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Traffic-Related Air Pollution and Risk of Preterm Birth in the San Joaquin Valley of California

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Abstract

We evaluated associations between traffic-related air pollution during pregnancy and preterm birth in births in four counties in California during years 2000–2006. We used logistic regression to examine the association between the highest quartile of ambient air pollutants (carbon monoxide, nitrogen dioxide, particulate matter <10 and 2.5 µm) and traffic density during pregnancy and each of five levels of prematurity based on gestational age at birth (20–23, 24–27, 28–31, 32–33 and 34–36 weeks) versus term (37–42 weeks). We examined trimester averages and the last month and last 6 weeks of pregnancy. Models were adjusted for birth weight, maternal age, race/ethnicity, education, prenatal care and birth costs payment. Neighborhood socioeconomic status was evaluated as a potential effect modifier. There were increased odds ratios for early preterm birth for those exposed to the highest quartile of each pollutant during the second trimester and the end of pregnancy (adjusted odds ratios: 1.4– 2.8). Associations were stronger among mothers living in low socioeconomic status neighborhoods (adjusted odds ratios: 2.1–4.3). We observed exposure-response associations for multiple pollutant exposures and early preterm birth. Inverse associations during the first trimester were observed. The results confirm associations between traffic-related air pollution and prematurity, particularly among very early preterm births and low socioeconomic status neighborhoods.

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Keywords

air pollution; preterm birth; pregnancy

Preterm birth is associated with perinatal mortality and adverse health consequences in childhood and adulthood. In the United States, 12% of all live births were preterm in 2010 (1). Being born preterm is costly in terms of suffering of infants and their families as well as the economic burden on society. Preterm birth is a complex phenomenon and can be considered as a continuum rather than a dichotomy of birth of <37 completed weeks gestation (versus≥37 weeks) (2). It has been argued that this classification is too simplistic for etiologic studies owing to the heterogeneity that has been observed with this outcome (3). Indeed, more detailed phenotypic classifications have even been suggested for extremely early (<28 weeks gestation) preterm birth (4, 5).

Several studies have examined the potential association between traffic-related air pollution and preterm birth; however, many are heterogeneous with regard to exposure and outcome assessment, geography covered, and statistical methods employed (6, 7). The majority of previous studies have examined preterm birth as a binary outcome rather than a continuous or more granular ordinal set of outcomes with a few notable exceptions (8–10). The current study examines exposures to several air pollutants (carbon monoxide, nitrogen dioxide, particulate matter <10 and 2.5 urn) and traffic during pregnancy and their associations with finer gestational designations of preterm birth in the San Joaquin Valley of California between 2000–2006. Additionally, we investigate neighborhood socioeconomic status and other factors as potential effect modifiers in the relationship between air pollution and preterm birth in response to earlier investigations of such interaction (11–14). Finally, we apply a multi-pollutant score analysis to determine the association with cumulative effects of multiple air pollutants.

Methods

Study Population

The Study of Air Pollution, Genetics and Early Life Events was designed to investigate the influence of exposure to traffic-related air pollution during pregnancy and birth outcomes. Birth certificates from all 2000–2006 births to women living in the four most populated counties in the San Joaquin Valley of California (Fresno, Kern, Stanislaus and San Joaquin) were obtained from the California Department of Health.

Analyses were limited to singleton births between 20 and 42 weeks gestation and birth weight between 500 and 5000 grams. Preterm birth was defined by gestational age at birth as determined from the last menstrual period on the birth certificate. Five categories of preterm birth were created based on gestational ages: 20–23 weeks, 24–27 weeks, 28–31 weeks, 32–33 weeks and 34–36 weeks. Term births (*i.e.*, 37–42 weeks) were considered the reference in all analyses.

The maternal residence at birth street address locations obtained from birth certificates were geocoded to an X and Y coordinate with ArcGIS software (ESRI, Redlands, California).

Residence addresses were corrected with ZP4 software (Semaphore Corporation, Aptos, California).

Ambient air quality data have been collected routinely at over 20 locations in the San Joaquin Valley since the 1970s and these data were acquired from U.S. Environmental Protection Agency's Air Quality System database (www.epa.gov/ttn/airs/airsaqs). Daily metrics of the following pollutants were calculated: carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter ≤ than 10 µm (PM_{10}), and PM ≤ than 2.5 µm ($PM_{2.5}$). These data were used to create averages for each trimester of pregnancy.

The station-specific daily air quality data were spatially interpolated using inverse distance-squared weighting. Data from up to four air quality measurement stations were included in each interpolation. Owing to the regional nature of NO_2, PM_{10}, and $PM_{2.5}$ concentrations, a maximum interpolation radius of 50 km was used. CO was interpolated using a smaller maximum interpolation radius of 25 km, since it reflects emitted pollutants with larger spatial gradients. When a residence was located within 5 km of one or more monitoring stations, the interpolation was based solely on the nearby values (15, 16). A 75% data completeness criterion was used for NO_2 and CO averages (i.e., the average was calculated if at least 75% of the period had available data), and a 15% data completeness criterion was used for PM_{10} and $PM_{2.5}$ to account for 1-in-6 day rather than everyday sampling schedules.

Traffic density was calculated from distance-decayed annual average daily traffic volumes within a 300m radius of geo-coded maternal residences (17). Roadway link-based traffic volumes were derived from Tele-Atlas/Geographic Data Technology traffic count data in 2005 using methodologies similar to those used in other health effects studies (17, 18). The Geographic Data Technology traffic count data were scaled to represent year 2003 traffic levels, based on county average vehicle-miles-traveled growth rates (California Department of Transportation, 2004). Further details about exposure assessment are presented in Supplemental Material 1.

