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Effectiveness of a Federal Healthy Start Program in Reducing the Impact of Particulate Air Pollutants on Feto-Infant Morbidity Outcomes

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Abstract We sought to assess (1) the relationship between air particulate pollutants and feto-infant morbidity outcomes and (2) the impact of a Federal Healthy Start program on this relationship. This is a retrospective cohort study using de-identified hospital discharge information linked to vital records, and air pollution data from 2000 through 2007 for the zip codes served by the Central Hillsborough Federal Healthy Start Project in Tampa, Florida. Mathematical modeling was employed to compute minimal Euclidean distances to capture exposure to ambient air particulate matter. The outcomes of interest were low birth weight (LBW), very low birth weight (VLBW), small for gestational age, preterm (PTB), and very preterm birth. We used odds ratios to approximate relative risks. A total of 12,356 live births were analyzed. Overall, women exposed to air particulate pollutants were at elevated risk for LBW (AOR = 1.24; 95% CI = 1.07–1.43), VLBW (AOR = 1.58; 95% CI = 1.09–2.29) and PTB (AOR = 1.18; 95% CI = 1.03–1.34). Analysis by race/ethnicity revealed that the adverse effects of air particulate pollutants were most profound among black infants. Infants of women who received services provided by the Central Hillsborough Federal Healthy Start Project experienced improved feto-infant morbidity outcomes despite exposure to air particulate pollutants. Environmental air pollutants represent important risk factors for adverse birth outcomes, particularly among black women. Multi-level interventional approaches implemented by the Central Hillsborough Federal Healthy Start were found to be associated with reduced likelihood for feto-infant morbidities triggered by exposure to ambient air particulate pollutants.

Keywords Healthy start · Air particulate pollutants · Low birth weight · Preterm birth · Disparity

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Introduction

Ambient air pollutants, such as particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and secondary pollutant ozone (O_3), are a significant public health concern due to their deleterious effects on the health of the general population. They are primarily the products of industrial and traffic emissions. In the United States, relative exposure to these contaminants is generally calculated using measurements from fixed monitoring stations in relation to their distance from residential areas [1–3].

In recent years, ambient air pollutants have received a large amount of interest for their possible impacts on maternal and fetal health outcomes. Multiple studies have examined the association between ambient air pollutants and birth outcomes, including birth weight [3–12], small for gestational age [1, 2, 4, 5, 7, 9, 10, 13], birth defects [9, 13–15], and preterm birth [4, 5, 10, 12, 16–19]. However, there has been inconsistency in risk assessments regarding air pollutants and feto-infant health outcomes across these studies [4, 5, 9, 15, 20]. The variations in findings may be partially attributed to differences in study design, as well as the tools and measures utilized to assess ambient air pollution.

Particulate matter (PM) is frequently used as a measure of ambient air pollution. PM, which is also known as particle pollution, is a complex mixture of extremely small particles and liquid droplets/aerosols. The two types of PM that are noted to influence health outcomes are $PM_{2.5}$, which are fine particles less than or equal to 2.5 µm (micrometers) in aerodynamic diameter, and PM_{10}, which are larger than 2.5 µm and less than or equal to 10 µm in aerodynamic diameter. Because of their small sizes, both $PM_{2.5}$ and PM_{10} are readily inhalable, are not filtered, and penetrate deeply into the body [1].

The association of $PM_{2.5}$ and PM_{10} with health effects in the general population has led to interest in elucidating the relationship between exposure to these air pollutants in pregnant women and fetal growth parameters, as well as other adverse birth outcomes. Several studies have found an association between $PM_{2.5}$ and PM_{10} and adverse effects to fetal growth parameters, including low birth weight [3, 6, 8], preterm birth [16–19], and small for gestational age [1, 2]. Additionally, some studies have shown that $PM_{2.5}$ alter cell activity [1], interfere with placental development [3], and reduce the amount of oxygen and nutrients the fetus receives in utero [1, 3].

A recent study tends to suggest that socio-economically disadvantaged population sub-groups are at higher risks for preterm birth when exposed to environmental pollutants, as compared to advantaged sub-groups [21], and that non-chemical approaches (e.g., cognitive-behavioral therapy) could reduce these exposures [22]. These findings are interesting and indicate the existence of a relationship between the social and the physical environment as well as the differential impact of physical environmental insults (e.g., air pollution) on health outcomes. Given this premise, we seek to determine whether a specific intervention such as the Federal Healthy Start project which is heavily dosed in changing the social environment to induce positive pregnancy outcome could influence the adverse effects of air pollutants during pregnancy. For this purpose, we have specifically selected the Central Hillsborough Healthy Start Project (CHHS) as the candidate program to use in testing this hypothesis based on the following justification:

1. In a recent rigorous evaluation, the CHHS showed that its services in the community it covers has reduced the preterm birth rate by 30% among service recipients over the previous decade [23]. The program, therefore, has documented evidence of effectiveness.
2. The areas where the CHHS provides its services are socio-economically disadvantaged with mostly minority subgroups: 68% blacks, 14% whites, 11% Latinos, and 7% other racial/ethnic groups. Around 56.0% of all births are to black mothers who are typically young, unmarried, undereducated, and Medicaid-eligible [24]. Compared to the rest of Hillsborough County, families in the CHHS service area tend to be poorer, with half the median income and double the unemployment rate [24]. Furthermore, this area has four times more households headed by single women and twice the number of women over the age of 25 with no high school diploma [24].
3. The risk reduction services offered to pregnant women by the CHHS project are based on social change and therefore, non-pharmacological.

