mothers (Bell et al., 2007b). To the best of our knowledge, this is the first study of K or Ti and pregnancy outcomes.

2. Materials and Methods

2.1 Air Pollution and Weather Data

The Connecticut and Massachusetts Departments of Environmental Protection maintain ambient monitoring networks to measure $PM_{2.5}$ total mass for regulatory purposes. We obtained the Teflon filters for the study time period (August 2000 – February 2004) for five monitors located in the city of Hartford, CT in Hartford Co., CT; the city of New Haven, CT in New Haven Co, CT; Bridgeport and Danbury, CT in Fairfield, Co., CT; and Springfield, MA in Hampden County, MA. Each filter represents a day (24-hour period) of $PM_{2.5}$ for a specific location. For each filter, x-ray fluorescence was used to measure K and Ti levels of $PM_{2.5}$ by the Desert Research Institute (Desert Research Institute, 2011). The resulting data are 24-hour levels of $PM_{2.5}$ K and Ti for each of the five monitor locations, although data were not available for every day for every monitoring location. These filter analyses have been used in previous work for other chemical components, and additional information is available elsewhere (Bell et al., 2010; Gent et al., 2009).

The National Climatic Data Center provided daily data on weather variables (temperature, dew point temperature) for each county. We calculated daily apparent temperature, a measure of weather that incorporates the body’s collective response to temperature and humidity (Kalkstein and Valimont, 1986).

2.2 Health Data

The National Center for Health Statistics, Division of Vital Statistics, provided birth certificate data for Connecticut and Massachusetts for August 2000 to February 2004. Birth certificate data include medical information as well as responses from the mother. Data include the birth weight, county of delivery, county of residence, month prenatal care began, parity, type of birth (primary caesarean section, repeat cesarean section, vaginal birth, unknown), gestational length (weeks), alcohol use by mother during pregnancy (yes/no), tobacco use of mother during pregnancy (yes/no), mother’s race, mother’s age, mother’s educational attainment (years), mother’s marital status (yes/no), and sex of infant. Due to the racial distribution of study subjects, mother’s race was categorized as African-American, white, and other. We did not include father’s race in the analysis; our previous work found mother’s and father’s race to be highly correlated in this study area (Bell et al., 2007b). We excluded births with counties of residence and delivery that were not identical or adjacent in order to minimize exposure bias. Study subjects were limited to births with gestations of 37 to 44 weeks and weights of 1,000 to 5,500g. Subjects with impossible gestational age and birth weight combinations were excluded (Alexander et al., 1996). Births with missing data on any covariates of interest were omitted, except for education and prenatal care for which a category for unknown was included (0.3% of births for prenatal care, 0.8% of births for education). After exclusions, 76,788 births were included in the analysis.

2.3 Exposure Assessment

For each day with data available, county-level exposures for each $PM_{2.5}$ chemical component (K and Ti) were calculated. Data were available for 92% of study days for the monitor at Hartford, CT, 88% at New Haven, CT, 59% at Springfield, MA, 32% at Bridgeport, CT, and 29% at Danbury, CT. Two monitors (Bridgeport and Danbury, CT) were located in the same county (Fairfield Co., CT). For this county, values from the two monitors were combined with population-weighted averaging based on 2000 Census tract values. For each study subject, exposure to each pollutant ($PM_{2.5}$ levels of K or Ti) was calculated for the gestation period. The time of gestation was estimated from birth certificate data using last menstrual period. Because the frequency of measurement can vary, weekly levels of exposure were generated, and these values were combined to estimate exposure over gestation. We adjusted for apparent temperature for each trimester of each pregnancy. These values were estimated with trimesters defined as 1–13 weeks, 14–26 weeks, and 27 weeks to birth.

2.4 Analysis of Risk

We used a linear model to estimate the associations between exposure to $PM_{2.5}$ K and Ti during pregnancy and birth weight as a continuous variable, and used a logistic model to estimate how these exposures are associated with risk of low birth weight (<2500 gm). Each chemical component was modeled separately. Covariates were included for alcohol use during pregnancy (yes/no), tobacco use during pregnancy (yes/no), year of birth, trimester prenatal care began (first, second, or third trimester; no care; unknown), sex of child, gestational length (weeks), mother's marital status (married, unmarried), mother's race (White, African-American, other), mother's educational attainment (<12, 12, 13–15, or >15 years; unknown), mother's age (<20, 20–24, 25–29, 30–34, 35–39, >39 years), type of delivery (primary caesarean, repeat caesarean, vaginal, unknown), mother's first child (yes/no), and apparent temperature for each trimester. Similar analyses have been performed in earlier studies for other exposures (Bell et al., 2010; Bell et al., 2007b; 2008; Maisonet et al., 2004; Parker et al., 2005; Wilhem and Ritz, 2003).

Sensitivity analysis was conducted using the subset of data for first births only, to account for multiparious mothers (i.e., mothers who gave birth two or more times in the study period). Interaction terms were used to investigate whether effects differed by sex of infant or mother's race. Additional sensitivity analysis was performed using two-pollutant models for K, Ti, and components that were previously identified as having an association with low birth weight (Bell et al., 2010) for component pairs with correlations no higher than 0.70.