Variables from birth certificates included in analyses were: infant birth weight, maternal age (<20, 20–24, 25–29, 30–34, ≥35 years), maternal race (White, Hispanic, African-American, Asian, other), maternal education (no high school, some high school, some college, bachelors or other degree), parity (0, ≥1), prenatal care (initiated in first trimester), Medi-Cal (Medicaid) or other government program payment of birth costs, infant sex, year (2000–2006) and maternal county of residence (Fresno, Kern, Stanislaus, San Joaquin). Analyses were restricted to births without reported maternal prepregnancy or gestational diabetes or hypertension.

Lower socioeconomic status (SES), such as poverty and unemployment, has been associated with adverse birth outcomes (19). Furthermore, SES has been identified as an effect modifier in the relationship between air pollution and adverse birth outcomes (11, 14, 20, 21), based on measures implemented by Ponce, et al. (14) we created an indicator variable for low neighborhood SES that had all of the following characteristics: unemployment >10%, income from public assistance >15% and families below poverty level >20% in the 2000 U.S. Census at the block group level (14, 22). This variable may not pertain directly to any individual, but is meant to provide contextual information about the neighborhoods in which the study population lived. This research was approved by institutional review boards from the University of California, Berkeley, Stanford University, and the California State Committee for the Protection of Human Subjects.

Statistical Analysis

First, second, and third pregnancy trimesters were defined as gestational weeks 1–13, 14–26, and 27 to birth, respectively. Additionally, we calculated metrics for the last month and last 6 weeks of pregnancy (birth minus 28 and 42 days, respectively). We used logistic regression to examine the association between the highest quartile of each pollutant or traffic metric individually compared to the lower three quartiles and each of the five gestational definitions of preterm birth (20–23 weeks, 24–27 weeks, 28–31 weeks, 32–33 weeks and 34–26 weeks) versus term (37–42 weeks). We chose this analysis a priori to be easily interpretable and comparable to previous studies. Exposure periods of the term births were truncated to match the same period as the comparison period-length of the preterm births.

According to our a priori analysis plan, models were adjusted for the following covariates: birth weight, maternal age, race/ethnicity, education, prenatal care in the first trimester, and Medi-Cal payment of birth costs. We stratified by race/ethnicity, maternal education and neighborhood SES to determine whether these characteristics modified an effect of air pollution on preterm birth.

We created a score of “cumulative” exposure based on the number of high exposures each participant was exposed to during each gestational time period. Those who were assigned within the lowest 3 quartiles for all exposures had a score of 0 and those in the highest quartile of exposure for all exposures received a score of 5.

We consider birth weight a potential confounder in the relationship between air pollution and preterm birth. Our main analysis included birth weight in the model, though we also included an analysis without birth weight for a comparison. Given the association between air pollution and low birth weight (6, 7, 23), our aim was to isolate the effect of air pollution on preterm birth independent of an association with birth weight.

We stratified on month of conception because it is strongly associated with air pollutant exposures and stratification allows for a granular examination of the change in estimates across the year. Additionally we stratified by parity and cesarean section to examine if the association between air pollution and preterm birth may be different in among these factors.

All analyses were performed with SAS 9.3 (Cary, NC).

Results

The four study counties included 329,650 births in 2000–2006. Exclusions were multiple births (n=8373), those missing file numbers (n=262), those with gestational age missing or <20 weeks or >42 weeks (n=44,699), and those with birth weight missing or <500g or >5000g (n=764). Completeness of pollutant assignments was 80% for CO, 94% for NO_2, 93% for PM_{10}, 93% for $PM_{2.5}$, and 96% for traffic density. The final study population included 263,204 births with measurements for at least one of these pollutants.

Most study mothers were Hispanic, had Medi-Cal payment of birth costs, and had at least a high school education (Table 1). In bivariable analyses, preterm birth was associated with Medi-Cal payment of birth costs, maternal age, race/ethnicity, and education.

Correlations of regional CO with NO_2 (r=0.75) and $PM_{2.5}$ (r=0.76) were high, which reflects the common source of motor vehicles. PM_{10} and $PM_{2.5}$ were correlated (r=0.70) and local traffic density was not correlated with the regional pollutant concentrations, as expected since the traffic density has a finer scale of spatial variation (The full correlation matrix can be found in Supplemental Material, Table S1).

There were statistically significant odds ratios of birth at 20–23 and 24–27 weeks gestation for high exposure to each air pollutant during the second trimester of pregnancy (Table 2; Supplemental Material, Figure S1). High CO and NO_2 exposures during the second trimester of pregnancy were associated with a 60% and 92% increase, respectively, in birth at 20–23 weeks gestation in adjusted analyses.

The adjusted estimates were not considerably different from the unadjusted results (Supplemental Material, Table S2). Model fit was evaluated by c-statistics. Models are typically considered reasonable when the c-statistic is higher than 0.7 and strong when it exceeds 0.8 (24). The c-statistics of the adjusted models ranged from 0.72–0.86 compared to 0.50–0.60 for crude models.

