SIZE FOR GESTATIONAL AGE AND NEIGHBORHOOD DEPRIVATION MEASURED WITH INCREASING PROXIMITY TO HOMES

By

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LIST OF ABBREVIATIONS

AGA ....Appropriate size for gestational age
ANOVA..Analysis of Variance
BMI ....Body Mass Index
CI...Confidence interval
EDU ....Education
FPL..Federal poverty level
GLM ....General linear model
IRB ....Institutional Review Board
km ....Kilometer
LBW ....Low birthweight
LGA ....Large size for gestational age
MAUP ....Modifiable Areal Unit Problem
NDI ....Neighborhood Deprivation Index
OR ....Odds Ratio
PCA..Principal Component Analysis
PRAMS ....Oregon Pregnancy Risk Assessment Monitoring System
PTB..Preterm Birth
SGA..Small size for gestational age
SEP...Socioeconomic Position
SES...Socioeconomic Status
US ....United States
USD..United States Dollars

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ABSTRACT

Background. Adverse birth outcomes disproportionately affect racial and ethnic minorities in the US and are associated with both short- and long-term health consequences. Individual risk factors for birth outcomes are shaped by environmental context, and neighborhood socioeconomic deprivation is a consistent predictor of low birthweight. The association with large birth size has not been explored, and the proximity within which neighborhood deprivation might influence birth outcomes is unknown.

Methods. A continuous neighborhood deprivation index (NDI) was generated for 1, 3, 5, and 8km buffers for the subset of 2004-2007 Oregon Pregnancy Risk Assessment Monitoring System (PRAMS) respondents in the Portland Tri-County Area. Multinomial logistic regression models estimated the effects of NDI on small (SGA) and large (LGA) compared to appropriate (AGA) size-for-gestational-age. Analysis was stratified by race/ethnicity and adjusted for individual risk factors.

Results. High neighborhood deprivation was associated with greater odds of LGA than low neighborhood deprivation [3km OR for 90th percentile of deprivation compared to 10th percentile: White = 2.74 (95% CI: 1.12-6.7); Asian = 1.10 (95% CI: 0.49-2.5); Native American = 1.91 (95% CI: 0.57-6.4); Hispanic = 1.39 (95%CI: 0.76-2.5)], except among the group of Black women in our sample for whom the opposite was true [3km OR= 0.36 (95%CI: 0.15-0.85)]. To a lesser extent, greater neighborhood deprivation was associated with increased odds of SGA [3km OR: White = 1.24 (95% CI: 0.53-2.9); Black = 1.23 (95% CI: 0.57-2.7); Hispanic = 1.51 (95%CI: 0.60-3.8)], except among the Asian group [3km OR=0.76 (95%CI: 0.42-1.4)]. The model fit and the magnitude of these associations was similar regardless of the size of the area.

Conclusion. The impact of NDI on women's perinatal health may be different across different racial and ethnic groups, and different mechanisms may play a role in accelerated or restricted fetal growth. Appropriate neighborhood size should be determined based on theory specific to the environmental exposure and population under study.

Background

Birth Outcomes and Disparities

Infant size at birth is associated with short-term health outcomes and also predicts risk of adult chronic disease, with outcomes ranging from infant mortality to diabetes, hypertension, and cardiovascular disease.[1-3] In the United States, the risk of adverse birth outcomes is not evenly distributed across racial and ethnic groups. Even after taking into account medical and behavioral risk factors, Black women have approximately twice the risk of giving birth to a low birthweight (weight <2500g) or small for gestational age infant (weight below 10^{th} percentile for week of gestation) as White women.[1-7] Limited evidence suggests that disparities also exist in very large birth size as well, with Hispanic infants more likely to be born large for gestational age (infant weight above 90^{th} percentile for week of gestation).[8-10]