3. Results

Table 1 provides summary statistics for the study population. Of the term births included in the study (N=76,788), 2.18% were low birth weight (<2500 gm). Use of alcohol or tobacco during pregnancy was low. Most study subjects were white, and about 95% were either white or African-American. The study population characteristics were similar across all counties (results not shown). Table 2 summarizes pollutant and weather exposures over the gestational period across the study area, and Supplemental Table 1 provides pollutant information by county.

Results from the linear model for K are shown in Figure 1 as the change in birth weight per interquartile range (IQR) increase in $PM_{2.5}$ levels of K. Figure 2 shows results from the logistic model as the percent increase in risk of low birth weight per IQR increase in K. Analogous results for Ti are provided in Figures 3 and 4. Higher levels of K or Ti during pregnancy were associated with lower birth weight and higher risk of low birth weight. An IQR increase in K was associated with an 8.75% (95% confidence interval (CI): 1.24, 16.8%) increase in risk of low birth weight, whereas an IQR increase of Ti was associated with a 12.1% (95% CI: 3.55, 21.4%) increase in risk of low birth weight. Additional numerical results are provided in the Supplemental Table 2.

Sensitivity analysis was performed for first births only to account more than one pregnancy from the same mother in the original dataset (Figures 1 to 4, Supplemental Table 2). This analysis reduced the sample size by 65% (26,534 study subjects compared to 76,788 subjects). The associations for K and Ti remained in both model structures in that the sign of the central estimates did not change, although 95% confidence intervals spanned 0 for the logistic model for both pollutants.

Interaction models were used to assess whether risk was higher for male or female infants (Figures 1 to 4, Supplemental Table 3). For both K and Ti, confidence intervals for male and female infants overlapped for either the linear or logistic model. Associations for risk of low birth weight only remained for female infants for K or Ti. For example, an IQR increase of K was associated with an 11.7% (95% CI: 2.27, 22.0%) increase in risk of low birth weight for female infants, and a 4.65% (95% CI: −5.60, 16.0%) increase for male infants.

Central estimates for infants of African-American mothers were higher than those of white mothers for K and Ti in the linear and logistic models (Figures 1 to 4, Supplemental Table 4), indicating potentially different effects by race; however, the confidence intervals overlapped. The increase in risk of low birth weight per IQR increase in gestational exposure to $PM_{2.5}$ K was 11.7% (95% CI: −2.57, 28.0%) for infants of African-American mothers and 7.55% (95% CI: −0.92, 16.8%) for infants of white mothers, whereas central effect estimates for $PM_{2.5}$ Ti were 23.7% (95% CI: 5.29, 45.4%) for infants of African-American mothers and 10.0% (95% CI: 0.15, 20.9%) for infants of white mothers.

Table 3 provides correlations of gestational exposures to $PM_{2.5}$ K and Ti as well as eight other $PM_{2.5}$ chemical components and $PM_{2.5}$ total mass. The other components shown in Table 3 are those that on average contribute 1% or more to $PM_{2.5}$ total mass.(Bell et al., 2007a) Correlations with K exceeded 0.70 only for zinc (0.73). Titanium was correlated (>0.70) with sulfur, silicon, elemental carbon, aluminum, and $PM_{2.5}$ total mass, with the highest correlation with aluminum (0.87).

Co-pollutant analysis was performed with components that were previously identified as having associations with low birth weight (Bell et al., 2010) that did not have correlations higher than 0.70 for with the pollutant of interest, K or Ti (correlations shown in Table 3). Results are provided in Supplemental Table 5. The change in birth weight for an IQR increase in K during gestation was robust to adjustment by aluminum, elemental carbon, titanium and silicon, with central estimates of −9.32 to −6.83 gm, but with adjustment by nickel became −6.18 gm (95% CI: −12.6, 0.22 gm). With adjustment by these co-pollutants, the percent change in risk of low birth weight per IQR increase in K remained positive (2.53 to 8.75%), although 95% confidence intervals spanned 0. Central estimate results for Ti and birth weight did not change direction with adjustment by K, nickel, vanadium, or zinc, with a range of 1.50 to 4.52 gm decrease per IQR increase in Ti exposure (compared with an original estimate of 6.64 gm), but confidence intervals of results with co-pollutant adjustment spanned 0. Similarly, central estimates for risk of low birth weight per IQR increase in Ti remained positive at 8.23 to 10.8%, which were lower than the original estimate of 12.1%, and confidence intervals of results with co-pollutant adjustment spanned 0.