Odds ratios were even stronger for models examining PM exposure. High exposure to $PM_{2.5}$ and PM_{10} during the second trimester of pregnancy was associated with a more than two-fold increased risk of birth at 20–23 weeks gestation. Similar results were seen among births 24–27 weeks. There were increases in risk of preterm birth for all categories of preterm birth gestational ages. The strength of the association increased with earlier onset of preterm birth.

Results for exposures in first and third trimesters were more variable, with some estimates in the opposite direction from previously reported associations. For example, the adjusted odds ratio of birth at 20–23 weeks gestation was 0.57 for CO and 0.64 for $PM_{2.5}$ during the first trimester.

Similar to the second trimester results, odds ratios comparing high levels of pollutants during the last month and last 6 weeks of pregnancy were higher for PM and for birth at earlier gestational ages. Those exposed to the highest quartile of each pollutant were twice as likely to be born at 20–23 weeks gestation (Table 3).

When stratified by neighborhood SES, the odds ratio for birth at 20–23 and 24–27 weeks gestation were substantially higher among women of lower neighborhood SES and exposed to high levels of pollutants during the second trimester (Table 4; Supplemental Material, Table S3). Tests of homogeneity using the Wald chi square showed evidence of effect modification for a majority of the estimates using a criterion of $p<0.1$. Stratification by race/ethnicity and maternal education did not show evidence of effect modification.

Traffic density was associated with preterm birth in unadjusted analyses; however, the association was attenuated and not significant after adjustment for covariates (Table 5).

For the pollutant score, 35% were in the lower three quartiles for all exposures and served as the referent (score=0). The scores had the following distribution: 22%, 10%, 8%, 7% and 3% of births were exposed to the highest quartile of 1–5 exposures, respectively. The distribution of pollutant scores by gestational age is presented in Supplemental Material, Table S4. The cumulative pollutant scores 1–5 (*i.e.*, those who lived in a place where they were in the highest quartile of at least one pollutant), were all associated with increased odds ratio for preterm birth compared to zero (the lowest 3 quartiles of all pollutants) and the majority were statistically significant. High pollutant score was associated with increased odds ratio for preterm birth, particularly during the second trimester (Table 6; Supplemental Material, Figure S2). The score-response was monotonic for second trimester exposures and risk for the 20–23 weeks category of preterm.

Results of the sensitivity analysis for an association between air pollutants and preterm birth stratified by month of conception are presented in Supplemental Material, Table S5. Associations were generally strong and for conceptions during the second half of the year (July-December) and there was an inverse association often apparent in the first half of the year (January–June).

Other sensitivity analyses did not produce different results, *i.e.*, removing birth weight from the model and removing those with birth defects did not change the estimates substantially. There were no substantive differences in odds ratios when stratified by cesarean section or by parity.

Discussion

We observed associations between ambient air pollutants and risk of early and late occurring preterm birth. Exposure to particulate matter (PM_{10} and $PM_{2.5}$), especially proximal to parturition, was associated with all gestational definitions of preterm birth with the strongest associations for the earliest preterm births. For PM_{10} and $PM_{2.5}$, there was a monotonic response across the outcomes according to gestational timing, with the stronger associations for the earliest preterm births. These associations were observed after adjustment of several potential confounding factors.

Furthermore, observed associations were modified by neighborhood SES. The odds ratios for birth at 20–23 and 24–27 weeks gestation were higher for those with lower SES and exposed to higher pollutant levels during the second trimester. Similar evidence of effect modification by neighborhood SES was found by previous studies (14, 21) for preterm birth defined at less than 37 weeks gestation. Our study is the first to our knowledge with these findings at earlier gestational definitions of preterm birth.

Exposure to multiple higher pollutant levels was associated with increased odds ratios for preterm birth, especially birth at 20–23 weeks gestation. As far as we know, this is the first time this kind of multi-pollutant approach has been used. Previous studies have stated the importance of multi-pollutant analyses and have implemented other strategies to investigate this challenging question (25).

We observed strong and consistent associations for the second trimester and the end of pregnancy (which coincide for early preterm births). This collection of results may indicate that exposures to pollutants nearer parturition may be contributing. Although the specific pathways need to be further clarified, inflammation has been hypothesized as a potential mechanism of action for preterm birth (26). Inflammation may reflect early activation of the normal parturition cascade, in which proinflammatory mediators such as cytokines are typically induced (27, 28). These pollutants may result in inflammatory responses that cause preterm birth. Ongoing studies may soon be able elucidate this potential mechanism (29).

The first trimester results were more muted and in some comparisons suggested a different direction of association. These findings may indicate that address at birth used to assign exposure was misclassified for earlier pregnancy time periods. That is, we know that upwards of 25% of women move between first trimester and delivery (30) and we assigned “exposure” based on address at delivery. Unfortunately, we cannot disentangle these various alternatives without having a complete address history across gestational periods. If mid to late pregnancy is indeed more critical for air pollution exposure, these associations may be driving the inverse associations for the first trimester. Furthermore, the seasonal patterns in air pollution and different results we found across trimesters prompted the month of conception sensitivity analysis and showed seasonal differences in air pollution, preterm birth and the relationship between them.

The current study was restricted to live births. Previous studies have suggested an association between air pollution and stillbirth (31, 32). This selection bias (survival) may explain the lack of or inverse associations in the first trimester. For example, if high levels of air pollution result in fetal demise and loss in the first trimester, the relationship between high exposure and preterm birth may be smaller or inverse among those who survive the first trimester.

