

Inequities of social and physical environment and adverse birth outcomes:
low birth weight and preterm births in Eastern Massachusetts

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Abstract

BACKGROUND and OBJECTIVES: Air pollution and social characteristics have been shown to affect indicators of health. While use of spatial methods to estimate exposure to air pollution has increased power to detect effects, questions have been raised about potential for confounding by social factors. **METHODS:** A study of singleton births in Eastern Massachusetts conducted between 1996 and 2002 examined the association between indicators of traffic, land use, individual and area-based socioeconomic measures (SEM), and adverse birth outcomes (*low birth weight, small for gestational age and preterm births*). **RESULTS:** We found effects of both individual and area based SEM with all three outcomes. For example, mothers with less than high school education had newborns with an 8.5g lower birth weight (95% CI: 12.8g, 4.2g). We found associations between traffic and land use variables only with birth weight. For example, incremental distance of 2 SD from a major highway was associated with a 3.8g (95% CI: 1.9g, 5.7g) increase. We also saw a signal of an interaction between education and median household income with indicators of traffic and land use. The protective effect of increased land use as open space in a neighborhood was only found among those with more than a high school education. **CONCLUSIONS:** Overall, the findings suggested greater likelihood of all birth outcomes among the more socially disadvantaged, and a greater risk of *low birth weight* associated also with greater traffic exposures.

BACKGROUND

Socioeconomic position and physical environment have been associated with increased incidence of low birth weight and its determinants, preterm births and intrauterine growth retardation [1-3]. The issue stands high in the public health concerns due to evidence that adverse health in early life can lead to later life diseases of childhood and adulthood [4-9].

Socioeconomic status is a determinant of health in populations [10, 11], and it has been linked to adverse birth outcomes [3, 12-16]. It is likely that socioeconomic status is a surrogate for access to health care, empowerment, stress, and other adverse environmental factors associated with low status, and among these air pollution exposure [17, 18]. Air pollution, a component of physical environment, has also been associated with low birth weight and preterm births [15, 19-22].

While different sources of air pollution have been associated with increased risk of adverse health, it is traffic pollutants that show the greater heterogeneity in concentration within urban areas [23]. Because measures of concentrations of air pollutants at individual addresses are unfeasible in large studies of births or other outcomes, either modeled concentrations or measures of traffic such as traffic density or distance to roadways have been used as exposure indices [24, 25]. One concern of this approach is that variability in socioeconomic measures (SEM) can predict distribution of indices of physical environment [26-28]. Hence the study of these two together can control each for confounding by the other, and allow for examination of interactions. In addition, the use of SEM at both the individual and area-based level allows one to capture both the effect of individual level SEM as well as any additional contextual effects that exist at the area level. Most epidemiologic studies examining socioeconomic position and birth outcomes were usually based on record-based information (birth certificates) and have as result measured socioeconomic factors at the individual level such as information on maternal

education, income, race/ethnicity, and prenatal care [24, 29, 30]. However, only a few studies have looked at individual and contextual level factors simultaneously, as well as measures of physical environment [24, 31, 32].

The present study was carried out to identify and explain disparities in low birth weight and preterm births in seven counties of Eastern Massachusetts between 1996 and 2002. We intended in this study to explain the variation in birth outcomes as a function of the individual and area-based level SEM, the physical environment, and their interaction. We also sought to assess the degree of confounding likely in previous reports that have examined measures of physical environment, or social environment, but not both.

MATERIAL AND METHODS

Study population

The study population included *all singleton live births* in Eastern Massachusetts for the counties of Bristol, Essex, Middlesex, Norfolk, Plymouth, Suffolk, and Worcester obtained from the Massachusetts Birth Registry for the period between January 1, 1996 and December 31, 2002, covering about 83 percent of the state's population. Individual address of mother at the time of birth provided to us was geocoded by a private firm and was reassessed by us for accuracy and completeness. The study and the use of birth data was approved by the Massachusetts Department of Public Health and the Human Subjects Committee of the Harvard School of Public Health. We restricted our study to births born between 20 and 45 weeks of gestation, with birth weight between 500 and 5500 grams. We also excluded those births that could not be correctly assigned an address (4.9 percent), resulting in the final number used for the study of 425 751.