Investigation of racial and ethnic disparities in adverse birth outcomes such as preterm birth or small birth size has a long history in epidemiology.[1] Large size for gestational age (LGA) is less-often considered in this literature, but with increasing prevalence of two known risk factors for large for gestational age (LGA) infants – obesity and diabetes,[11-13] this outcome demands as much attention as small size for gestational age (SGA). Both small and large birth size are associated with a dramatic increase in infant mortality and contribute to racial health disparities throughout the lifespan.[1,2,8,12-14] Risk factors for these birth outcomes include maternal age, income, education, prenatal care, smoking, alcohol use, diabetes, obesity, and stress. However, what causes adverse birth outcomes is not necessarily the same as the cause of the disparities. Individual-level maternal characteristics fail to explain racial and ethnic disparities in birth outcomes,[3,6,15,16] which are anchored in social inequalities stemming from macro-level conditions.[1,5,17]

Neighborhood Context

A growing body of literature has moved beyond individual risk factors and focused on the impact of environmental conditions on pregnancy health. Racial residential segregation present in the United States may result in inequitable exposure to environmental conditions.[18,19] Modest associations exist between neighborhood environments and birth outcomes,[14,20-25] which may be responsible for at least a portion of the disparities unexplained by individual risk factors.[26] A variety of area-level measures such as violent crime,[26] income,[21,24] vacancy/housing stock,[24,25] walkability,[22] presence of social spaces,[22] and residential segregation[27] are associated with birth outcomes. Of these neighborhood-level indicators, low birthweight, preterm birth, and small size for gestational age are the most strongly and consistently associated with neighborhood sociodemographic context.[21,23,28-30]

Neighborhood socioeconomic disadvantage is hypothesized to have an impact on maternal health through access to material resources and psychosocial factors.[17,31] The first pathway involves resources such as healthcare, affordable nutritious food, and opportunities for exercise, which can affect health directly or modify health behaviors.[14,21,23] For example, a healthy diet and high quality prenatal care may improve pregnancy health. Opportunities for exercise and easy access to nutritious food are also examples of material resources that can modify individual lifestyle or behaviors that in turn modify risk factors for adverse birth outcomes such as obesity and diabetes.[14,23]

The second mechanism by which neighborhood socioeconomic disadvantage has been hypothesized to impact individual health is through psychosocial factors resulting from experiences of the environment.[17,32] Neighborhood environments may act as a source of individual psychosocial stress with impacts that go above and beyond individual socioeconomic position.[17,32] High stress levels can lead to unhealthy coping behaviors such as alcohol or tobacco use, which both increase risk of low birthweight and preterm birth.[14,21,23,32] Stress also has an effect on fetal development through biological pathways including increased susceptibility to infection and physiological response to stress hormones,[2,15,33,34] although the direct connection between stress due to the neighborhood environment and adverse birth outcomes is not well-understood.[23] Stress can interact with nutrition by influencing food choices and the metabolic fate of nutrients, both of which play an important role in fetal development.[35] Black women have higher documented levels of biological markers of chronic stress, termed allostatic load, than

Black men or White women, but the only available study of allostatic load among pregnant women was quite limited in sample size and not consistent with the magnitude of Black-White differences in the US.[36] Evidence from animal studies shows that elevated perinatal stress does lead to low birthweight.[35] A woman's residential environment can affect her health through psychosocial factors or by providing access to material resources.

Modifiable Areal Unit Problem

In order to measure any neighborhood exposure, one must specify an area to comprise the neighborhood. Researchers often use census units as proxies for neighborhoods in the US. These political boundaries are convenient because most neighborhood sociodemographic information originates from the US Census, and because census tracts and block groups are relatively stable over time and were designed to reflect neighborhoods with similar housing stock and socioeconomic status.[37,38] However, the geographic area that may have an effect on health may not follow political boundaries, and there is no limit to the possible approaches for drawing borders through continuous geographic space to delineate neighborhoods. In other words, the areal unit used to define the exposure is modifiable. An important issue named the Modifiable Areal Unit Problem (MAUP) arises where an association observed using the same data and geographic area may be very different depending on how neighborhood boundaries are drawn, or which areas are aggregated.[31,37-40] The MAUP can be considered to have two main components, a zone effect and a scale effect.

The scale effect refers to how the size of the area considered can affect the exposure level. Consider individuals residing in two neighborhood locations: (1) a place where all surrounding areas are very deprived, and (2) one small pocket of severe economic disadvantage situated within a larger area characterized by less deprivation. Small area units would detect high deprivation in both locations. However, a larger area unit would capture high deprivation for the first individual and lower deprivation for the second. These differences would be due to real differences in the neighborhood context of these individuals.