There have been numerous studies of ambient air pollution and preterm birth including several reviews (6, 7, 33). Overall, many associations have been noted though there is little consistency across studies as to which of the correlated pollutants are responsible and which exposure periods are the most critical for assessing preterm birth risk. The following pollutants have been associated with preterm birth: NO_2 during the each trimester (26, 34, 35); NO during the first and third trimester (26); CO during the last month (36); PM_{10} during the last six weeks (37); and $PM_{2.5}$ during the first trimester (38). Additional studies have also found associations between proximity to high traffic areas and preterm birth (14, 39–41). Our study adds to the evidence of associations between traffic-related air pollution and preterm birth.

Furthermore, our study adds to the sparse literature that assess associations of air pollution with risk of early preterm birth (8–10). Wu *et al.* found that exposure to NO_x (OR=2.28 for a 5.65 ppb increase) and $PM_{2.5}$ (OR=1.81 for a 1.35 μg/m^3 increase) were associated with birth at <30 weeks gestation in Los Angeles air basin (8). Another study in Vancouver found exposures to NO (OR=1.26 for 10 μg/m^3 increase) and CO (OR=1.16 for 100 μg/m^3 increase) were associated with birth <30 weeks gestation (10). Living within 200m of major roads was associated with birth <32 weeks gestation (OR=1.6) and birth <28 weeks (OR=1.8) in Japan (9).

A recent study of air pollution and preterm premature rupture of membranes identifies a potential mechanism of action, by which air pollution may cause preterm birth (42). The current study could not specify whether preterm births were spontaneous or indicated; however, the early preterm birth categories are more likely to be spontaneous and preterm premature rupture of membranes may be responsible for up to one-third of those births (43).

Although this is the first study to our knowledge that examined effect modification of neighborhood SES with early preterm birth, previous studies have examined its role with a binary classification of preterm birth (less than 37 weeks gestation). Ponce *et al.* found stronger associations between traffic exposures and preterm birth for those of low neighborhood SES and born in the winter in Los Angeles (14). A study in South Korea found the association between PM_{10} and preterm birth was increased for with low neighborhood SES (13).

The role of season in the study of air pollution and preterm birth is complex. Although there are expected seasonal changes in air pollution due to sources (e.g., wood smoke) and meteorological phenomena (e.g., temperature inversions), it is unknown why there are such noticeable differences in preterm birth across the year. Air pollution may be a factor in these seasonal differences, though it is difficult to separate from other seasonal patterns such as infection and dietary changes.

We acknowledge several limitations to our study. We recognize the possibility of exposure misclassification due to mothers' mobility during pregnancy. We used the maternal residence at birth for the entire period and the duration of time spent at the given address is unknown. Further, exposures were assigned based on where a woman lived. Clearly, such exposure assignments reflect only a portion of what a woman may encounter in a mobile environment. These sources of misclassification would be expected to be non-differential reducing our precision to estimate potential associations.

We were limited to the information that was available on the birth certificate for individual covariates. For example, we do not have data on maternal height and weight and there were insufficient data on maternal smoking, for which an association with preterm birth is established (44). The prevalence of cigarette smoking among pregnant women in California was relatively low, e.g., 8.7% in 2003 (45), but we do not know how smoking is related to air pollution exposure. Both active and passive smoking are important risk factors for preterm birth, particularly in homes with poor ventilation (46). The birth certificate does not indicate whether preterm births were spontaneous or medically indicated. It is expected that the majority of early preterm births are spontaneous and we did exclude those with diabetes or hypertension to minimize the proportion of medically indicated preterm births.

Despite these limitations, this study population is a large sample with geographic diversity in a highly exposed area of the U.S. The San Joaquin Valley was classified as nonattainment for the O_3, $PM_{2.5}$, and PM_{10} National Ambient Air Quality Standards (http://www.epa.gov/oaqps001/greenbk/mapnpoll.html) during this time period. Furthermore, the street addresses were geo-coded at a precise level and did not rely on exposure metrics at cruder geographic levels such as zip code. Finally, we captured a simple, multi-pollutant measure that assessed the cumulative effect of being exposed to high levels of multiple pollutants. Although this method does not reveal which selection of pollutants are most harmful in conjunction with one another, it does show that risk of preterm birth increases with high levels of an increasing number of pollutants.

In conclusion, exposure to traffic-related air pollution, particularly proximal to birth, was associated with an increased risk of preterm birth, and even more strongly for early preterm births – a gestational period when preterm labor onset would clearly be spontaneous rather than electively induced. The neonatal morbidity and mortality, as well as the long-term health and developmental problems, is significantly higher for those born at 20–27 weeks. These associations are further modified by neighborhood socioeconomic status.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Abbreviations

aOR	adjusted odds ratio
CI	confidence interval
CO	carbon monoxide
PM_{10}	particulate matter less than 10 μm
$PM_{2.5}$	particulate matter less than 2.5 μm
NO_2	nitrogen dioxide

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Table 1

Distribution of covariates by gestational age in births in the four most populous counties in San Joaquin Valley, California, 2000–2006 (%) (N=263,204).