4. Discussion

Lower birth weight, while not a disease outcome, has been linked to a range of adverse health endpoints ranging from academic difficulties (Klebanov et al., 1994; Roberts et al., 2007) to coronary heart disease (Vos et al., 2006) to premature mortality (McCormick, 1985). In the US, 8.2% percent of births are at low birth weight, representing over 300,000 infants each year (Centers for Disease Control and Prevention, 2010). Whereas our previous work indicated that birth weight is associated with exposure to $PM_{2.5}$ total mass, $PM_{2.5}$ from oil combustion, and $PM_{2.5}$ components of elemental carbon, zinc, vanadium, and nickel (Bell et al., 2010; Bell et al., 2007b; 2008), this study identified associations for the chemical components of K and Ti.

The associations with birth weight for K and Ti are on the same order of magnitude as associations identified earlier for $PM_{2.5}$ total mass and several other chemical components (Bell et al., 2010). The decrease in birth weight per IQR increase in exposure was 7.68g for K and 6.64g for Ti, whereas for components studied earlier (aluminum, chloride, elemental carbon, nickel, silicon, sulfur, vanadium, and zinc) the central estimate ranged from 2 to 7 g. The estimates for K and Ti are higher than for $PM_{2.5}$ total mass, which had a decrease of 3g (95 CI: −2, 9 g) per IQR increase in gestational exposure.

Although previous research has not explored K or Ti exposure in relation to pregnancy outcomes, other studies have indicated potentially harmful human health effects from $PM_{2.5}$ K or Ti for other health endpoints. The mortality impact of long-term exposure to $PM_{2.5}$ chemical components was investigated using data from the California Teacher's study. An IQR of $PM_{2.5}$ K (0.05 $\mu g/m^3$) was associated with a hazards ratio of 1.90 (95% CI: 1.63, 2.21) for all cause mortality, 1.72 (95% CI: 1.40, 2.11) for cardiopulmonary mortality, 2.59 (95% CI: 1.79, 3.73) for ischemic heart disease, and 1.22 (95% CI: 0.82, 1.83) for pulmonary mortality (Ostro et al., 2010). The authors note that they could not disentangle the independent effects of the components due high correlations among many components. Daily exposure to $PM_{2.5}$ K was associated with risk of children's hospital admissions for respiratory causes, pneumonia, and acute bronchitis in a study of six California counties. (Ostro et al., 2009). In other studies of six California counties, authors found associations with K and risk of cardiovascular mortality, and Ti and respiratory mortality (Ostro et al., 2007).

One of the studies of six California counties found evidence for effect modification by race/ethnicity for the effects of K and Ti on cardiovascular mortality. Effects for Hispanic populations were statistically higher than for non-Hispanic white populations (Ostro et al., 2008). Our findings indicate potentially higher susceptibility to infants of African-American mothers than white mothers, although results were not conclusive and additional research is necessary. Effect modification by race may relate to differences in baseline health status, socio-economic status and access to health care, biology, or other factors. The differential impact of air pollution by race is of particular importance, given that African-Americans are at higher risk of low birth weight. Including pre-term births, African-Americans have an estimated 11.6% of births at low birth weight in the US in 2008, compared to 5.7% for Hispanic infants and 5.4% for non-Hispanic whites (Centers for Disease Control and Prevention, 2010). For our dataset, 95% of study subjects were White or African American. Future research should investigate potential effect modification by additional race/ethnicity categories, including Hispanics. In the California study, K and Ti cardiovascular mortality effects were observed for women, but not men, although effect estimates were not statistically different by sex (Ostro et al., 2008). We also found that risk of low birth weight was associated with exposure in K and Ti for female infants, but not male infants, although confidence intervals for males and females overlapped.

All $PM_{2.5}$ chemical components have multiple sources, and all sources produce multiple components, thus distinguishing the effects of different $PM_{2.5}$ chemical components can be challenging. Airborne potassium can be derived from crustal material (i.e., soil, dirt) from agriculture, mining, and construction activities (Adams et al., 1988; Schlesinger, 2007). Potassium also results from combustion of organic material, such as the wood burning, and has been used as an indicator for biomass burning (Schlesinger, 2007; Thurston et al., 2011; Watson et al., 2001). Titanium is often considered part of the crustal material, but also produced in the manufacture of metals, and through steam generators and boilers (Hains et al., 2007; Wien et al., 2001).

The associations we observed for K and Ti may relate to other components from similar sources, as the levels of some components can co-vary. For example, our previous work found associations between low birth weight and $PM_{2.5}$ chemical components for which K and Ti exhibit some correlation: elemental carbon (0.82 correlation with Ti), vanadium (0.61 correlation with K, 0.66 with Ti), nickel (0.65 correlation with K or Ti), silicon (0.85 correlation with Ti), and zinc (0.73 correlation with K) (Bell et al., 2010). Thus, risk effect estimates observed for a given chemical component may reflect the toxicity of a different component or set of components with similar sources. Issues that warrant further investigation include the study of impacts from specific sources, as well as spatial misalignment and the possible resulting exposure misclassification due to spatial heterogeneity of concentrations within a community.