Outcome

We focused on three measures of adverse birth outcomes: *birth weight*, *small for gestational age*, and *preterm birth*. Low birth weight among term newborns (born at ≥ 37 to 45 weeks of gestation) may represent intrauterine growth retardation. We constructed *small for gestational age* as an indicator of intrauterine growth retardation, by taking the lowest decile of the distribution of weight by gestational week, maternal race, and infant gender among all term births as the cutoff. We assigned 1 to those births falling below this cutoff, and 0 otherwise (reference group). *Preterm births* were defined as all neonates born between 20 and 37 weeks of gestation. The reference group for preterm births was defined as all term birth weighting between 2500 and 5500 grams.

Exposure

We calculated several measures of traffic to assign at each individual address of the infant provided by the Birth Registry.

Cumulative traffic density. We obtained a road spatial dataset for roads and highways in Eastern Massachusetts in 2002 from the Massachusetts Highway Department (MHD 2002), which conducts annual traffic data collection. This dataset included average daily traffic (ADT) as an attribute.

A grid made up of points spaced 200 meters apart was created over the study area of Eastern Massachusetts, using ArcGIS 9.1 (ESRI, Redlands, CA) buffer tool. Around each grid point we created 100 meters radius circles. We intersected these circles with the MHD 2002 roads to create a combined dataset of roads within each circle. Cumulative ADT (CADT) was calculated for all road segments within 100 meters around each grid point as: $CADT = \sum(ADT * \text{road segment length})$, and that value was assigned to the grid point. Birth addresses were then assigned a weighted average of the estimates of the four grid points around it, using bilinear interpolation.

Distance to roadways. Birth addresses were joined by spatial location to major roadways, using ArcGIS 9.1. The data were obtained through US Census 2000 Topologically Integrated Geographic Encoding and Referencing system (TIGER) [33]. The resulting database identified the road nearest to birth address and the distance to the nearest road for primary highways with “limited access”. The roads in this category can only be accessed through ramps, and they have multiple lanes of traffic, with no direct intersection with other roads. The TIGER roads were chosen because they are likely to be similar to the roads in the proprietary database used for geocoding the addresses which were originally derived from the Census TIGER files.

Land use for recreation and conservation (open space). Protected and recreational open space was downloaded from MassGIS, Massachusetts Executive Office of Environmental Affairs [34]. The subset of the open space designated for recreation, conservation, water supply, and forestry was intersected with 2000 Census tract boundaries (also downloaded from MassGIS) using ArcGIS 9.1. The percent of each census tract that was open space was then calculated and assigned to addresses belonging to that tract.

Socioeconomic indicators

Individual variables. We obtained from the birth registry information on mother’s race, education, and the Kotelchuck index of adequacy of prenatal care utilization (APNCU). We categorized education as: *low* (≤ 12 years of educational attainment); *high* (13-15 years); and *college or higher* (≥ 16 years).

Adequacy of prenatal care can be a predictor of accessibility of mother to health care, and inability to have appropriate prenatal care is more likely for those living in poorer neighborhoods. We categorized the APNCU [35], a measure based on the number, and the time of start of mother’s

prenatal visits, into: *inadequate* (<50 percent of expected visits used); *intermediate* (50-79 percent); *appropriate* (80-109 percent); and *appropriate plus* (≥ 110 percent).

Contextual variables. We obtained data from the US Census Bureau of 2000 on median household income for each census tract in the study area, and assigned these to births whose address belonged to that tract. Preliminary analyses controlled for several other variables at the census tract level: percent below poverty, percent with low education, percent of ethnic background (African-American, Hispanic) and found no association or confounding by these factors, therefore not presented in this work.