Covariate	**Gestational age in weeks (%)**^{a}						**Total**
	37–42 n=232,241	**34–36 n=22,321**	**32–33 n=4011**	**28–31 n=2938**	**24–27 n=1233**	**20–23 n=460**	
First born	35.2	32.9	33.9	34.7	38.5	34.1	35.0
Neighborhood low SES	17.5	20.6	24.1	23.9	23.8	27.4	17.9
Medi-Cal payment of costs	53.7	60.8	65.0	65.8	63.3	70.9	54.7
Male	50.9	54.0	54.4	55.3	56.4	57.8	51.3
Cesarean section	24.8	28.4	34.6	41.1	41.0	30.0	25.5
Prenatal care in 1st trimester	81.7	77.7	73.6	68.8	70.2	66.5	81.0
Maternal age (years)							
<20	13.3	15.3	16.9	20.1	18.7	21.1	13.7
20–24	28.8	28.5	28.3	28.3	27.2	29.8	28.8
25–29	27.6	25.3	23.4	22.8	22.6	21.3	27.2
30–34	19.4	18.3	18.0	15.7	18.5	16.5	19.2
≥35	10.9	12.6	13.5	13.1	13.1	11.3	11.1
Race/ethnicity							
White, non-Hispanic	30.3	25.6	22.6	22.8	22.4	19.1	29.6
Asian	7.5	8.8	8.8	9.9	9.3	8.5	7.7
African-American	4.9	6.7	7.9	9.2	9.0	8.0	5.1
Hispanic	55.8	57.4	59.3	56.6	57.7	61.3	56.0
Other	1.5	1.5	1.5	1.5	1.6	3.0	1.5
Year							
2000	13.2	12.4	12.4	12.3	13.7	11.3	13.1
2001	13.4	12.6	11.5	12.3	11.0	8.0	13.2
2002	13.7	12.9	13.1	11.7	10.9	9.8	13.6
2003	13.9	13.9	13.8	12.5	11.6	9.8	13.9
2004	14.5	14.6	14.2	13.0	13.1	12.2	14.4
2005	15.1	16.1	15.7	18.7	21.1	26.5	15.2

Covariate	**Gestational age in weeks (%)**[a]						**Total**
	37–42 **n=232,241**	**34–36** **n=22,321**	**32–33** **n=4011**	**28–31** **n=2938**	**24–27** **n=1233**	**20–23** **n=460**	
2006	16.3	17.5	19.2	19.7	18.7	22.4	16.5
Education							
<High school	11.8	12.2	13.5	11.7	11.4	13.9	11.9
High school	52.0	56.1	57.5	61.1	58.5	61.5	52.6
Some college	21.0	19.2	17.9	16.9	18.9	15.0	20.7
College degree	12.9	9.7	7.9	7.0	7.3	7.0	12.5
Missing	2.3	2.8	3.1	3.4	3.9	2.6	2.3
County							
Fresno	32.5	35.2	35.9	37.4	44.3	53.5	32.9
Stanislaus	18.5	16.7	16.5	17.1	14.7	12.2	18.3
Kern	23.8	25.5	27.0	24.2	21.3	19.4	23.9
San Joaquin	25.3	22.6	20.7	21.3	19.8	15.0	24.9
Pregnancy complications							
Diabetes	2.0	2.7	2.4	1.6	1.2	0.7	2.0
Hypertension	1.5	3.4	5.1	4.9	3.6	1.1	1.7
	Mean (SD)						
Infant birth weight (g)	3426 (466)	3003 (582)	2663 (761)	2289 (976)	1818 (1190)	2197 (1314)	3356 (546)
Exposures	Mean (P_5–P_{95})						
CO (ppm)	0.52 (0.34, 0.79)	0.52 (0.32, 0.82)	0.52 (0.30, 0.85)	0.52 (0.29, 0.85)	0.51 (0.28, 0.90)	0.49 (0.27, 0.95)	0.52 (0.34, 0.79)
NO_2 (ppb)	17.48 (12.48, 23.68)	17.58 (12.30, 24.17)	17.68 (12.16, 24.67)	17.69 (11.91, 24.79)	17.55 (10.92, 25.14)	16.75 (9.15, 24.97)	17.49 (12.44, 23.73)
PM_{10} (μg/m^3)	37.14 (24.67, 53.21)	37.60 (24.34, 54.73)	37.97 (24.14, 56.80)	37.39 (23.36, 54.86)	38.52 (22.82, 58.81)	40.01 (23.87, 54.61)	37.21 (24.62, 53.36)
$PM_{2.5}$ (μg/m^3)	17.99 (10.84, 28.44)	18.19 (10.30, 29.92)	18.45 (10.06, 30.91)	18.39 (9.56, 31.25)	18.60 (9.24, 32.85)	18.61 (9.11, 33.68)	18.02 (10.75, 28.58)
Traffic density	34.97 (0.00, 38.84)	37.45 (0.00, 47.39)	39.15 (0.00, 48.04)	39.73 (0.00, 52.99)	42.04 (0.00, 71.86)	42.83 (0.00, 52.74)	35.35 (0.00, 40.31)

Abbreviations: SD, standard deviation; g, grams, P_5–P_{95}, 5th and 95th percentile

[a] Percentages may not equal 100 owing to rounding.

Table 2

Adjusted[a] odds ratios (aOR) and 95% confidence intervals (CI) for preterm birth comparing highest quartile[b] to lower 3 quartiles of each pollutant exposure in four counties in San Joaquin Valley, 2000–2006 (N=247,487).