Limitations of this study include the use of birth certificate data. Although this data source is widely used, several studies have identified quality concerns for birth certificate data. Potential shortcomings relate to the ability to identify medical conditions such as pre-pregnancy diabetes mellitus and gestational diabetes mellitus (Devlin et al., 2009), missing or uncertain last menstrual period (Martin, 2007), pregnancy complications (Zollinger et al., 2006), or identification of facial cleft defects (Green et al., 1979). Birth certificate data on tobacco use and alcohol use during pregnancy, which are self-reported by the mother, are under-reported (Northam and Knapp, 2006). In contrast, the variable for tobacco use showed 84% agreement between birth certificates and hospital records in a study of 395 births from 42 hospitals in North Carolina, US, although data on hospital records may also have been self reported (Buescher et al., 1993). Data on parents demographics, delivery method, and birth weight were found to be valid (Buescher et al., 1993; Northam and Knapp, 2006; Piper et al., 1993; Zollinger et al., 2006). Fortunately for this study, the key variable of interest (birth weight) is one of the most accurate birth certificate variables. However, the dataset was restricted to births within a specific range of gestational ages, so inaccuracies in that variable may have an impact on results. Other variables that are more problematic, such as tobacco use during pregnancy, were used in this study as potential confounders, although this dataset may not be appropriate if these were the key variables of interest. Some issues regarding the accuracy of birth certificate data may be alleviated with cohort data, although this method would be far more expensive. An additional research need is whether accuracy on birth certificates varies by sub-population (Reichman and Schwartz-Soicher, 2007).

Another key limitation is exposure misclassification. This study used the county as the spatial unit, although pollutant concentrations can vary within communities. This spatial heterogeneity may be larger for $PM_{2.5}$ chemical components than for $PM_{2.5}$ total mass (Bell et al., 2007a; Peng and Bell, 2010). Exposure was based on the residence at time of delivery, although the mother may have moved during pregnancy introducing exposure misclassification. A recent review of studies assessing residential mobility during pregnancy found that overall mobility rates were 9–32% and that most moves were a short distance, with a median of less than 10km (Bell and Belanger, in press). Although results were inconsistent across studies, some research indicated that mobility during pregnancy varied by population with respect to age, marital status, and race. Other limitations of this study include residual confounding by maternal weight gain or income. Although we adjusted by mother's educational attainment, this is not a full proxy for socio-economic status, which includes a range of sources of income, past income, etc. (O'Neill et al., 2003).

The biological mechanisms of how K and Ti could affect birth outcomes is not fully understood, nor are the mechanisms for the role of $PM_{2.5}$ total mass in pregnancy outcomes. Research identifying hospital admissions and mortality effects of K and Ti suggest that these are exposures of interest for research on other health outcomes. Exposure could impact birth weight through direct effects on the fetus through the placenta or from impacts on the health of the mother (Glinianaia et al., 2004). Some have hypothesized that $PM_{2.5}$ affects pregnancy outcomes by changing heart rate variability, disruption of endocrine and nervous systems, and alveolar inflammation (Glinianaia et al., 2004; Maisonet et al., 2004; Šrám et al., 2005).

Conclusions

This work adds evidence supporting the hypothesis that exposure to airborne particles during pregnancy can affect birth weight, and that some chemical components may be more harmful than others. Results indicate that exposure to airborne K and Ti during pregnancy is associated with lower birth weight, with some evidence that risks are higher for infants of African -American mothers than white mothers. Additional research is needed to disentangle the health impacts of $PM_{2.5}$ K and Ti from those of other sources and components.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Highlights

- We examined exposure to fine particulate matter components of potassium and titanium during pregnancy.
- Exposure to potassium and titanium were associated with lower birth weight.
- Results are suggestive of a higher risk for infants of African-American mothers.