Methods

For this study, we utilized the de-identified linked Florida hospital discharge and vital statistics data files, as well as environmental monitoring data, for the study period of 2000–2007. The Hospital Inpatient Discharge (HID) data were obtained from the Florida Agency for Health Care Administration and were linked to Florida vital statistics records. The primary purpose of the linkage is to follow women over time; therefore, it was important to have maternal social security number available for the linkage. During the period of the study, 11.5% of the records did not have a known maternal social security number, mainly because the mothers were not legal residents, and these were excluded from the linkage process since their follow-up would not be possible. Next, the HID and birth records were cleaned and linking variables standardized and formatted prior to data linkage. Singleton live birth records were linked to inpatient hospitalizations using a multistage, stepwise approach for the linkage. Variables, such as date of birth, facility of birth, infant sex, and mother's residential zip code, were used to ensure that the maternal social security information was accurate and reliable. The dataset includes all institutions in the state of Florida, except for military and Veterans Administration institutions. Overall, approximately 97.6% of unique singleton infants with known maternal social security numbers were linked. This database has been used in other studies by researchers with findings comparable to literature reports [25, 26].

Air pollution and meteorological data were obtained from the Environmental Protection Agency (EPA), USA

Air Quality System, which is publicly available [27]. The EPA data included 6-day concentrations of $PM_{2.5}$ and PM_{10}, allowing for the computation of 24-h daily maximum concentrations. The pollutants were monitored at 14 different fixed monitoring stations located throughout Hillsborough County in Florida and included latitudes and longitudes, which were converted to zip codes using relevant information from the Hillsborough Environmental Pollution Commission.

The study analysis was limited to the service population of the Central Hillsborough Healthy Start Project (CHHS), which encompassed zip codes 33602, 33603, 33605, 33607, and 33610 of Hillsborough County in Tampa, Florida. The resulting study population consisted of a total of 12,356 records identified as singleton live births in the CHHS service population during the study period.

Variables

For the main exposure category in this study, maternal exposure to air pollution during pregnancy ($PM_{2.5}$ and PM_{10}) was used. To assess exposure, we computed the Euclidian distances between the centroid of the mother's residential zip code during pregnancy and the centroid of each zip code of the 14 monitoring stations. Since there were 14 monitoring sites and five residential zip codes in the CHHS service population, we had a matrix with entries of 5×14 distances (each residential zip code had 14 computed distances). The monitoring site with the minimum distance was assigned to each residential zip code since this was the monitor with the greatest exposure for the mothers within that zip code. If there were missing data from the closest site for a particular day of gestation, then the reading was taken from the next closest site without missing data. If the daily readings were missing across all sites, then the daily exposure estimate was left as missing.

Maternal exposure to air pollution during pregnancy was estimated using date of birth of the infant and the length of each gestational age, resulting in weekly exposure data (for $PM_{2.5}$ or PM_{10}) for each pregnancy. Mean exposures to each air pollutant for the length of each pregnancy were assigned to each birth. We classified a mother as being exposed to a specific particulate if the value of the particulate pollutant fell above the median. It is noteworthy that most of the values for the pollutants were below the EPA cutpoints for particulate matter. The $PM_{2.5}$ values had a range from 8.75 to 23.20 with a median of 10.97; however, the EPA cutpoint for $PM_{2.5}$ is 15.0 $\mu g/m^3$, a value that is 5 points higher than the median of the study sample. For PM_{10}, all of the values in the dataset were below the EPA cutoff value of 50 $\mu g/m^3$, ranging from 13 to 42 and having a median of 25.04. Given the range of values for these two critical measures, it was reasonable not to use the EPA cutpoint to classify the exposed and the unexposed group in our study.

The coarse fraction of PM, defined as PM_{10}–$PM_{2.5}$, was also calculated. Women were assigned to the exposed group (comprising mothers exposed to one or more of the three particulates—$PM_{2.5}$, PM_{10}, or PM coarse fraction—during pregnancy) or the unexposed group (comprising mothers not exposed to any of the particulates during pregnancy).

The main outcomes of interest in this study were fetal growth parameters: LBW, VLBW, SGA, PTB, and VPTB. LBW was defined as infants weighing below 2,500 g at birth; VLBW when infants weighed below 1,500 g at birth; SGA was defined as infants weighing below the 10th percentile of birth weight for a given GA using normalized growth curves [28]; PTB was defined as birth before 37 completed weeks of gestation; and VPTB were births before 32 completed weeks of gestation. Gestational age was computed in weeks as the interval between the last menstrual period and the date of delivery of the fetus. When the menstrual estimate of gestational age was inconsistent with the birth weight (e.g., very low birth weight at term), a clinical estimate of gestational age based on the vital records was used instead [29].

Vital statistics data were utilized for the abstraction of maternal socio-demographic data, including race/ethnicity, age, education, marital status, and parity. Race/ethnicity was categorized into four groups: non-Hispanic black (black), non-Hispanic white (white), Hispanic, and other. Hispanic was determined to be any woman listed as "ethnic Hispanic" on the birth certificate, regardless of racial classification; all women listed as "white" and not Hispanic were classified as "white"; all women listed as "black" and not Hispanic were classified as "black." Any individuals not belonging to any of these categories were classified as "other." Maternal age was categorized as <35 years or advanced age, ≥ 35 years, at the time of delivery. Educational level was classified as those with ≥ 12 years and those with <12 years. Maternal marital status was dichotomized as either married or not married, with all persons of unknown marital status, widowed, divorced, or single categorized as not married. Parity was defined as either nulliparous or multiparous.

Basic health measures were also assessed using vital statistics information and included cigarette smoking during pregnancy and adequacy of prenatal care. Cigarette smoking during pregnancy was dichotomized as yes or no. Adequacy of prenatal care was assessed using the revised graduated index algorithm, which has been found to be more accurate than several others, especially in describing the level of prenatal care utilization among groups that are high risk [30]. This index assesses the adequacy of care based on when the trimester prenatal care began, number of visits, and the gestational age of the infant at birth. Using this algorithm, adequacy of prenatal care was grouped as either adequate or inadequate.