Exposure	Gestational age weeks	N	Entire Pregnancy			First Trimester			Second Trimester			Third Trimester		
			aOR	95% CI		aOR	95% CI		aOR	95% CI		aOR	95% CI	
CO	37–42	183,973	1.00	–	–	1.00	–	–	1.00	–	–	1.00	–	–
	34–36	17,299	**1.14**	1.10	1.18	1.03	1.00	1.07	**1.05**	1.01	1.09	0.98	0.95	1.02
	32–33	3039	**1.11**	1.02	1.21	**0.90**	0.83	0.98	1.03	0.95	1.12	1.08	1.00	1.18
	28–31	2276	1.04	0.93	1.16	**0.87**	0.78	0.96	**1.19**	1.08	1.32	1.06	0.95	1.18
	24–27	975	**0.80**	0.66	0.97	**0.76**	0.63	0.90	**1.78**	1.51	2.09	NC	–	–
	20–23	379	**0.62**	0.46	0.82	**0.57**	0.44	0.74	**1.60**	1.28	2.01	NC	–	–
NO_2	37–42	215,873	1.00	–	–	1.00	–	–	1.00	–	–	1.00	–	–
	34–36	20,100	**1.10**	1.06	1.14	1.02	0.99	1.05	**1.06**	1.03	1.10	1.01	0.98	1.04
	32–33	3530	**1.15**	1.06	1.24	0.98	0.91	1.05	1.07	0.99	1.15	1.07	0.99	1.15
	28–31	2612	1.07	0.97	1.18	0.98	0.90	1.08	**1.11**	1.01	1.22	1.04	0.94	1.15
	24–27	1108	1.08	0.91	1.28	**0.81**	0.69	0.96	**1.38**	1.18	1.61	NC	–	–
	20–23	426	0.88	0.69	1.12	**0.56**	0.44	0.72	**1.92**	1.52	2.42	NC	–	–
PM_{10}	37–42	214,564	1.00	–	–	1.00	–	–	1.00	–	–	1.00	–	–
	34–36	19,931	**1.11**	1.07	1.15	**1.11**	1.07	1.15	**1.11**	1.07	1.15	1.02	0.99	1.06
	32–33	3426	**1.16**	1.07	1.25	**1.21**	1.12	1.30	**1.17**	1.08	1.27	1.02	0.95	1.11
	28–31	2414	**1.14**	1.03	1.27	**1.24**	1.12	1.37	**1.27**	1.15	1.40	**0.83**	0.75	0.93
	24–27	1093	**1.98**	1.69	2.33	**1.40**	1.20	1.65	**1.75**	1.49	2.04	NC	–	–
	20–23	418	**2.34**	1.88	2.90	1.12	0.89	1.40	**2.80**	2.26	3.47	NC	–	–
$PM_{2.5}$	37–42	214,206	1.00	–	–	1.00	–	–	1.00	–	–	1.00	–	–
	34–36	19,892	**1.27**	1.23	1.31	1.03	1.00	1.06	**1.09**	1.05	1.12	**0.96**	0.93	1.00
	32–33	3483	**1.56**	1.44	1.68	0.96	0.89	1.03	**1.21**	1.12	1.30	1.03	0.96	1.12
	28–31	2560	**1.62**	1.47	1.78	0.94	0.86	1.04	**1.55**	1.41	1.70	**1.34**	1.22	1.48
	24–27	1093	**1.96**	1.68	2.30	**0.78**	0.66	0.91	**2.14**	1.84	2.50	NC	–	–
	20–23	421	1.08	0.85	1.38	**0.64**	0.51	0.81	**2.83**	2.29	3.50	NC	–	–

Abbreviations: OR, odds ratio; CI, confidence interval; NC, not calculated

[a] Adjusted for maternal age, education, race, infant birth weight, prenatal care initiation in first trimester, Medi-Cal payment of birth costs

[b] Cut-offs for highest quartile of exposure: CO 0.60 ppm; NO_2 19.49 ppb; PM_{10} 42.77 μg/m^3; $PM_{2.5}$ 20.75 μg/m^3

Table 3

Adjusted[a] odds ratios (aOR) and 95% confidence intervals (CI) for preterm birth comparing highest quartile[b] to lower 3 quartiles of each pollutant exposure during the last month and last 6 weeks of pregnancy in four counties in San Joaquin Valley, 2000–2006 (N=247,487).

Exposure	Gestational age weeks	N	Last month of pregnancy			N	Last six weeks of pregnancy		
			aOR	95% CI			aOR	95% CI	
CO	37–42	185,604	1.00	–	–	185,689	1.00	–	–
	34–36	4811	0.95	0.92	0.99	4850	0.97	0.93	1.00
	32–33	925	1.06	0.98	1.15	910	1.03	0.95	1.12
	28–31	626	0.89	0.80	0.99	633	0.9	0.81	1.00
	24–27	335	1.53	1.30	1.81	368	1.94	1.65	2.28
	20–23	163	2.23	1.78	2.80	150	1.86	1.48	2.33
NO_2	37–42	215,810	1.00	–	–	215,817	1.00	–	–
	34–36	5941	0.98	0.95	1.01	6065	1.01	0.98	1.04
	32–33	1134	1.08	1.00	1.16	1114	1.04	0.96	1.12
	28–31	775	0.94	0.85	1.04	782	0.93	0.85	1.03
	24–27	351	1.15	0.98	1.35	392	1.39	1.19	1.62
	20–23	196	2.24	1.82	2.77	204	2.29	1.85	2.83
PM_{10}	37–42	214,693	1.00	–	–	214,692	1.00	–	–
	34–36	5612	0.97	0.93	1.00	5577	0.96	0.93	1.00
	32–33	997	0.96	0.89	1.04	983	0.95	0.87	1.02
	28–31	664	0.79	0.72	0.88	662	0.83	0.75	0.92
	24–27	352	1.33	1.13	1.56	349	1.29	1.10	1.52
	20–23	170	1.93	1.56	2.4	194	2.49	2.02	3.08
$PM_{2.5}$	37–42	214,513	1.00	–	–	214,549	1.00	–	–
	34–36	5366	0.98	0.94	1.01	5599	1.01	0.97	1.04
	32–33	1070	1.15	1.06	1.24	1094	1.16	1.08	1.25
	28–31	821	1.30	1.19	1.43	913	1.51	1.37	1.65
	24–27	400	2.05	1.75	2.39	421	2.19	1.87	2.55
	20–23	198	2.84	2.29	3.52	200	2.69	2.18	3.33