The second component is the zone effect, meaning the association between the exposure and outcome depends upon the boundaries used to define an area.[37,39] Many researchers use census tracts or block groups as neighborhood boundaries. However, assigning all individuals within one census tract to the same exposure level assumes that individuals on opposite ends of the census tract have more in common than individuals who live across the street from one another but in separate census tracts.[40] Alternative methods of delineating neighborhoods include networks of connected streets,[22,41] circular buffers around each respondent's place of residence,[41,42] and primary adjacency communities (blocks immediately connected to the block of residence).[25,32] These alternatives specify area units using physical or spatial boundaries within the environment.

Appropriate area size must be based in theory relevant to the exposure of interest.[39] A study examining the relationship between physical activity in adolescents and count of physical activity facilities within circular buffers (indicating proximity of the exposure to an individual) found that the association varied by buffer size; 1-5 km buffers produced stronger associations than 8 km buffers, and the most consistent associations were found using 3 km buffers.[41] In another study considering multiple neighborhood definitions, greater walkability was associated with lower smoking among Black women at all units of aggregation, but for White women walkability was associated with smoking only for units of aggregation smaller than a census tract.[22] In the previous example, the authors hypothesized that a very small neighborhood based on interconnected streets surrounding a place of residence might better approximate walkability (a local activity) than the census tract, and found that performing analysis only at the census-tract level would not have detected a significant association between walkability and smoking.[22]

Many findings are similar between census tract and block group neighborhood definitions.[20,42-44] For example, an investigation of neighborhood socioeconomic status and myocardial infarction hypothesized that smaller areas would provide a stronger association but found no consistent differences in the association between 1 km buffers, block groups, census tracts, or zip codes.[44] In another study of area socioeconomic measures and birth outcomes, Krieger et al.[20] found similar results when using census tracts or block groups to measure area socioeconomic exposures. This study did detect smaller effect sizes for the larger geographic units of zip codes than for census tracts or block groups.[20] Both the size of the specified area and the political boundaries may play a role in this example, as larger areas were defined using political boundaries. Aggregating areas with very different exposures or taking the opposite approach and using very small area units can result in inaccurate assignment of exposure and spurious associations.[31,40]

The validity of using area-based measures depends on the extent to which study-defined spatial borders represent the geographical exposure of the individuals in the study population.[45] Inconsistent methods of defining a neighborhood can lead to inconsistent findings across studies[41] as well as spurious associations.[39] This investigation compared the estimated effect of neighborhood deprivation measured over four units of aggregation defined by direct proximity to a woman's place of residence. By comparing these units of aggregation that include sequentially larger areas, we examine the extent to which the observed association between neighborhood deprivation and size for gestational age depends upon the size of the area chosen to represent a neighborhood.

Materials and Methods

Data sources

Oregon PRAMS

This study used 2004-2007 Oregon Pregnancy Risk Assessment Monitoring System (PRAMS) data. PRAMS is an ongoing, population-based surveillance system that randomly samples women from the state birth record. During this study period, women who gave birth to low birthweight infants and racial and ethnic minorities were oversampled to allow for meaningful statistical analysis of these smaller groups. Each month, a random sample was selected from the Oregon birth certificate file, stratified on race/ethnicity group and with one stratum of White low birthweight individuals. Subjects were generally selected 2-4 months after giving birth and were sent an introduction letter followed by a written questionnaire one week later. A thank you/reminder to fill out the questionnaire called a "tickler" was sent within 7-10 days of the written questionnaire. A second questionnaire packet was sent to women who had not responded 7-14 days after the tickler. A telephone interview was attempted with women who had not responded within 7-14 days of receiving the second survey. The sample excluded women who did not live in Oregon, women who gave birth more than 180 days before sampling (usually due to increased time required for processing the birth certificate), and multiple births greater than three gestations. The survey collected information on maternal characteristics, behaviors, and experiences before, during, and shortly after pregnancy. Women listed as Hispanic on the birth certificate were sent a questionnaire in both English and Spanish. The results from the questionnaire were combined with data from the corresponding birth certificate.

Table 1: Variables by data source.