Maternal pregnancy complications obtained from the hospital discharge data, based on ICD-9 principal and other diagnostic codes, included anemia (280–286), gestational diabetes (648.8), diabetes mellitus (250,648.0), gestational hypertension (642.3), chronic hypertension (642.0, 401.0, 401.1, 401.9, 642.1, 642.2, 742.7), preeclampsia (642.4, 642.5, 642.7, 642.9), eclampsia (642.6), placental abruption (641.2), placental previa (641.0, 641.1) and renal disease (642.1, 646.2). Researchers have observed improved accuracy with discharge data compared to the birth certificate data in terms of maternal pregnancy complications [31, 32].

Statistical Analysis

We calculated the frequencies of maternal socio-demographic factors, as well as birth outcomes within the CHHS service population. Additionally, we assessed differences between those who were either exposed to one of the three particulates ($PM_{2.5}$, PM_{10}, or PM coarse fraction) during pregnancy versus those who were unexposed with respect to these variables using chi-square tests.

The risk for feto-infant growth outcomes (i.e., low birth weight, very low birth weight, preterm birth, very preterm birth, and small for gestational age) among the exposed group were compared with the unexposed group using odds ratios and 95% confidence intervals after adjusting for baseline characteristics in multiple logistic models. Further analyses were conducted to assess risk differences based on the receipt of services during pregnancy from CHHS. We also calculated odds ratios for the feto-infant growth outcomes by race/ethnicity. The LOGISTIC procedure in SAS (SAS Institute, Inc., Cary, North Carolina, version 9.2) was used to generate odds ratios and 95% confidence intervals. All tests of hypothesis were two-tailed with a type 1 error rate fixed at 5%. Prior to initiation, this study was approved by the Institutional Review Board at the University of South Florida.

Results

We analyzed a total of 12,356 singleton live births in the service population of the Central Hillsborough Healthy Start (CHHS) in Tampa, Florida during the study period of 2000–2007. Of these births, 3,378 (27.3%) women received services from CHHS, whereas 8,978 (72.7%) did not receive services. The overall sample was successfully categorized into an exposed and an unexposed group based on exposure to one of the three particulates ($PM_{2.5}$, PM_{10}, or PM coarse fraction) during pregnancy. Of these, 3,565 (28.9%) were unexposed, and 8,791 (71.1%) were exposed.

Table 1 Rates (%) of selected maternal socio-demographic characteristics and pregnancy complications among women in the Central Hillsborough Healthy Start (CHHS) service area of Tampa, Florida by exposure status to $PM_{2.5}$, PM_{10}, or PM coarse fraction (2000–2007)

Characteristics	Unexposed (N = 3,565)	Exposed (N = 8,791)	*P* value[a]
Race/ethnicity			**<0.01**
White	21.72	21.27	
Black	59.78	53.07	
Hispanic	13.23	17.07	
Other	5.26	8.59	
Maternal age (≥35 years)	7.42	8.31	0.12
Marital status (Married)	29.66	31.30	0.23
Maternal educational level (>12 years)	64.88	65.10	0.87
Maternal prenatal smoking	6.47	6.36	0.20
Adequate prenatal care	61.88	63.84	0.05
Pregnancy complications			
Nulliparous	67.13	68.22	0.26
Anemia	14.51	15.85	0.08
Gestational diabetes	4.67	4.73	0.89
Diabetes mellitus	0.98	0.87	0.58
Gestational hypertension	5.23	5.16	0.89
Chronic hypertension	1.96	2.00	0.89
Preeclampsia	5.03	4.55	0.27
Eclampsia	0.10	0.15	0.50
Abruption	0.69	1.18	**0.02**
Placenta previa	0.52	0.63	0.49
Renal disease	0.07	0.08	0.86

CHHS service area zipcodes in Hillsborough County include: 33602, 33603, 33605, 33607 and 33610

[a] *P* values of <0.05 considered significant. Significant values in bold font

The socio-demographic characteristics of the study population are presented in Table 1. Overall, more than half of the study population was black, and roughly one-fifth was white. Besides race/ethnicity, there were no significant differences within the study population by maternal characteristics. Pregnancy complications experienced by women in the study were similar, regardless of exposure status, except for placental abruption, which was nearly twice as high in the exposed group (0.69% unexposed vs. 1.18% exposed, $P = 0.02$).

The distribution of the crude frequencies of feto-infant morbidity outcomes in the study population by exposure status and the provision of services by CHHS is presented in Fig. 1. Overall, nearly one-fourth (n = 2,787, 22.6%) of infants in the CHHS service area had any morbidity outcome, with 1,224 (9.9%) having low birth weight, 193