Model covariates

Measures of traffic were log transformed to stabilize the variance and used as such in the analyses. We controlled additionally in the models for age of mother, gestational age and maternal race (where necessary), amount of cigarettes smoked during pregnancy, chronic conditions of mother or conditions of pregnancy (renal disease, lung disease, hypertension, gestational diabetes or diabetes diagnosed otherwise, uterine bleeding), if the mother ever had a previous preterm birth, if the mother ever had a previous infant weighting more than 4000 grams, gender of infant, and year of birth to control for time trends.

Smoking during pregnancy is an important covariate which has not been controlled for in many previous studies [21, 24, 29, 31]. Since it varies with social class in the United States [36] it may represent an important confounder. Information on smoking was self-reported from mother on birth certificate, and it reflects the number of cigarettes smoked per day during and pre-pregnancy.

Statistical Methods

Modeling for gaussian data. For continuous outcomes such as birth weight, linear mixed regression models were carried out [37]. For example, let Y_{ij} be the response (*birth weight*) in the i^{th} subject in census tract j , and $child\ sex_i$, $maternal\ age_i$, $traffic\ at\ individual\ address\ of\ mother_i$, individual-level socioeconomic measures (ILSEM) $_i$, census tract-level socioeconomic measures (TLSEM) $_j$ denote the set of covariates of interest. Then we considered models of the form

$$Y_{ij} = u_j + b_0 + b_1 child\ sex_i + b_2 maternal\ age_i + \dots + b_3 Traffic_i + b_4 ILSEM_i + b_5 TLSEM_j + \dots + e_{ij}$$

Here e_{ij} is the error term, and u_j is the tract-specific random intercept and represents the variation of the rate in the groups due to unmeasured factors. This intercept is randomly generated from a normal distribution as suggested by Pickle [38], modeled with the SAS procedure MIXED (SAS Institute).

Modeling for binomial data. Binomial data was modeled similarly to the normal data. For *small for gestational age* and *premature births*, Y_{ij} will be the outcome in the i^{th} subject in the j^{th} census tract, with the model of the form

$$\text{Logit}(\Pr Y_{ij}=1|X) = u_j + \beta_0 + \beta_1 * child\ sex_i + \beta_2 * maternal\ age_i + \dots + \beta_3 * Traffic_i + \beta_4 ILSEM_i + \beta_5 * TLSEM_j$$

where u_j is a random census tract intercept. This approach was implemented using a recent version of the SAS procedure GLIMMIX [39].

It was likely that the u_i would exhibit spatial correlation, from either the models for Gaussian or Binomial data. We modeled this spatial correlation by assigning the latitude and longitude of the population centroid of each census tract to each observation in the group i , and fitting an exponential spatial correlation structure.

We examined effect modification by median household income and maternal education for the association between birth weight and traffic and land use. We assessed statistical significance of the difference of effects by calculating 95 percent confidence intervals around that difference [40].

RESULTS

Univariate Analyses

Among the final 425 751 singleton births included in the study, the majority were of white mothers (table 1). Due to small numbers we excluded Native American births (total of 674) from the analyses. Younger mothers were more likely to have smaller children and preterm births, and more likely to be of African-American or Hispanic ethnicity (14 percent and 30 percent of mothers under age 20 respectively).

Smaller infants and premature births were more often observed among mothers with lower education, of African-American, Hispanic, or Asian ethnicity, and mothers that had inadequate prenatal care. However, mothers with *more than appropriate* prenatal care index had smaller weight infants, and greatly larger proportion of preterm births than the reference group.

Smoking before and during pregnancy was an indicator for all birth outcomes.

All adverse birth outcomes were more likely with greater traffic density, closer distance to major highways, lower percent of open space, and lower median household income (table 2).

Multivariate Analyses

We estimated the covariate adjusted associations between individual and census tract level socioeconomic indicators, traffic and land use variables and birth outcomes in one model and results of that model are presented in tables 3 and 4. To assess confounding of the social and physical environmental variables by each other, and of the individual versus contextual level social variables, we also examined models selectively deleting each category, and assessed the change in the coefficients compared to the full model. The effect of that control is presented below.