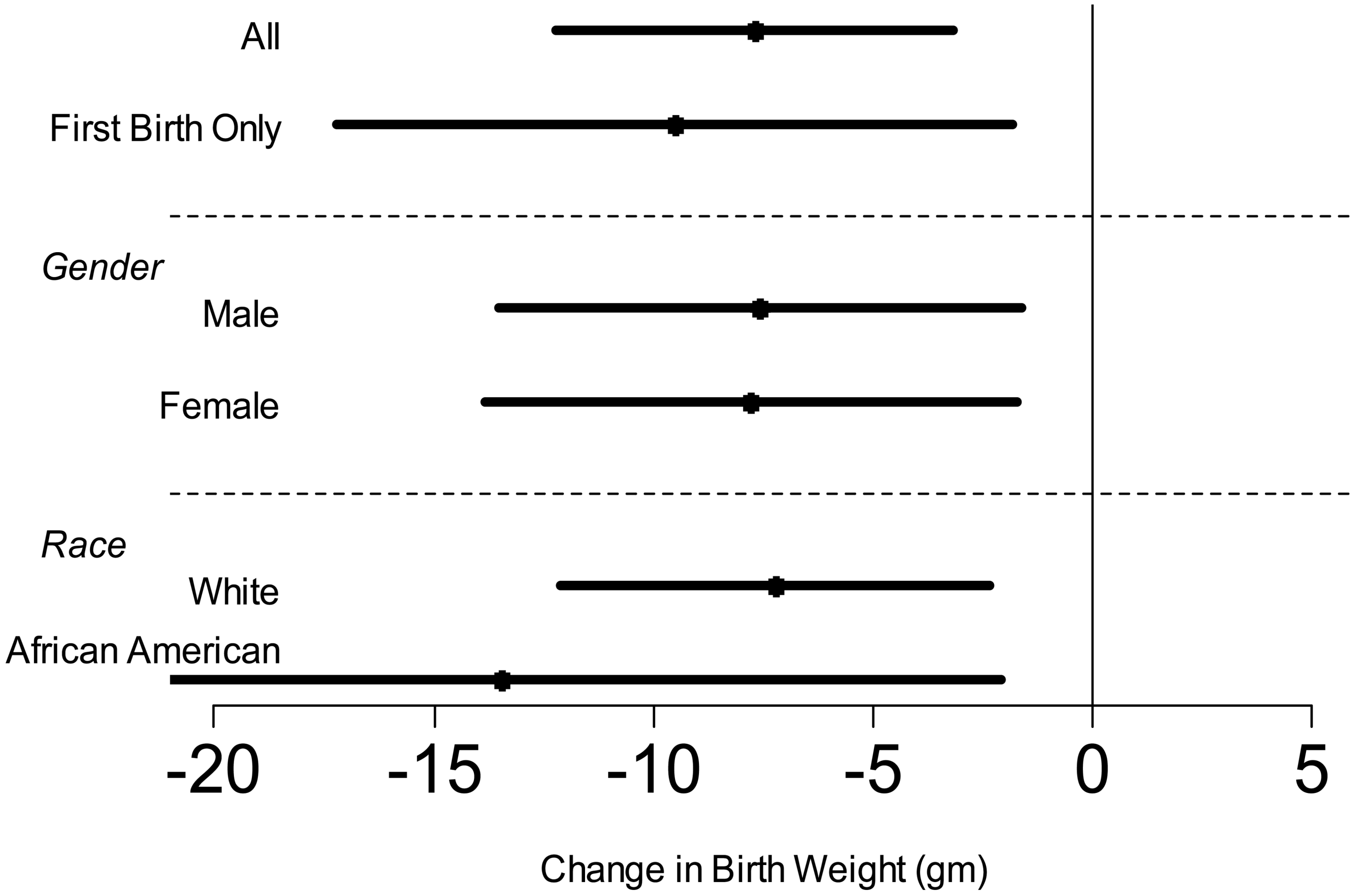

Figure 1.
Change in birth weight (gm) per IQR increase (6.4×10^{-3} μg/m^3) in potassium $PM_{2.5}$
Note: Models were adjusted for year of birth; trimester prenatal care began; sex of child; gestational length; mother's marital status, race, educational attainment, age, and alcohol and tobacco use during pregnancy; type of delivery, mother's first child (yes/no), and apparent temperature for each trimester.