Measure	Notes
PRAMS	
Income	Categorical (USD)
Household size	Count
Birth Certificate	
Maternal age	Years (continuous)
Maternal education	Years, dichotomized: ≤12 or >12
Parity	Count, dichotomized: 0 or ≥1
Marital status	Dichotomous: Married/Separated or Unmarried/Divorced/Annulled/Not reported
Race/ethnicity*	White, Black, Hispanic, Native American, Asian
Residential location	
Insurance coverage	Dichotomous: private insurance paid for birth
Gestational age**	Clinical Estimate (weeks)
Birth weight**	Continuous (grams)
US Census	
Neighborhood deprivation index***	Continuous index generated from census variables for four circular buffers.

*Race/ethnicity is stratification variable. **Size for gestational age is outcome of interest. ***NDI is main exposure.

Birth certificate

The Oregon Office of Family Health linked variables from the Oregon state birth record were to PRAMS data with a unique ID. The Office of Family Health provided information on how these variables are coded (Appendix Table A-1).

United States Census

Neighborhood sociodemographic data were obtained from the 2000 US Census for each census tract captured in whole or in part by a 5 mile (8.05 km) Euclidean neighborhood buffer around each respondent home. This data included 20 variables (Appendix Table A-2) in seven main domains: poverty, housing, occupation, employment, education, residential stability, and racial composition. To preserve participant confidentiality, special precautions approved by the Oregon Health & Science University IRB and the Oregon Office of Family Health were taken when linking geographic data to the anonymized PRAMS dataset.

Study Sample

We collected geographic information for all PRAMS respondents residing in Multnomah, Clackamas, and Washington counties (N=3,930). Of these 3,930 women, 153 had multiple births and were excluded because multiple pregnancies are expected to result in small size for gestational age regardless of other maternal or environmental risk factors. Of the remaining population of 3,777 women in the Tri-County Area with singleton births, 3 were missing birthweight, 3 had an implausible birthweight of less than 400g recorded, and six had an implausible estimated gestational age of greater than 42 weeks or less than 20 weeks. Excluding those for whom our outcome variable was not available or reliable left 3,765 individuals. Of these women, 10 were excluded because of missing information on the mother's race/ethnicity, 1 had no age recorded, 30 were missing information on education, and one was missing parity, leaving 3,722 women for whom we had information recorded on our important confounding variables other than individual income. Of this group, we excluded 6 women who were at extreme ages (five over age 44, and one under age 14) leaving 3,717. One of these women was excluded because of missing information on insurance provider, for a final sample size of 3,716 (Appendix Figure A-1).

Variables

Stratification variable: Race and ethnicity

All analysis was performed separately for each race/ethnicity group. Stratifying on race and ethnicity avoids comparing groups for whom we have not completely controlled for confounding by socioeconomic status and also allows detection of different effects between different groups. The mother's race/ethnicity was reported on the birth certificate (Appendix Table A-1).

We used a standard approach to group individuals into mutually exclusive race/ethnicity categories. A woman is categorized as Hispanic if the birth certificate recorded that she was of any Hispanic origin, including Mexican, Puerto Rican, Cuban, Central or South American, or "Other or Unknown Hispanic," regardless of which race was recorded. Refer to Table 2 for each definition.

Table 2: Race and ethnicity groups.

Race/Ethnicity	Birth certificate label
White	White (Caucasian)
Black	Black, African American
Asian	Chinese, Japanese, Hawaiian, Filipino, or other Asian or Pacific Islander.
Native American	Indian (North, Central, South American, Eskimo, Aleut)
Hispanic	Mexican, Puerto Rican, Cuban, Central or South American, or "Other or Unknown Hispanic," regardless of race recorded.

Exposure: 1, 3, 5, and 8 km radius Neighborhood Deprivation Index

From median household income, households in poverty, and education or employment status of residents, to housing vacancy, damage, or crowding, multiple indicators have been used to parameterize neighborhood sociodemographic context.[21,24,25,46,47] This study uses a standardized neighborhood deprivation index (NDI), which is commonly used in studies of the effect of neighborhood socioeconomic disadvantage on individual health. The index combines information from a set of US census measures including neighborhood poverty, education, vacancy, employment, and occupation. Because it takes a variety of variables into account, the neighborhood deprivation index represents the multidimensional property of community socioeconomic position.[30] Neighborhood deprivation has been consistently associated with adverse birth outcomes.[23,28,29,47]

Addresses of each PRAMS respondent in the tri-county area were geocoded on site at the PRAMS coordinating center. The neighborhood deprivation index was created at the census-tract level using a standard process described previously.[30] Briefly, the index is a summary score of 20 sociodemographic variables from the US Census (Appendix Table A-2). To generate an NDI score for each circular buffer, a weighted average was created according to the proportion of each census tract falling within the circle (Figure 1). The NDI score is a continuous variable, and a higher or more positive score represents a more socioeconomically deprived area.