Individual level SEM. Education was a predictor of birth weight (table 3). *Low education* was associated with lower birth weight when compared to infants born from mothers with high education. In contrast, being born from mothers with *college* and *postgraduate education* (≥ 16 years) was associated with an increase in birth weight.

Low education of mother was also associated with greater risk of small for gestational age and preterm births.

Being born of African-American, Asian or Hispanic mothers was associated with lower birth weight, when compared to births from White mothers. Risk of preterm birth was also increased for mothers of African-American or Hispanic group, but not of mothers of Asian ethnicity.

Greater risk of adverse births was seen for mothers who had been provided with less than appropriate prenatal care. However, similar finding was observed in mothers with more than appropriate prenatal care. *More than appropriate* prenatal care is usually provided to mothers at risk of pregnancy complications, therefore at greater risk of poor birth outcomes.

Contextual level SEM. Controlling for individual education, race and indicators of physical environment, census tract level median household income was positively associated with birth weight, and inversely related to the risk of small for gestational age (full model, table 3).

When race and maternal education were excluded from the full model, the effect of median household income on birth weight increased to 19.4g (95 percent CI: 16.4g, 22.4g), and if race but not maternal education were included, the effect of median household income was 7.4g (95 percent CI: 4.9g, 9.8g). Hence, while median household income was significant in our model, the effect was reduced by 65 percent by control for individual SEM covariates.

Measures of traffic and land use. The results for measures of traffic are presented for one standard deviation (SD) change in distribution of the log-transformed variable, and for land use for 1 SD change in the variable distribution (table 4). The measure of traffic density in proximity to each birth address was suggestive of lower birth weight, although only marginally significant. In contrast, a significant increase in birth weight associated with increase in distance to major highways was seen; a similar association was also seen for percent open space.

We saw evidence of an effect of cumulative traffic density and increased risk of small for gestational age.

Inclusion in the models of traffic and land use variables did not affect the coefficients for educational attainment, or the coefficients for race and the index of prenatal care. However, we observed a reduction in the effect of median household income on birth weight by 23 percent in the presence of indicators of physical environment (model without physical environment variables: 8.8g; 95 percent CI: 6.5g, 11.2g).

Similarly, the effect of distance to roadways on birth weight was also reduced when SEM indicators were included in the model. The effect of distance to roads from the model with race but not

educational attainment or the indicator of median household income was 4.2g (95 percent CI: 2.3g, 6.1g), while the effect from the model with both educational attainment and median household income (5.2g; 95 percent CI: 3.0g, 7.3g), but not race was not very different from that of model without any of the SEM variables (5.7g; 95 percent CI: 3.4g, 7.9g).

There was no significant difference observed for the effect of cumulative traffic density on birth weight by educational attainment (table 5). We observed a marginally significant difference of effect on birth weight for distance to major highways (-3.1g; 95 percent confidence interval of difference (CI): -6.8g, 0.7g; p-value: 0.11), and an important difference for the association with land use (difference: -5.2g; 95 percent CI: -9.6g, -1.0g; p-value: 0.02). In these cases, the protective effect of greater distance from highway or greater open space land in the census tract was larger in the more advantaged. For open space, the protective effect was clearly only in those residents of the tract with greater education. There was no difference in the effect of distance to major highways or land use by median household income, and an indication of a stronger effect of traffic density in the less advantaged group, although not significant.

We also examined three way interactions between maternal education, median household income by tract, and our measures of the physical environment and found no significant differences (data not shown).

DISCUSSION

We examined the effect of social and physical environment on birth outcomes in a study of singleton births in Eastern Massachusetts, North East US. Measures of traffic exposure, estimated at the residential address of mother, were associated with lower birth weight, and for traffic density, with small for gestational age, after control for both individual and area based measures of social position.