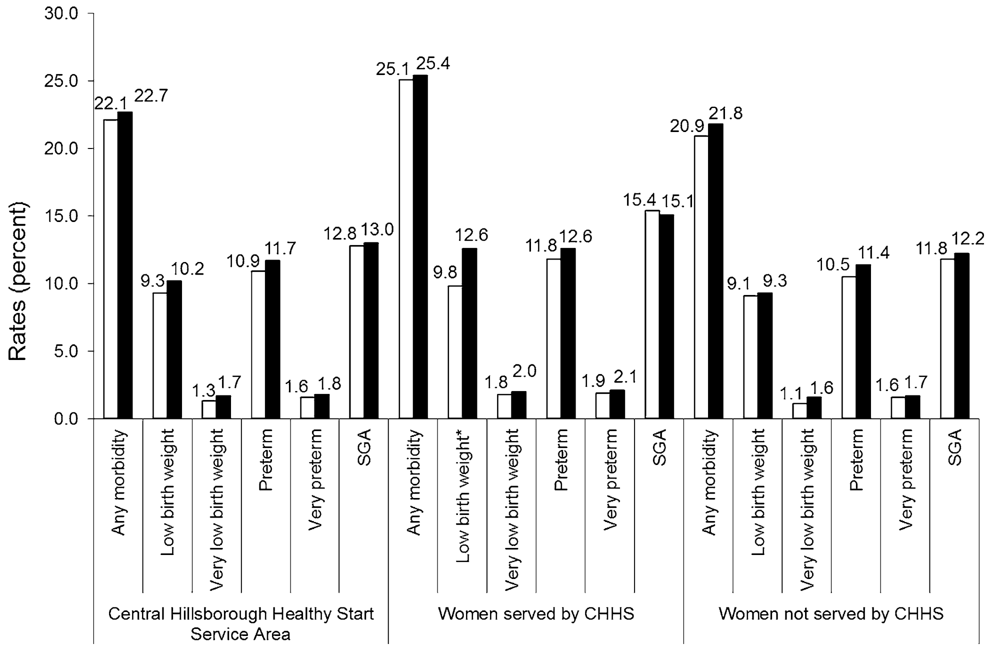

Fig. 1 Comparison of crude rates (%) of feto-infant morbidity outcomes among women exposed to any particulate matter to those who were unexposed in the Central Hillsborough Healthy Start (CHHS) service area (2000–2007)[a,b]. [a]CHHS service area zipcodes in Hillsborough County include: 33602, 33603, 33605, 33607 and 33610. [b]*Filled square* women who were exposed to any particulate matter; *open square* unexposed women. **P* value = 0.04; *P* value for all other comparisons <0.01

(0.8%) having very low birth weight, 1,421 (11.5%) delivered preterm, 215 (1.7%) delivered very preterm, and 1,595 (12.9%) being small for gestational age. Table 2 depicts the adjusted estimates for the relationship between the exposure variables, $PM_{2.5}$, PM_{10}, and PM coarse fraction, and the outcomes of interest. Section A presents the findings of all women in the CHHS service population, whereas Section B features the results of those who received CHHS services, and Section C includes those who did not receive CHHS services. Within the overall CHHS service population, there were no significant associations with VPTB. However, infants of exposed women were at a slightly increased risk for LBW, VLBW, and PTB. When delineated by exposure type, infants of women exposed to the PM coarse fraction or $PM_{2.5}$ had a 14–15% higher risk for LBW. Infants bore a 36–39% greater risk of VLBW if their mothers were exposed to the PM coarse fraction or PM_{10}, respectively. For preterm birth, there was a 17% increase in risk among infants whose mothers were exposed to the PM coarse fraction. Elevated risk for SGA was only observed among infants of women who were exposed to PM_{10}.

When assessing differences based on whether women received services from CHHS, it appears that infants of women who received services from CHHS and were exposed to particulates were only at increased risk for LBW (AOR = 1.49, 95% CI = 1.14–1.95). Women who were exposed to $PM_{2.5}$ and received CHHS services were 47% more likely to have an LBW infant and 36% more likely to deliver preterm. Exposed women who did not receive CHHS services were at 67% greater risk of having a VLBW infant and showed an 18% greater risk of having a PTB. When exposed to PM_{10}, women who did not receive CHHS services were at increased risk for VLBW (AOR = 1.48, 95% CI = 1.03–2.12), PTB (AOR = 1.17, 95% CI = 1.02–1.34), SGA (AOR = 1.19, 95% CI = 1.04–1.35), and any of the included feto-infant morbidities (AOR = 1.19, 95% CI = 1.07–1.31). The risk for PTB (AOR = 1.24, 95% CI = 1.09–1.42) and any morbidity (AOR = 1.20, 95% CI = 1.09–1.33) increased slightly among these women when exposed to $PM_{2.5}$.

The breakdown of the crude frequencies of feto-infant morbidity outcomes by exposure status and race/ethnicity are shown in Fig. 2 while Table 3 presents the stratified adjusted estimates for the relationship between exposure to particulate matter and the outcomes of interest within the CHHS service area by race/ethnicity. Overall, black women were at increased risk for LBW, SGA, and any of the observed feto-infant morbidities regardless of exposure status. Black women exposed to any of the three particulate pollutants were more than three times as likely to have a VLBW infant (AOR = 3.32, 95% CI = 1.33–8.30), more than twice as likely to have a LBW infant (AOR = 2.24, 95% CI = 1.63–3.08), and about twice as likely to have an infant that was SGA (AOR = 1.99, 95% CI = 1.50–2.64). Additionally, exposed black women were at 31% greater risk of having a preterm delivery and at 66% greater risk to experience any feto-infant morbidity.

Discussion

There are three main findings in the study. Firstly, we observed in this population elevated risks for feto-infant

Table 2 Adjusted estimates for the association between exposure to particulate pollutants and feto-infant morbidity outcomes, overall and whether or not they received CHHS services (2000–2007)