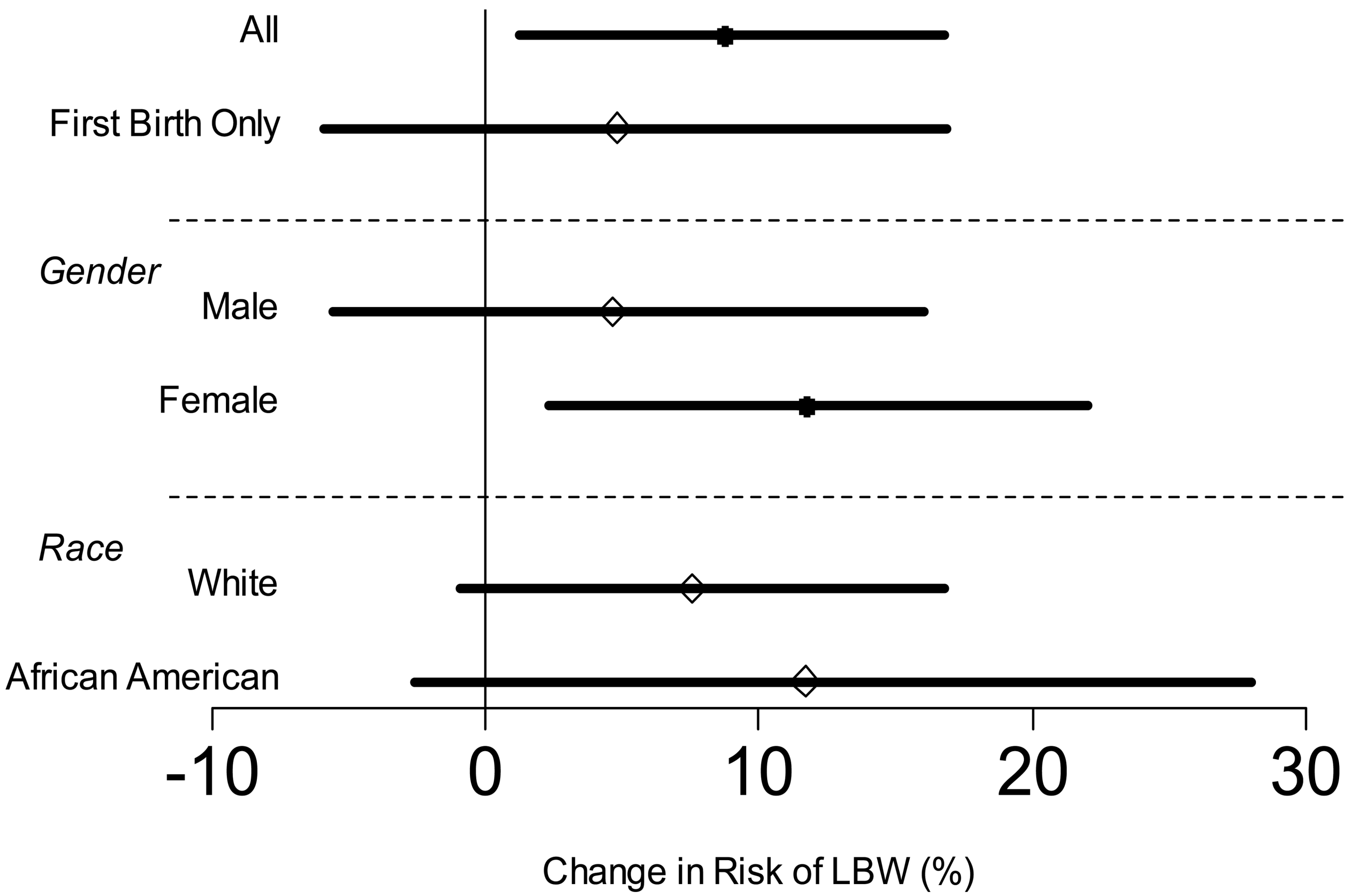

Figure 2.
Percent increase in risk of low birth weight per IQR (6.4×10^{-3} μg/m^3) increase in potassium $PM_{2.5}$
Note: Models were adjusted for year of birth; trimester prenatal care began; sex of child; gestational length; mother's marital status, race, educational attainment, age, and alcohol and tobacco use during pregnancy; type of delivery, mother's first child (yes/no), and apparent temperature for each trimester.