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval

[a] Adjusted for maternal age, education, race, infant birth weight, prenatal care initiation in first trimester, Medi-Cal payment of birth costs

[b] Cut-offs for highest quartile of exposure: CO 0.60 ppm; NO_2 19.49 ppb; PMio 42.77 μg/m^3; $PM_{2.5}$ 20.75 μg/m^3

Table 4

Adjusted odds[a] ratios (aOR) and 95% confidence intervals (CI) for preterm birth comparing highest quartile[b] to lower 3 quartiles of each pollutant exposure among those with low neighborhood socioeconomic status in four counties in San Joaquin Valley, 2000–2006 (N=44,231).

Exposure	**Gestational age in weeks**	**N**	**Entire Pregnancy**			**First Trimester**			**Second Trimester**			**Third Trimester**		
			aOR	**95% CI**		**aOR**	**95% CI**		**aOR**	**95% CI**		**aOR**	**95% CI**	
CO	37–42	35,295	1.00	–	–	1.00	–	–	1.00	–	–	1.00	–	–
	34–36	3912	**1.11**	1.03	1.20	0.98	0.92	1.06	**1.09**	1.01	1.17	0.95	0.88	1.02
	32–33	808	1.06	0.90	1.25	0.86	0.74	1.01	1.00	0.86	1.17	1.05	0.89	1.22
	28–31	573	0.90	0.73	1.11	**0.79**	0.65	0.96	**1.25**	1.04	1.51	1.02	0.83	1.25
	24–27	266	0.71	0.50	1.01	**0.52**	0.37	0.74	**2.73**	2.02	3.68	NC	–	–
	20–23	113	**0.58**	0.35	0.95	**0.55**	0.35	0.87	**2.38**	1.60	3.54	NC	–	–
NO_2	37–42	37,815	1.00	–	–	1.00	–	–	1.00	–	–	1.00	–	–
	34–36	4178	1.06	0.99	1.13	0.98	0.92	1.05	1.07	1.00	1.15	1.00	0.94	1.07
	32–33	859	1.10	0.95	1.28	0.94	0.82	1.09	1.06	0.92	1.22	1.12	0.97	1.29
	28–31	633	0.89	0.74	1.08	1.00	0.84	1.20	1.11	0.93	1.33	1.05	0.88	1.27
	24–27	274	0.98	0.72	1.32	**0.60**	0.44	0.81	**2.14**	1.58	2.90	NC	–	–
	20–23	115	0.77	0.51	1.17	**0.42**	0.27	0.66	**3.67**	2.28	5.91	NC	–	–
PM_{10}	37–42	37,811	1.00	–	–	1.00	–	–	1.00	–	–	1.00	–	–
	34–36	4170	**1.13**	1.05	1.21	1.08	1.00	1.16	**1.13**	1.06	1.22	0.99	0.92	1.06
	32–33	843	**1.21**	1.03	1.41	**1.25**	1.07	1.45	**1.24**	1.06	1.44	0.97	0.84	1.14
	28–31	586	0.98	0.80	1.21	1.06	0.87	1.29	**1.23**	1.02	1.50	**0.63**	0.50	0.78
	24–27	274	**2.64**	1.95	3.56	1.22	0.90	1.66	**2.49**	1.86	3.34	NC	–	–
	20–23	114	**2.37**	1.59	3.52	1.18	0.78	1.77	**3.98**	2.66	5.98	NC	–	–
$PM_{2.5}$	37–42	37,740	1.00	–	–	1.00	–	–	1.00	–	–	1.00	–	–
	34–36	4168	**1.24**	1.15	1.33	0.99	0.92	1.06	**1.13**	1.05	1.21	0.97	0.90	1.04
	32–33	854	**1.58**	1.36	1.84	0.93	0.80	1.08	**1.25**	1.08	1.45	1.09	0.93	1.26
	28–31	623	**1.59**	1.31	1.92	0.85	0.70	1.03	**1.82**	1.52	2.19	**1.63**	1.35	1.97
	24–27	274	**2.36**	1.75	3.18	**0.46**	0.33	0.66	**3.14**	2.33	4.24	NC	–	–
	20–23	115	0.69	0.42	1.11	**0.50**	0.31	0.79	**4.30**	2.85	6.48	NC	–	–

Abbreviations: OR, odds ratio; CI, confidence interval; NC, not calculated

[a] Adjusted for maternal age, education, race, infant birth weight, prenatal care initiation in first trimester, Medi-Cal payment of birth costs

[b] Cut-offs for highest quartile of exposure: CO 0.60 ppm; NO_2 19.49 ppb; PM_{10} 42.77 µg/m^3; $PM_{2.5}$ 20.75 µg/m^3

Table 5

Odds ratios and 95% confidence intervals (CI) for preterm birth comparing highest quartile[b] to lower 3 quartiles of traffic density for births in four counties in San Joaquin Valley, 2000–2006 (N=247,487).