Two key components of this study are worth mentioning. *First*, the study used individual estimates of exposure metrics for each subject, based on distance to roadways or traffic density within a radius of the subjects' home. A number of epidemiologic studies from the US and other countries have shown a relationship between air pollution and birth weight and preterm births, in particular with carbon monoxide and particulate matter [15, 19, 21, 29, 41-43]. The evidence however has not been fully corroborated possibly due to inadequate control for individual and neighborhood level socioeconomic indicators. Studies have shown that most of the factors that account for socioeconomic position of the mother can influence birth outcomes: ethnic background [20, 30], education [30, 42], and area based factors such as income and level of poverty by area [32]. However, only a limited number of studies have examined the influence of these factors, either alone or in combination, on the effects of air pollution on birth outcomes. Several studies from California, US, have examined air pollution effects on birth weight and preterm births controlling for individual or area based SEM, but rarely controlled for both or examined interaction [2, 21, 29].

Only a few studies have examined both individual and contextual SEM, indicators of physical environment and birth outcomes. In Wilhelm and Ritz [24], individual and neighborhood-level SEM measures were adjusted simultaneously, however, using a one-level model. A recent study of the same population examined confounding and effect modification of traffic effect estimates for preterm birth by both individual and contextual SEM variables in two-level random effect models [31]. In a hierarchical multilevel model, Williams and coworkers [32] also examined relations between air pollution and SEM variables in multi-level models, although they did not focus on traffic pollution specifically. They found a negative effect of ambient concentrations of lead and sulfur dioxide on birth weight; also a negative effect of poverty level of mother's residential census tract.

We estimated the effects of both, individual and contextual level SEM, and that of physical environment using a two-level hierarchical model, the *second* key component of this study. While we found effects of individual and contextual level SEM for all three outcomes in the study (birth weight, SGA, and preterm births), the effect of traffic and land use variables was only seen with birth weight, with the exception of an effect of cumulative traffic density and SGA.

By using the two-level modeling approach, it enabled us to estimate the variability in the outcome due to neighborhood and individual SEM and indicators of physical environment. The approach can control for confounding of one factor by the other. For example, while the effect for educational attainment on birth weight did not change after controlling for indicators of physical environment (traffic and land use), the coefficient for median household income was reduced by 23 percent. We also saw a reduction in the effect of distance to roads on birth weight after controlling for SEM. There was suggestion that educational attainment modified the effects on birth weight of traffic and land use variables, with worse outcomes among the more disadvantaged. Traffic density had a greater impact on births from mothers with lower educational attainment or race, and the positive effects of distance to major road and open space was less in the lower education group. We observed an indication of a greater effect of cumulative traffic density in the lower category of median household income by census tract. Overall, we observed a signal for an interaction between the social and physical environmental variables, suggesting poorer outcomes among the disadvantaged.

The precision of the observed relationship between air pollution and adverse birth outcomes in other studies has been largely affected by the measure of exposure assigned to each individual in the study. The majority of the studies that examined this relationship have not taken into account variation in pollution exposure within small localities, which can lead to exposure misclassification and distortion of the association. Two studies in California, US, merely averaged monitors within few miles of the

residence of the child, for example [2, 30]; a study in Europe [19] and another one in Brazil [42] used averaged county level data. As it has been indicated in previous studies, small scale variations are related also to variations in the socio-economic status [27]. Traffic measures instead were used as predictors of air pollution in our study: cumulative traffic density and distance to major highways. Distance to roadways has been reported to approximate somewhat better personal exposure levels of air pollutants. Studies have reported strong gradients of pollutant concentrations and particle size distribution for distances beyond 100 meters from the roads [25, 44]. In our study we observed associations of traffic variables with low birth weight, suggestive evidence for the index of intrauterine growth retardation (SGA), but not with preterm births. In combination with the indicator of land use, our results suggested that the increased level of urbanization increases the likelihood of exposure and that of adverse births. We found an association of increased open space and space for recreation with a better outcome of birth weight. It may be suggested that this variable indicates greater distance to traffic, more green areas, and less urbanized residence, therefore contributing to less exposure.