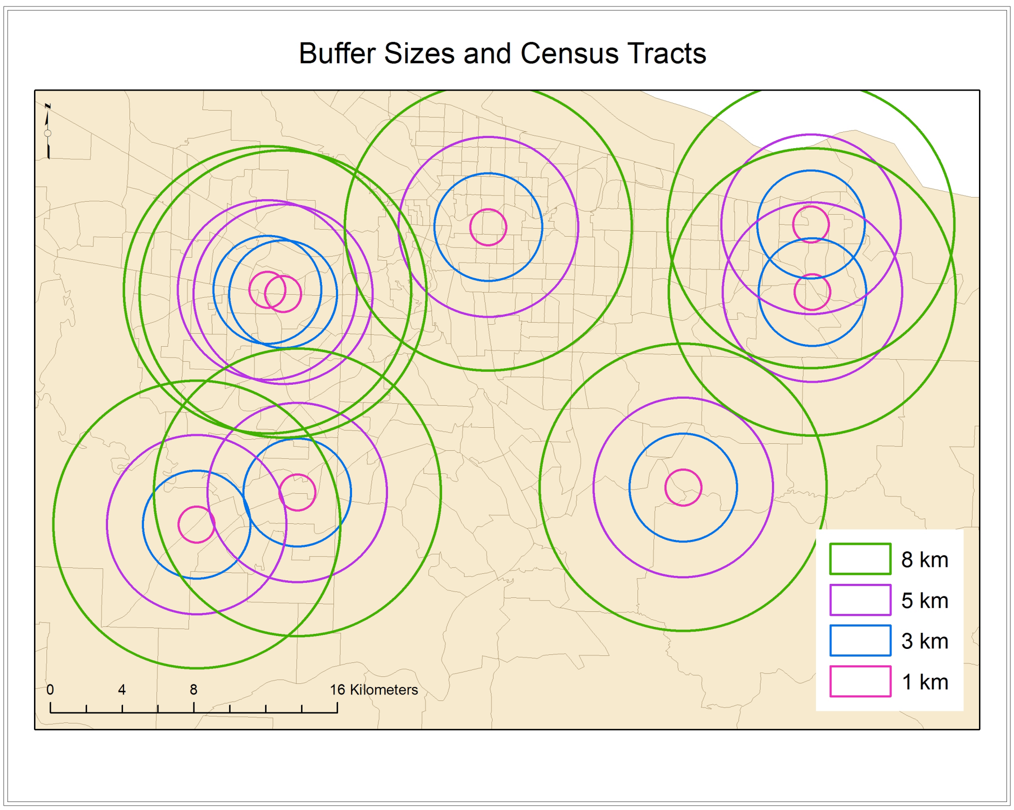

Figure 1: Example of Euclidean buffers with 1-8 km radii mapped onto census tracts. The central point of each circle represents a hypothetical place of residence of one PRAMS respondent.

Outcome: Size for Gestational Age

The nominal outcome variable size for gestational age was calculated from the birthweight and the clinical estimate of gestational age recorded on the birth certificate (Appendix B Part 1). Small for gestational age is defined as below the 10th percentile of weight for the week of gestation. Infants above the 90th percentile of weight for week of gestation are large for gestational age, and the reference category appropriate for gestational age includes all infants not in either of these two extremes (Appendix A Figure A). Specific weight percentiles for each week of gestation used for cut-points between categories come from Hadlock et al.[48] The small for gestational age outcome is eliminated in the Native American group because of very few observations (n=7), resulting in a dichotomous outcome (appropriate vs. large for gestational age) for this group. These observations are included in the descriptive analysis.