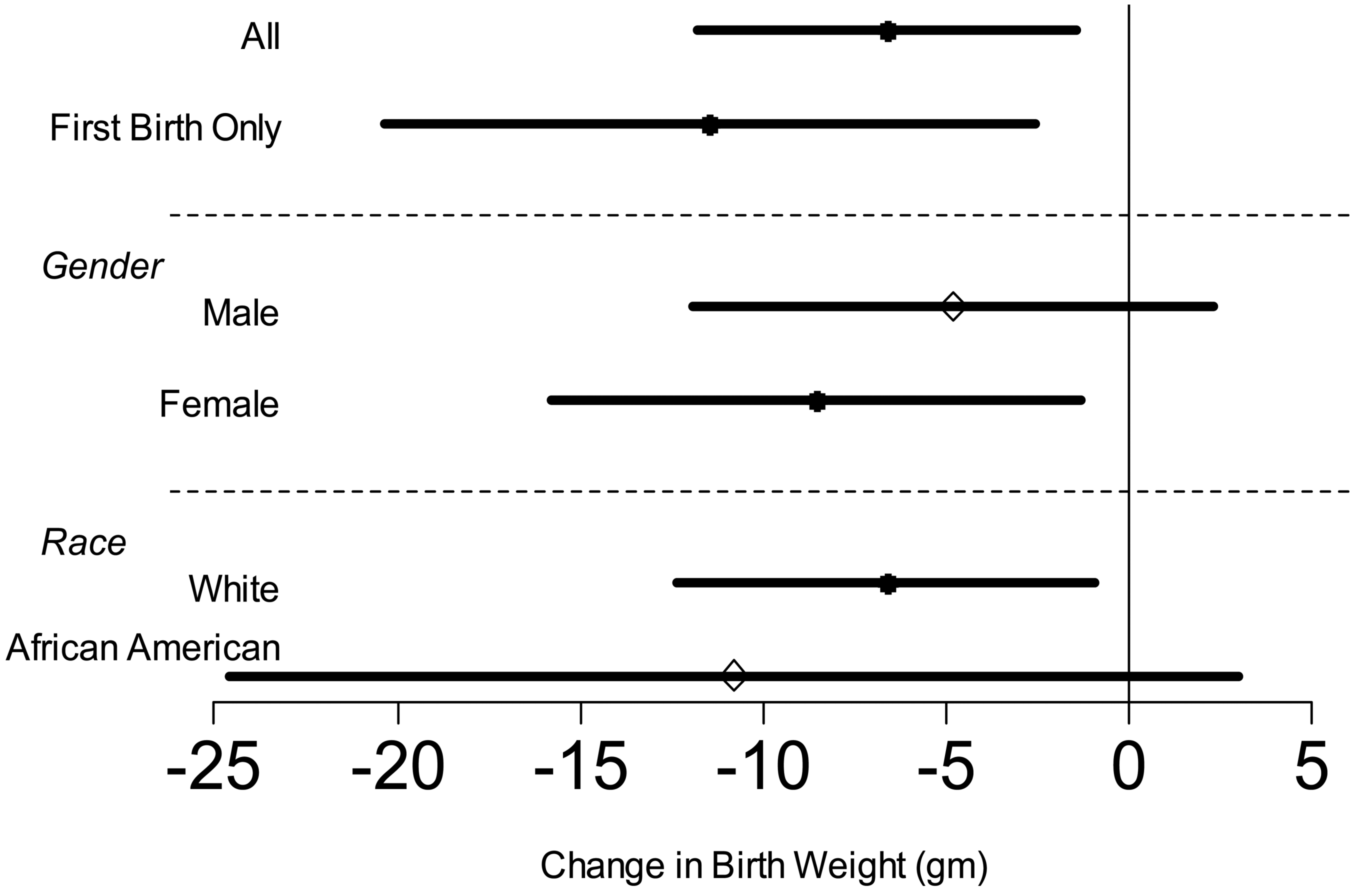

Figure 3.

Change in birth weight (gm) per IQR increase (2.6×10^{-3} μg/m^3) in titanium $PM_{2.5}$

Note: Models were adjusted for year of birth; trimester prenatal care began; sex of child; gestational length; mother's marital status, race, educational attainment, age, and alcohol and tobacco use during pregnancy; type of delivery, mother's first child (yes/no), and apparent temperature for each trimester.