Outcomes[a]	n	Exposed AOR (95% CI)	$PM_{2.5}$ AOR (95% CI)	PM_{10} AOR (95% CI)	PM coarse fraction AOR (95% CI)
Section A: All women in CHHS service area (N = 12,356)					
LBW	1,224	**1.24 (1.07–1.43)**	**1.15 (1.01–1.31)**	1.12 (0.99–1.26)	**1.14 (1.01–1.29)**
VLBW	193	**1.58 (1.09–2.29)**	1.18 (0.87–1.61)	**1.39 (1.04–1.85)**	**1.36 (1.02–1.81)**
PTB	1,421	**1.18 (1.03–1.34)**	1.10 (0.98–1.25)	1.11 (0.99–1.24)	**1.17 (1.05–1.31)**
VPTB	215	1.26 (0.91–1.76)	1.04 (0.77–1.40)	1.12 (0.85–1.47)	1.22 (0.93–1.60)
SGA	1,595	1.03 (0.91–1.16)	1.05 (0.93–1.18)	**1.14 (1.03–1.27)**	1.11 (1.00–1.24)
Any	2,787	1.09 (0.99–1.20)	1.08 (0.99–1.19)	**1.13 (1.04–1.24)**	**1.15 (1.06–1.26)**
Section B: Women served by CHHS (N = 3,378)					
LBW	396	**1.49 (1.14–1.95)**	**1.47 (1.18–1.83)**	1.04 (0.84–1.30)	1.09 (0.88–1.36)
VLBW	65	1.29 (0.69–2.39)	1.41 (0.85–2.34)	1.11 (0.67–1.83)	1.23 (0.73–2.05)
PTB	417	1.16 (0.91–1.49)	**1.36 (1.10–1.69)**	0.97 (0.79–1.20)	1.02 (0.83–1.26)
VPTB	68	1.14 (0.64–2.04)	1.54 (0.94–2.52)	0.79 (0.48–1.30)	0.92 (0.56–1.50)
SGA	514	1.02 (0.82–1.28)	0.96 (0.78–1.17)	1.03 (0.85–1.25)	1.06 (0.87–1.29)
Any	854	1.07 (0.89–1.29)	1.18 (1.00–1.39)	0.99 (0.85–1.17)	1.03 (0.87–1.21)
Section C: Women not served by CHHS (N = 8,978)					
LBW	828	1.12 (0.95–1.33)	0.98 (0.83–1.15)	1.13 (0.98–1.31)	1.15 (0.99–1.33)
VLBW	128	**1.67 (1.05–2.67)**	1.01 (0.68–1.51)	**1.48 (1.03–2.12)**	1.38 (0.97–1.97)
PTB	1,004	**1.18 (1.01–1.38)**	0.99 (0.85–1.14)	**1.17 (1.02–1.34)**	**1.24 (1.09–1.42)**
VPTB	147	1.28 (0.85–1.92)	0.80 (0.55–1.17)	1.27 (0.91–1.77)	1.35 (0.97–1.88)
SGA	1,081	1.01 (0.87–1.17)	1.07 (0.92–1.24)	**1.19 (1.04–1.35)**	1.13 (0.99–1.29)
Any	1,933	1.08 (0.96–1.22)	1.02 (0.91–1.15)	**1.18 (1.07–1.31)**	**1.20 (1.09–1.33)**

Significant values are in bold font

Adjusted odds ratios were generated after controlling for year of birth, education, maternal age, tobacco use, parity, marital status, adequacy of prenatal care, sex of the infant, anemia, gestational diabetes, diabetes mellitus, gestational hypertension, chronic hypertension, preeclampsia, eclampsia, placental abruption, placenta previa, and renal diseases

[a] Outcomes: *LBW* low birth weight, <2,500 g; *VLBW* very low birth weight, <1,500 g; *PTB* preterm birth, <37 completed weeks gestation; *VPTB* very preterm birth, <32 completed weeks gestation; *SGA* small for gestational age; *Any* any of the observed feto-infant morbidity outcomes

morbidity outcomes among women exposed to greater than median values of particulate air pollutants. Exposure to $PM_{2.5}$ or the coarse fraction was generally associated with a significantly increased risk for low birth weight, while women who were exposed to PM_{10} were more likely to have infants with very low birth weight and small-for-gestational age. These findings are consistent with results published in the literature by other investigators [15–17, 19] and strengthen the suspicion that air particulate pollutants represent potential hazards to the developing embryo/fetus.

A second major finding in our analysis is the differential impact of air particulate pollutants on feto-infant outcomes across racial/ethnic sub-populations. Sub-analysis revealed that the only significant findings for the association between exposure to particulate pollutants and feto-infant morbidity outcomes were restricted to black infants. Black women who were exposed to greater than median values of any of the air particulate pollutants showed increased magnitude of risks for each of the feto-infant morbidity outcomes considered in this study. Since race/ethnicity correlates strongly with socio-economic level in society, these specific findings concur with those of a recent large study from South Korea covering 433,173 singleton births stratified by socio-economic status (SES) [21]. The authors found that area-level SES modified the effects of air particulate pollutants on preterm birth, specifically among those who live in low SES areas.

One possible explanation for the amplified risk found in exposed black infants is lowered vulnerability threshold for the expression of harm induced by additional insults among babies born to women who already bear a heavy burden of

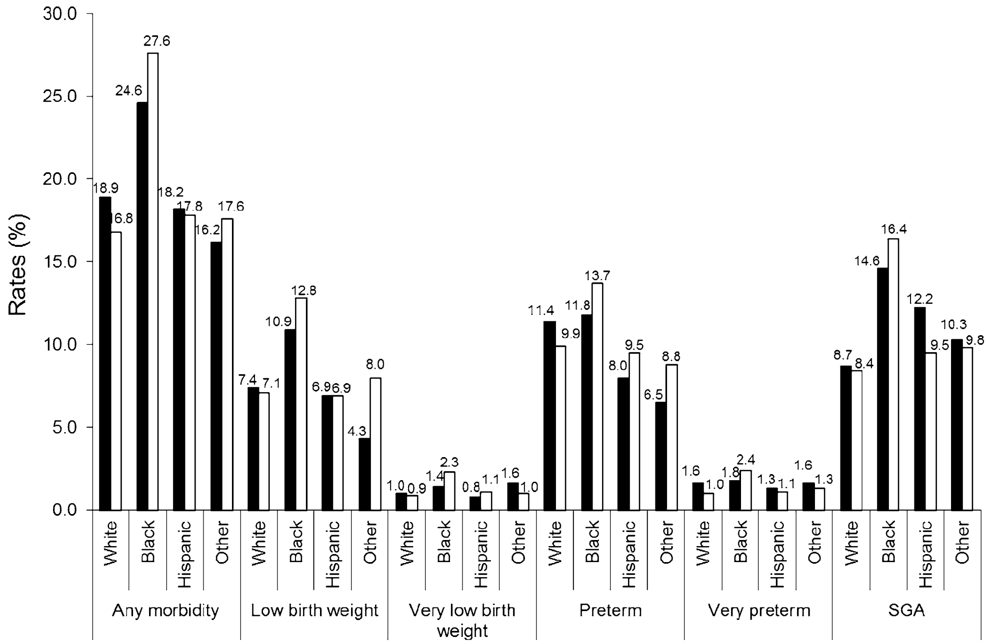

Fig. 2 Comparison of crude rates (%) of feto-infant morbidity outcomes among women exposed to any particulate matter to those who were unexposed in the Central Hillsborough Healthy Start (CHHS) service area by race/ethnicity (2000–2007)[a,b]. [a]CHHS service area zipcodes in Hillsborough County include: 33602, 33603, 33605, 33607 and 33610. [b]*Filled square* women who were exposed to any particulate matter; *open square* unexposed women