The geographic differences in the distribution of air pollutants are related to the geographical distribution of wealth and socioeconomic status [18, 45, 46]. However, traffic is only partly explaining the variability in exposures observed in diverse neighborhoods. Increased susceptibility to the effects of air pollution due to disadvantaged socioeconomic status may be related to factors like reduced access to health care, poorer nutrition, or psychological stress and violence; potentially greater likelihood for co-exposures due to either living conditions, or occupation. We measured socioeconomic status at the individual level by educational attainment, the index of prenatal care, and race, and at the census tract level by median household income.

There are limitations to this study that need to be mentioned. Exposure was estimated by distance to major highways and cumulative traffic density at individual birth addresses. Such measures are however, not directly related to personal exposure concentrations of each study subject therefore exposure misclassification in our study may be possible.

In conclusion, the study offers a way to look at adverse health in two perspectives simultaneously: the physical and social environment. The understanding of the mechanisms that determine poor health, in our case that of newborn children, by using a broader view in what determines health, can improve epidemiologic research and as result influence in reducing health disparities in populations.

Abbreviations:

ADT – average daily traffic

APNCU – adequacy of prenatal care utilization

CADT – cumulative average daily traffic

MHD – Massachusetts Highway Department

SGA – small for gestational age

SEM – socioeconomic measures

TIGER – Topologically Integrated Geographic Encoding and Reference Systems

Competing interests: The authors declare that they have no competing interests for this work. They have read and approved this final draft of work.

Authors' contribution: All authors have made substantial contribution to this work. AZ coordinated the study (data access and geocoding), analyzed the data and drafted this manuscript. SJM participated with geocoding and exposure estimation for this work. JS conceived and mentored throughout the study, and helped with drafting of this manuscript.

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TABLE 1. Descriptive characteristics of the study population. All singleton births in seven counties of Eastern Massachusetts born between 1996 and 2002

Characteristics	All births (% of total)	Mean birth weight (in grams) (SD)	Small for gestational age N (%)	Preterm N (%)	Reference (>37 weeks; >2500 grams) N (%)
Mother race					
White	75.3	3463 (545)	32103 76.2	22160 66.8	266329 76.0
African-American	7.4	3236 (638)	2938 7.0	3994 12.0	24530 7.0
Asian	6.0	3241 (510)	2471 5.9	2194 6.6	20900 6.0
Hispanic	11.0	3306 (565)	4531 10.8	4730 14.3	37691 10.8
Native American	0.2	3371 (581)	66 0.2	68 0.2	537 0.2
Missing	0.1	3426 (622)	0 0	38 0.1	417 0.1
Mother age at birth					
<20	8.9	3246 (565)	5616 13.3	4020 12.1	28308 8.1
20 – 29	36.6	3389 (550)	16783 39.9	12007 36.2	127149 36.3
30 – 34	33.7	3465 (546)	12143 28.8	10017 30.2	121240 34.6
35 – 39	17.4	3462 (574)	6196 14.7	5762 17.4	61997 17.7
> 39	3.4	3422 (600)	1371 3.3	1378 4.2	11710 3.3
Mother education					
Low (<8 years)	2.6	3296 (561)	1307 3.1	1126 3.4	8073 2.3
Medium (8-12 years)	29.0	3338 (576)	15190 36.1	11453 34.5	96981 27.7
High (>12-15 years)	39.9	3481 (533)	13354 31.7	11012 33.2	145698 41.6
College or higher (16+ years)	22.6	3433 (562)	9118 21.7	7269 21.9	79975 22.8
Missing	5.9	3333 (573)	3140 7.5	2324 7.0	19677 5.6
Prenatal care index					
None	0.6	3267 (714)	251 0.6	337 1.0	1825 0.5
Inadequate	7.8	3308 (571)	4511 10.7	3147 9.5	25652 7.3
Intermediate	8.0	3487 (509)	3842 9.1	1036 3.1	28985 8.3
Appropriate	48.1	3507 (487)	20185 47.9	3263 9.8	181619 51.8
Appropriate plus	35.5	3301 (627)	13320 31.6	25401 76.5	112323 32.1
Number of cigarettes smoked during pregnancy (per day)					
None	90.0	3438 (555)	33410 79.3	29001 87.4	320511 91.5