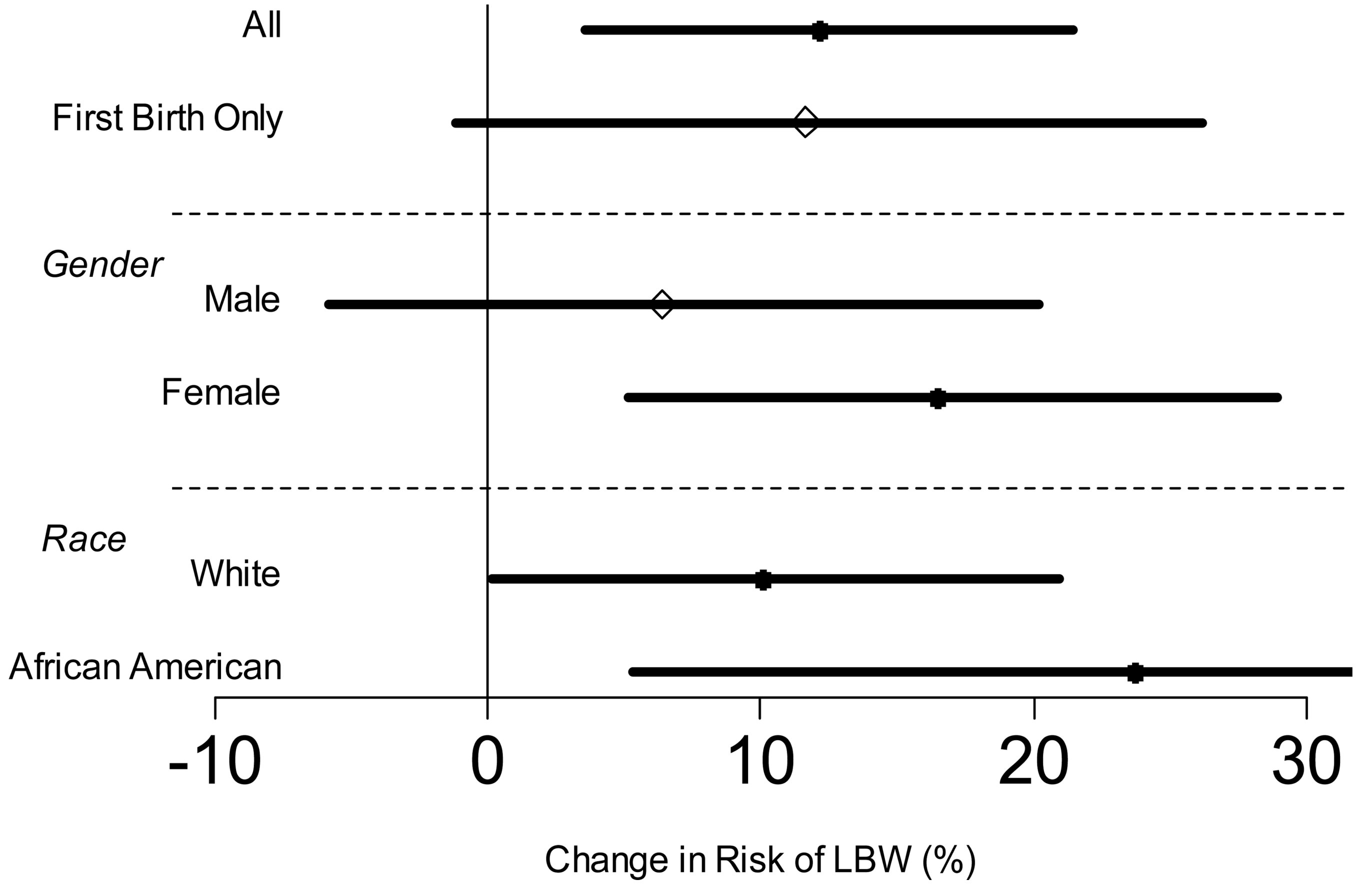

Figure 4.
Percent increase in risk of low birth weight per IQR increase (2.6×10^{-3} μg/m^3) in titanium $PM_{2.5}$
Note: Models were adjusted for year of birth; trimester prenatal care began; sex of child; gestational length; mother's marital status, race, educational attainment, age, and alcohol and tobacco use during pregnancy; type of delivery, mother's first child (yes/no), and apparent temperature for each trimester.

Table 1

Summary statistics of study population

	Number of study subjects, except where specified	Percent of study subjects, except where specified
Location of residence		
Fairfield Co., CT	25,450	33.1%
New Haven Co., CT	22,911	29.8%
Hartford Co., CT	21,947	28.6%
Hampden Co., MA	6,480	8.44%
Infant's characteristics		
Sex		
Male	39,245	51.1%
Female	37,543	48.9%
Parity		
First child	26,534	34.6%
Second or later child	50,254	63.6%
Term low birth weight	1,671	2.2%
Birth weight	Mean: 3,434 gm	Standard deviation: 470 gm
Gestational length	Mean: 39.3 weeks	Standard deviation: 1.35 weeks
Type of delivery		
Primary caesarean section	10,565	13.8%
Repeat caesarean section	7,237	9.4%
Vaginal birth	58,986	76.8%
Trimester prenatal care began		
1st trimester	67,816	88.3%
2nd trimester	7,500	9.8%
3rd trimester	1,134	1.5%
No care	90	0.1%
Unknown	248	0.3%
Mother's characteristics		
Tobacco used during pregnancy	4,445	5.8%
Alcohol used during pregnancy	489	0.6%
Married	53,298	69.4%
Race:		
White	63,051	82.1%
African-American	9,678	12.6%
Other	4,059	5.3%
Age	Mean: 29.3 years	Standard deviation: 6.16 years
< 20 years	5,597	7.3%
20–24 years	12,749	16.6%
25–29 years	17,957	23.4%

	Number of study subjects, except where specified	Percent of study subjects, except where specified
30–34 years	24,291	31.6%
35–39 years	13,342	17.4%
≥ 40 years	2,852	3.7%
Education	Mean: 13.8 years	Standard deviation: 2.65 years
<12 years	10,317	13.4%
12 years	18,522	24.1%
13–15 years	16,842	21.9%
>15 years	30,498	39.7%
Unknown	609	0.8%

Table 2

Summary statistics of pollutant and weather exposures during pregnancy

	Mean	Median	Standard deviation	25th percentile	75th percentile	Interquartile Range
Potassium (K) (μg/m^3)	49.4×10^{-3}	49.2×10^{-3}	5.0×10^{-3}	46.1×10^{-3}	52.3×10^{-3}	6.4×10^{-3}
Titanium (Ti) (μg/m^3)	5.3×10^{-3}	4.8×10^{-3}	1.6×10^{-3}	4.1×10^{-3}	6.6×10^{-3}	2.6×10^{-3}
$PM_{2.5}$ total mass (μg/m^3)	14.0	13.5	2.13	12.3	16.0	3.69
Temperature (°F)	50.5	51.1	6.2	45.3	56.1	10.8
Dew point temperature (°F)	40.2	40.7	6.2	34.9	46.0	11.1
Apparent Temperature (°F)	56.4	61.1	25.0	42.9	68.7	25.8

Table 3

Pearson correlations of gestational exposures to $PM_{2.5}$ total mass and $PM_{2.5}$ chemical components

	$PM_{2.5}$	Zn	V	S	Si	Ni	EC	Cl	Al	Ti
Potassium (K)	**0.66**	**0.73**	**0.61**	**0.28**	**0.54**	**0.65**	**0.58**	**0.59**	**0.59**	**0.51**
Titanium (Ti)	**0.82**	**0.58**	**0.66**	**0.73**	**0.85**	**0.65**	**0.82**	**0.48**	**0.87**	
Aluminum (Al)	0.90	0.66	0.84	0.73	0.98	0.80	0.90	0.62		
Chlorine (Cl)	0.66	0.73	0.53	0.28	0.66	0.64	0.59			
Elemental Carbon (EC)	0.94	0.78	0.91	0.66	0.87	0.90				
Nickel (Ni)	0.85	0.85	0.96	0.51	0.80					
Silicon (Si)	0.87	0.66	0.82	0.72						
Sulfur (S)	0.75	0.23	0.54							
Vanadium (V)	0.86	0.80								
Zinc (Zn)	0.75									