Table 3 Adjusted estimates for the association between exposure to any particulate matter and feto-infant morbidity outcomes categorized by race/ethnicity in the Central Hillsborough Healthy Start (CHHS) service area (2000–2007)

Outcomes[a]	White		Black		Hispanic		Other	
	Unexposed n = 769	Exposed n = 1,873	Unexposed n = 2,134	Exposed n = 4,629	Unexposed n = 477	Exposed n = 1,515	Unexposed n = 185	Exposed n = 774
LBW	1.00	1.11	**1.75**	**2.24**	1.13	1.13	0.56	1.23
n = 1,224		(0.79–1.57)	**(1.25–2.47)**	**(1.63–3.08)**	(0.70–1.84)	(0.79–1.62)	(0.24–1.34)	(0.82–1.83)
VLBW	1.00	1.43	1.89	**3.32**	1.38	1.55	1.74	1.56
n = 193		(0.53–3.82)	(0.71–5.05)	**(1.33–8.30)**	(0.37–5.20)	(0.57–4.26)	(0.33–9.07)	(0.52–4.71)
PTB	1.00	0.94	1.05	**1.31**	0.68	0.88	0.61	0.76
n = 1,421		(0.70–1.24)	(0.79–1.41)	**(1.01–1.71)**	(0.44–1.05)	(0.65–1.18)	(0.31–1.18)	(0.53–1.07)
VPTB	1.00	0.83	1.19	1.83	1.11	0.82	0.95	1.05
n = 215		(0.38–1.82)	(0.55–2.57)	(0.91–3.68)	(0.39–3.17)	(0.36–1.87)	(0.20–4.44)	(0.43–2.58)
SGA	1.00	0.95	**1.81**	**1.99**	1.47	1.16	1.18	1.17
n = 1,595		(0.70–1.30)	**(1.34–2.44)**	**(1.50–2.64)**	(0.99–2.20)	(0.84–1.59)	(0.66–2.12)	(0.82–1.67)
Any	1.00	0.90	**1.42**	**1.66**	0.96	0.99	0.87	0.94
n = 2,787		(0.72–1.14)	**(1.13–1.79)**	**(1.34–2.05)**	(0.70–1.33)	(0.78–1.25)	(0.54–1.38)	(0.72–1.23)

CHHS service area zipcodes in Hillsborough County include: 33602, 33603, 33605, 33607 and 33610

Significant values are in bold font

Adjusted odds ratios were generated after controlling for year of birth, education, maternal age, tobacco use, parity, marital status, adequacy of prenatal care, sex of the infant, anemia, gestational diabetes, diabetes mellitus, gestational hypertension, chronic hypertension, preeclampsia, eclampsia, placental abruption, placenta previa, and renal diseases

[a] Outcomes: *LBW* low birth weight, <2,500 g; *VLBW* very low birth weight, <1,500 g; *PTB* preterm birth, <37 completed weeks gestation; *VPTB* very preterm birth, <32 completed weeks gestation; *SGA* small for gestational age; *Any* any of the observed feto-infant morbidity outcomes

allostatic load associated with other stressors. It has been suggested that an interaction between the biologic and social environment may predispose individuals to the harmful effects of environmental insults through epigenetic processes at the DNA level [33, 34]. Gene expression is mediated, not only by DNA sequence, but also by epigenetic factors (e.g., DNA methylation). Reinforcing the role of epigenetic processes in fetal growth and development is the finding that several of the genes involved in pregnancy maintenance and parturition are epigenetically regulated

[35, 36]. Further, epidemiologic studies have noted that women who are born preterm are more likely to deliver preterm infants themselves and it is plausible that this is at least partially controlled by maternal imprinting [37, 38]. Since some of these epigenetic processes could be environmentally influenced (e.g., Sub-optimal methylation can also occur as a result of poor diet or environmental hazards during early postnatal life [35]), it is likely that epigenetic processes represent a candidate pathway for the interaction of social and environmental insults in elevating risk status of affected individuals as found among black infants in this study. Unfortunately, our analysis lacks data on DNA methylation profiles of study participants.

The most promising finding in this analysis is the attenuation of the adverse effects of air particulate pollutants among infants of mothers who received services from the Federal Healthy Start. This observation is of great importance since the areas targeted by the CHHS are socioeconomically disadvantaged communities located in neighborhoods exposed to high levels of stressors. The reduction of the expected effects of these ambient air pollutants among Federal Healthy Start Program recipients in the area is clear demonstration that social interventions engineered with appropriate cultural input could reduce the impact of environmentally induced physical/biologic insults, as recently proven in a randomized trial [22].

A major question arising from this analysis is the following: what specific program component could have been responsible for the favorable finding of reduced adverse effects of environmental particulate pollutants among program clients? An in-depth understanding regarding the specificity of the effective program component is needed to enhance our ability to refine and improve its potency and replication elsewhere, and this should represent one of the future study goals of the program. Additionally, future randomized trials at the community level could provide more robust evidence so that health policy planners could have a template for decision-making as well as formulation of appropriate effectiveness services to enhance birth outcomes, especially in socio-economically deprived settings.

The findings in this study need to be interpreted with certain limitations in mind. The exact definition of what represents true exposure was problematic in our analysis. Infants were classified as exposed based on a population-level estimation of the values of the particulate pollutants rather than the actual amount/concentration of the particulates detected in the individual's biologic sample (e.g., maternal blood). There is, therefore, the possibility of exposure misclassification because county-wide monitors were used to capture exposures at the individual level. This limitation is, however, not peculiar to our study as other investigators [3, 7, 14, 39–42] also encountered a similar source of measurement error. While individual level information is preferable, we do not have such information in our dataset, which is population-based. It is pertinent to mention that dichotomizing exposure status based on the median ignores minimal exposure effects arising from values below the median, an approach that could have underestimated the magnitude of the association being reported in this paper.