Any amount	9.8	3208	(558)	8655	20.6	4115	12.4	29301	8.4
Missing	0.2	3369	(648)	44	0.1	68	0.2	592	0.2
Number of cigarettes smoked before pregnancy (per day)									
None	83.0	3437	(556)	30580	72.6	26896	81.1	295766	84.4
Any amount	16.6	3309	(566)	11398	27.1	6120	18.4	53238	15.2
Missing	0.4	3384	(620)	131	0.3	168	0.5	1400	0.4
Previous infant > 4000 grams									
None	98.6	3411	(556)	41851	99.4	32730	98.6	344956	98.4
Yes	0.9	3938	(546)	63	0.1	175	0.5	3626	1.0
Missing	0.5	3355	(712)	195	0.5	279	0.8	1822	0.5
Previous infant preterm									
None	98.6	3419	(556)	41256	98.0	31946	96.3	346553	98.9
Yes	0.9	3011	(678)	658	1.6	959	2.9	2029	0.6
Missing	0.5	3355	(712)	195	0.5	279	0.8	1822	0.5
Gender of infant									
Male	51.2	3473	(572)	21631	51.4	18172	54.8	178071	50.8
Female	48.8	3355	(540)	20478	48.6	15012	45.2	172333	49.2

N – number; SD – standard deviation

TABLE 2. Descriptive statistics for birth weight, small for gestational age, and preterm births by quartiles of traffic variables, land use, and median household income

Exposure variables (quartiles)	Mean birth weight (SD)		Small for gestational age N (%)		Preterm N (%)		Reference (>37 weeks; >2500 grams) N (%)	
	Cumulative traffic density /1000							
< 261.0	3469	(539)	9441	22.4	7187	21.7	89628	25.6
> 261.0 – 704.6	3427	(526)	10398	24.7	8105	24.4	87756	25.0
> 704.6 – 1602.0	3398	(564)	10944	26.0	8628	26.0	86674	24.7
> 1602.0	3368	(569)	11256	26.7	9207	27.7	85785	24.5
Missing (688)	3413	(560)	70	0.2	57	0.2	561	0.2
Distance to primary highways (in meters)								
< 1107	3398	(555)	11067	26.3	8460	25.5	86888	24.8
> 1107 – 2150	3403	(565)	10741	25.5	8496	25.6	87196	24.9
> 2150 – 3745	3413	(563)	10482	24.9	8422	25.4	87529	25.0
> 3750	3448	(554)	9819	23.3	7806	23.5	88791	25.3
% land use for recreation and conservation (open space)								
< 4.0	3363	(568)	11184	26.6	8905	26.8	81668	23.3
> 4.0 – 9.4	3403	(567)	10861	25.8	8711	26.3	86966	24.8
> 9.4 – 17.8	3447	(547)	9658	22.9	7182	21.6	85787	24.5
> 17.8	3458	(546)	9210	21.9	7328	22.1	87770	25.0
Missing (10470)	3319	(597)	1196	2.8	1058	3.2	8213	2.3
Median household income (in US \$)								
< 46336	3303	(581)	12853	30.5	10736	32.4	83081	23.7
> 46336 – 62773	3406	(564)	10984	26.1	8405	25.3	86917	24.8
> 62773 – 78583	3467	(547)	9778	23.2	7253	21.9	89304	25.5
> 78583	3486	(526)	8494	20.2	6790	20.5	91102	26.0

N – number; SD – standard deviation

TABLE 3. The effects of socio-demographic indicators on low birth weight, small for gestational age and pre term births in the study of singleton births in Eastern Massachusetts between 1996 and 2002.