Gestational age in weeks	**N**	**Unadjusted pooled**			**Adjusted pooled**			**Low neighborhood SES**				**Non-lowneighborhood SES**			
		OR	**95% CIs**		**aOR**	**95% CIs**		**N**	**aOR**	**95% CIs**		**N**	**aOR**	**95% CIs**	
37–42	219,237	1.00	–	–	1.00	–	–	38,131	1.00	–	–	181,106	1.00	–	–
34–36	20,427	**1.10**	1.06	1.13	1.04	1.00	1.07	1638	1.04	0.97	1.11	16,222	1.03	0.99	1.07
32–33	3599	**1.19**	1.11	1.29	**1.10**	1.01	1.19	865	1.04	0.90	1.21	2734	1.09	1.00	1.20
28–31	2657	**1.21**	1.11	1.31	1.05	0.95	1.15	268	**1.22**	1.02	1.46	2021	0.97	0.86	1.09
24–27	1129	**1.25**	1.10	1.42	1.13	0.96	1.33	276	1.31	0.98	1.75	853	1.03	0.84	1.25
20–23	135	**1.35**	1.10	1.66	1.25	1.00	1.56	118	1.09	0.73	1.61	320	1.29	0.98	1.69

Abbreviations: aOR, adjusted odds ratio; CI, confidence interval

[a] Adjusted for maternal age, education, race, infant birth weight, prenatal care initiation in first trimester, Medi-Cal payment of birth costs

[b] Cut-offs for highest quartile of exposure: 13,561 vehicles per day

Table 6

Adjusted[a] odds ratios (aOR) and 95% confidence intervals (CIs) comparing each score (number of exposures above the highest quartile) compared to those without having a high level any exposure for births in four counties in San Joaquin Valley, 2000–2006 (N=247,487).

Gestational age in weeks	Score	First Trimester			Second Trimester			Third Trimester		
		aOR	95% CIs		aOR	95% CIs		aOR	95% CIs	
34–36	0	1.00	–	–	1.00	–	–	1.00	–	–
	1	**1.06**	1.01	1.10	**1.06**	1.02	1.11	1.03	0.99	1.08
	2	**1.09**	1.04	1.15	**1.07**	1.01	1.13	**1.07**	1.01	1.12
	3	1.04	0.98	1.10	**1.10**	1.04	1.16	**1.07**	1.02	1.13
	4	**1.07**	1.02	1.13	**1.16**	1.10	1.22	0.96	0.90	1.02
	5	**1.10**	1.01	1.19	1.07	0.98	1.16	0.99	0.90	1.09
32–33	0	1.00	–	–	1.00	–	–	1.00	–	–
	1	1.07	0.97	1.19	1.05	0.95	1.16	**1.18**	1.07	1.31
	2	**1.17**	1.03	1.32	**1.27**	1.12	1.43	**1.25**	1.10	1.41
	3	0.98	0.86	1.12	1.13	0.99	1.29	**1.22**	1.07	1.39
	4	0.99	0.87	1.13	**1.25**	1.10	1.42	1.10	0.96	1.26
	5	1.13	0.94	1.37	1.13	0.92	1.38	1.20	0.97	1.47
28–31	0	1.00	–	–	1.00	–	–	1.00	–	–
	1	**1.15**	1.01	1.31	1.09	0.95	1.24	1.14	0.99	1.30
	2	**1.24**	1.06	1.45	**1.40**	1.19	1.64	**1.20**	1.02	1.42
	3	1.02	0.87	1.21	**1.24**	1.05	1.47	**1.46**	1.25	1.72
	4	1.05	0.89	1.24	**1.58**	1.35	1.84	1.09	0.91	1.31
	5	1.08	0.84	1.38	**1.57**	1.24	1.98	0.93	0.69	1.26
24–27	0	1.00	–	–	1.00	–	–	NC		
	1	**1.45**	1.18	1.78	1.17	0.93	1.46			
	2	1.24	0.96	1.62	**1.54**	1.17	2.01			
	3	1.04	0.79	1.37	**1.54**	1.17	2.03			
	4	1.05	0.80	1.38	**1.83**	1.41	2.38			
	5	0.62	0.38	1.02	**3.29**	2.37	4.55			
20–23	0	1.00	–	–	1.00	–	–	NC		

Gestational age in weeks	**Score**	**First Trimester**			**Second Trimester**			**Third Trimester**		
		aOR	**95% CIs**		**aOR**	**95% CIs**		**aOR**	**95% CIs**	
	1	1.31	1.00	1.72	1.23	0.86	1.76			
	2	0.77	0.52	1.15	**1.55**	1.01	2.38			
	3	0.50	0.32	0.79	**1.65**	1.08	2.53			
	4	0.83	0.57	1.21	**2.82**	1.94	4.10			
	5	0.63	0.33	1.20	**4.05**	2.51	6.54			

Abbreviations: OR, odds ratio; CI, confidence interval; NC, not calculated

[a] Adjusted for maternal age, education, race, infant birth weight, prenatal care initiation in first trimester, Medi-Cal payment of birth costs

[b] Cut-offs for highest quartile of exposure: CO 0.60 ppm; NO_2 19.49 ppb; PM_{10} 42.77 μg/m^3; $PM_{2.5}$ 20.75 μg/m^3