We were also unable to control for individual exposure variability induced by other factors, including distance from roads, traffic, place of work, as well as period of time spent at the current address. Studies have shown that 12–33% of women move from their initial address during pregnancy [14, 43–46], a potential source of non-differential misclassification [43], which could have led to an underestimation of the association between the three pollutants and feto-infant morbidity outcomes examined in this study. Similarly, the study could not identify the exact pollution source, information that will be pertinent for further analyses and intervention strategies. However, such information goes well beyond the scope and objectives of the study and will require more elaborate instrumentation and sampling strategies, which will demand a lot of resources at the population level.

Despite the aforementioned shortcomings, certain strengths of the study merit mention as well. One of the strengths is the availability of ample sample size. We had data for births from 2000 to 2007 and air pollution records for the same period. We were also able to examine various feto-infant morbidity outcomes at birth unlike other studies that focused only on low birth weight. We controlled for several potential confounders, although we cannot rule out residual confounding due to unmeasured variables.

In summary, we found an association between exposure to abnormal levels of air particulate pollutants ($PM_{2.5}$, PM_{10}, and PM coarse fraction, PM_{10}–$PM_{2.5}$) and specific feto-infant morbidity outcomes. We also observed that this association was most pronounced among black infants. The most promising finding reported is that grassroots level interventions that target psychosocial constructs (e.g., maternal stressors), potentially curtail the burden of feto-infant morbidity triggered by exposure to ambient air particulate pollutants.

References

1. Rich, D. Q., Demissie, K., Lu, S.-E., et al. (2009). Ambient air pollutant concentrations during pregnancy and the risk of fetal growth restriction. *Journal of Epidemiology and Community Health, 63*, 488–496.
2. Parker, J. D., Woodruff, T. J., Basu, R., et al. (2005). Air pollution and birth weight among term infants in California. *Pediatrics, 115*, 121–128.