Model covariates	Birth weight			Small for gestational age			Preterm		
	Change (in grams)	95 % CI		OR	95 % CI		OR	95 % CI	
Mother's education									
Low (≤ 12 years)	-8.5	-12.8,	-4.2	1.18	1.14,	1.22	1.10	1.05,	1.14
High (13 -15 years)	Reference								
College or higher (≥ 16 years)	6.0	2.0,	10.0	1.05	1.02,	1.08	0.99	0.95,	1.03
Mother's race									
White	Reference								
African-American	-113.1	-119.7,	-106.4	*			1.09	1.03,	1.16
Asian	-192.2	-198.6,	-185.8				0.76	0.72,	0.81
Hispanic	-77.7	-83.3,	-72.1				1.07	1.02,	1.13
Prenatal care index									
Inadequate	-53.2	-59.0,	-47.4	1.26	1.21,	1.31	4.52	4.25,	4.81
Intermediate	-39.0	-44.6,	-33.3	1.12	1.08,	1.17	1.91	1.76,	2.08
Appropriate	Reference								
Appropriate plus	-11.0	-14.4,	-7.5	0.98	0.96,	1.01	9.05	8.67,	9.45
Median household income [†]	6.8	4.3,	9.3	0.93	0.92,	0.95	1.03	1.01,	1.05

CI – confidence interval; OR – odds ratio; SD – standard deviation

All variables in this table and the following table were included in one model. Models were also adjusted for mother age, race, gestational age (for models with LBW as the outcome), cigarette smoking during pregnancy, previous infant greater than 4000 grams, previous preterm birth, and chronic or gestational conditions of mother.

*Race is already controlled for in the definition of “small for gestational age”

[†]The effect is for 1 SD change in the median household income by tract

TABLE 4. The relationship between traffic measures and land use and birth weight, small for gestational age and preterm births in a study of singleton births in Eastern Massachusetts between 1996 and 2002

Model covariates	Birth weight			Small for gestational age			Preterm		
	Change (in grams)	95 % CI		OR	95 % CI		OR	95 % CI	
Cumulative traffic density*	-0.4	-2.0,	1.3	1.02	1.00,	1.03	1.00	0.98,	1.01
Distance to major highways	3.8	1.9,	5.7	0.99	0.97,	1.00	1.01	0.99,	1.02
% land use for recreation and conservation (open space)	4.4	2.1,	6.6	0.98	0.97,	1.00	1.00	0.98,	1.02

CI – confidence interval; OR – odds ratio; SD – standard deviation

All variables in this table and the previous table were included in one model. Models were also adjusted for mother age, race, gestational age (for models with LBW as the outcome), cigarette smoking during pregnancy, previous infant greater than 4000 grams, previous preterm birth, and chronic or gestational conditions of mother.

*The effect is for 1 SD change in distribution of log-transformed traffic exposures and 1 SD change in distribution of % open space in census tract.

TABLE 5. Stratified models by level of education and median household income for the association between birth weight and traffic variables in a study of singleton births in Eastern Massachusetts between 1996 and 2002

Model covariates	Educational attainment						Median Household Income by census tract**					
	Low (<12 years)			High (>12 years)			≤50 %			>50 %		
	Change (in grams)	95 % CI		Change (in grams)	95 % CI		Change (in grams)	95 % CI		Change (in grams)	95 % CI	
Cumulative traffic density*	-0.7	-4.3,	3.0	-0.1	-1.9,	1.6	-1.7	-4.6,	1.3	0.6	-1.3,	2.5
Distance to major highways	1.8	-1.3,	4.9	4.9	2.8,	7.0	3.8	1.0,	6.5	4.1	1.5,	6.7
% land use for recreation and conservation (open space)	0.3	-3.3,	3.8	5.5	3.1,	8.0	4.4	1.0,	7.9	4.2	1.3,	7.1

CI – confidence interval; SD – standard deviation

Models were controlled for race, education of mother, median household income by census tract (where necessary), race, prenatal care index, mother age, race, gestational age, cigarette smoking during pregnancy, previous infant greater than 4000 grams, previous preterm birth, and chronic or gestational conditions of mother.

*The effect is for 1 SD change in distribution of log-transformed traffic exposures and 1 SD change in distribution of % open space in census tract.

†Categories of median household income: below and above the median of the distribution