3. Lee, B. E., Ha, E. H., Park, H. S., et al. (2003). Exposure to air pollution during different gestational phases contributes to risks of low birth weight. *Human Reproduction, 18*, 638–643.
4. Hansen, C., Neller, A., Williams, G., et al. (2007). Low levels of ambient air pollution during pregnancy and fetal growth among term neonates in Brisbane, Australia. *Environmental Research, 103*, 383–389.
5. Gehring, U., van Eijsden, M., Dijkema, M. B. A., et al. (2011). Traffic-related air pollution and pregnancy outcomes in the Dutch ABCD birth cohort study. *Occupational and Environmental Medicine, 68*(1), 36–43.
6. Gouveia, N., Bremner, S. A., et al. (2004). Association between ambient air pollution and birth weight in Sao Paulo, Brazil. *Journal of Epidemiology and Community Health, 58*(1), 11–17.
7. Ballester, F., Estarlich, M., Iñiguez, C., et al. (2010). Air pollution exposure during pregnancy and reduced birth size: A prospective birth cohort study in Valencia, Spain. *Environmental Health, 9*, 6.
8. Bell, M. L., Ebisu, K., & Belanger, K. (2007). Ambient air pollution and low birth weight in Connecticut and Massachusetts. *Environmental Health Perspectives, 115*(7), 1118–1124.
9. Srám, R. J., Binková, B., Dejmek, J., et al. (2005). Ambient air pollution and pregnancy outcomes: A review of the literature. *Environmental Health Perspectives, 113*(4), 375–382.
10. Brauer, M., Lencar, C., Tamburic, L., et al. (2008). A cohort study of traffic-related air pollution impacts on birth outcomes. *Environmental Health Perspectives, 116*(5), 680–686.
11. Dugandzic, R., Dodds, L., Stieb, D., et al. (2006). The association between low level exposures to ambient air pollution and term low birth weight: A retrospective cohort study. *Environmental Health, 5*, 3.
12. Maisonet, M., Correa, A., Misra, D., et al. (2004). A review of the literature on the effects of ambient air pollution on fetal growth. *Environmental Research, 95*(1), 106–115.
13. Ren, C., Melly, S., & Schwartz, J. (2010). Modifiers of short-term effects of ozone on mortality in eastern Massachusetts—a case-crossover analysis at individual level. *Environmental Health, 9*, 3.
14. Hansen, C. A., Barnett, A. G., Jalaludin, B. B., et al. (2009). Ambient air pollution and birth defects in Brisbane, Australia. *PLoS One, 4*(4), e5408.
15. Ritz, B., Yu, F., Fruin, S., et al. (2002). Ambient air pollution and risk of birth defects in Southern California. *American Journal of Epidemiology, 155*(1), 17–25.
16. Ritz, B., Wilhelm, M., Hoggatt, K. J., et al. (2007). Ambient air pollution and preterm birth in the Environment and Pregnancy Outcomes Study at the University of California, Los Angeles. *American Journal of Epidemiology, 166*, 1045–1052.
17. Hansen, C., Neller, A., Williams, G., et al. (2006). Maternal exposure to low levels of ambient air pollution and preterm birth in Brisbane, Australia. *British Journal of Obstetrics and Gynaecology, 113*(8), 935–941.
18. Huynh, M., Woodruff, T. J., Parker, J. D., et al. (2006). Relationships between air pollution and preterm birth in California. *Paediatric and Perinatal Epidemiology, 20*(6), 454–461.
19. Wu, J., Ren, C., Delfino, R. J., et al. (2009). Association between local traffic-generated air pollution and preeclampsia and preterm delivery in the south coast air basin of California. *Environmental Health Perspectives, 117*(11), 1773–1779.
20. Glinianaia, S. V., Rankin, J., Bell, R., et al. (2004). Particulate air pollution and fetal health: A systematic review of the epidemiologic evidence. *Epidemiology, 15*(1), 36–45.
21. Yi, O., Kim, H., & Ha, E. (2009). Does area level socioeconomic status modify the effects of PM(10) on preterm delivery? *Environmental Research, 110*(1), 55–61.
22. El-Mohandes, A. A., Kiely, M., Blake, S. M., et al. (2010). An intervention to reduce environmental tobacco smoke exposure improves pregnancy outcomes. *Pediatrics, 125*, 721–728.
23. Salihu, H. M., Mbah, A. K., Jeffers, D., et al. (2009). Healthy start program and feto-infant morbidity outcomes: Evaluation of program effectiveness. *Maternal and Child Health Journal, 13*(1), 56–65.
24. US Census Bureau. (2003). State and county facts. Available at: http://www.census.gov/.
25. Mbah, A. K., Alio, A. P., Marty, P. J., Bruder, K., Wilson, R., & Salihu, H. M. (2011). Recurrent versus isolated pre-eclampsia and risk of feto-infant morbidity outcomes: Racial/ethnic disparity. *European Journal of Obstetrics, Gynecology, and Reproductive Biology, 156*(1), 23–28.
26. Salihu, H. M., Stanley, K. M., Mbah, A. K., August, E. M., Alio, A. P., & Marty, P. J. (2010). Disparities in rates and trends of HIV/AIDS during pregnancy across the decade, 1998–2007. *Journal of Acquired Immune Deficiency Syndromes, 55*(3), 391–396.
27. Environmental Protection Agency. (2011). USA air quality system. Available at: http://www.epa.gov/ttn/airs/airsaqs/.
28. Alexander, G. R., Kogan, M., Martin, J., & Papiernik, E. (1998). What are the fetal growth patterns of singletons, twins, and triplets in the United States? *Clinical Obstetrics and Gynecology, 41*, 114–125.
29. Taffel, S., Johnson, D., & Heuser, R. (1982). A method of imputing length of gestation on birth certificates. *Vital Health Statistics, 2*(93), 1–11.
30. Alexander, G. R., & Kotelchuck, M. (1996). Quantifying the adequacy of prenatal care: A comparison of indices. *Public Health Report, 3*, 408–418.
31. Kahn, E. B., Berg, C. J., & Callaghan, W. M. (2009). Cesarean delivery among women with low-risk pregnancies: A comparison of birth certificates and hospital discharge data. *Obstetrics and Gynecology, 113*(1), 33–40.
32. Lydon-Rochelle, M. T., Holt, V. L., Cárdenas, V., Nelson, J. C., Easterling, T. R., Gardella, C., et al. (2005). The reporting of pre-existing maternal medical conditions and complications of pregnancy on birth certificates and in hospital discharge data. *American Journal of Obstetrics and Gynecology, 193*(1), 125–134.
33. Kuzawa, C. W., & Sweet, E. (2009). Epigenetics and the embodiment of race: Developmental origins of US racial disparities in cardiovascular health. *American Journal of Human Biology, 21*(1), 2–15.
34. Burris, H. H., & Collins, J. W. (2010). Race and preterm birth—the case for epigenetic inquiry. *Ethnicity and Disease, 20*(3), 296–299.
35. Cutfield, W. S., Hofman, P. L., Mitchell, M., et al. (2007). Could epigenetics play a role in the developmental origins of health and disease? *Pediatric Research, 61*(5), 68R–75R.
36. Mitchell, M. D. (2006). Unique suppression of prostaglandin H synthase-2 expression by inhibition of histone deacetylation, specifically in human amnion but not adjacent choriodecidua. *Molecular Cell Biology, 17*(1), 549–553.
37. Dolinoy, D. C., Weidman, J. R., & Jirtle, R. L. (2007). Epigenetic gene regulation: Linking early developmental environment to adult disease. *Reproductive Toxicology, 23*(3), 297–307.
38. Porter, T. F., Fraser, A. M., Hunter, C. Y., et al. (1997). The risk of preterm birth across generations. *Obstetrics and Gynecology, 90*(1), 63–67.
39. Woodruff, T. J., Grillo, J., & Schoendorf, K. C. (1997). The relationship between selected causes of postneonatal infant mortality and particulate air pollution in the United States. *Environmental Health Perspective, 105*(6), 608–612.

40. van den Hooven, E. H., Jaddoe, V. W., de Kluizenaar, Y., et al. (2009). Residential traffic exposure and pregnancy-related outcomes: A prospective birth cohort study. *Environmental Health, 8*, 59.
41. Mannes, T., Jalaludin, B., Morgan, G., et al. (2005). Impact of ambient air pollution on birth weight in Sydney, Australia. *Occupational and Environmental Medicine, 62*(8), 524–530.
42. Salam, M. T., Millstein, J., Li, Y. F., et al. (2005). Birth outcomes and prenatal exposure to ozone, carbon monoxide, and particulate matter: Results from the Children's Health Study. *Environmental Health Perspective, 113*(11), 1638–1644.
43. Shaw, G. M., & Malcoe, L. H. (1992). Residential mobility during pregnancy for mothers of infants with or without congenital cardiac anomalies: A reprint. *Archives of Environmental Health, 47*(3), 236–238.
44. Canfield, M. A., Ramadhani, T. A., Langlois, P. H., et al. (2006). Residential mobility patterns and exposure misclassification in epidemiologic studies of birth defects. *Journal of Exposure Science and Environmental Epidemiology, 16*(6), 538–543.
45. Fell, D. B., Dodds, L., & King, W. D. (2004). Residential mobility during pregnancy. *Pediatric and Perinatal Epidemiology, 18*(6), 408–414.
46. Khoury, M. J., Stewart, W., Weinstein, A., et al. (1988). Residential mobility during pregnancy: Implications for environmental teratogenesis. *Journal of Clinical Epidemiology, 41*(6), 15–20.