Statistical Analysis

An initial analysis consisted of a repeated ANOVA to determine if the mean NDI measurements were significantly different for each buffer size. Next, we built four multivariable multinomial logistic regression models with outcome size for gestational age, separately for each race/ethnicity group. The main exposure variable for each model is the neighborhood deprivation index for one size circular buffer. The buffers were defined individually. While some individuals may have overlapping buffers, it is unlikely that many women lie within the same geographic area, and this was not a multilevel analysis. Furthermore, individuals were selected randomly from the entire state of Oregon and were not sampled based on census tract or other geographic criteria. Data are weighted to reflect sampling scheme and nonresponse. All analysis was completed with SAS version 9.2 software, using the suite of survey procedures in order to adjust for stratified sampling and weighting whenever possible. In order to estimate variance as accurately as possible, we used the DOMAIN statement with all SAS survey procedures to limit the population to the study sample and to stratify by race/ethnicity groups.

NDI characterization

Analysis began by determining the correlation between the different NDI measurements and testing the null hypothesis that there was no difference in mean NDI across the four buffers. These steps were achieved using the GLM (general linear model) procedure in SAS, which takes into account weighting but not stratification variables. Pairwise Pearson correlations were calculated for the NDI measurements for each size buffer. A repeated ANOVA F-test with Huynh-Feldt Epsilon adjusted degrees of freedom tested the within-subjects effect of buffer radius at $\alpha = 0.05$ on repeated dependent variables (H_0: 1 km NDI = 3 km NDI = 5 km NDI = 8 km NDI) to determine if at least one NDI score was significantly different from the others. Planned *a priori* pairwise comparisons tested if each measurement of NDI had in fact captured different estimates of the exposure as the other radii buffers. These steps were not stratified by race and ethnicity.

Univariate

We described the study population as a whole and for each race/ethnic group separately. First, we calculated counts and percentages of categorical variables (size for gestational age, insurance status, maternal education, and parity) and means and standard deviations of continuous variables (NDI, maternal age). The SURVEYFREQ procedure was used to generate contingency tables for categorical variables, taking into account the weighting and stratified sampling design. The SURVEYMEANS procedure took into account weighting and sampling strata to estimate means and standard deviations of continuous variables.

Bivariate

Still stratifying on race/ethnicity, bivariate analysis was performed using the same survey procedures as the univariate analysis. Counts and percentages were calculated for categorical variables across size for gestational age categories. At this point in the analysis, education was dichotomized to high school graduate or less (≤12 years) or any education beyond high school (> 12 years). This cut-point was used for all race/ethnic groups. Dividing education into more than two categories and maintaining sufficient cell counts was not possible due to substantial differences in educational attainment across race/ethnic groups (Appendix B Part 2). In the bivariate analysis, each cell had a sufficient number of observations (unweighted n≥5) to be used in the multivariate regression. We calculated means and standard deviations for maternal age and NDI at each unit of aggregation across size for gestational age categories.

Multinomial logistic regression

Next we used the SURVEYLOGISTIC procedure to run a multivariate model for each race/ethnic group to quantify the association between neighborhood deprivation and size for gestational age. For White, Black, Asian, and Hispanic groups, a multinomial logistic regression with a logit link simultaneously estimated adjusted odds ratios for large for gestational age compared to appropriate for gestational age (LGA/AGA) and small for gestational age compared to appropriate for gestational age (SGA/AGA) with increasing NDI. Because very few births in the Native American group were small for gestational age (unweighted n=7), these observations were excluded and a logistic regression was used to estimate the adjusted odds of LGA compared to AGA in relation to NDI in this group.

In order to compare the association between size for gestational age and neighborhood deprivation index within each of four neighborhood buffer sizes, we used a constant set of control variables for all models. Because statistical model selection procedures could generate a different model for each buffer size and each race/ethnic group, we identified confounding variables based on prior literature and substantive knowledge. Prior literature included published studies examining the adjusted association between neighborhood deprivation or another neighborhood-level socioeconomic measure and size for gestational age, birthweight, or preterm birth (Appendix Table B-1).

Briefly, the potential covariates encompassed in the identified literature included parity, maternal age, education, insurance status, individual poverty, pre-pregnancy BMI, smoking, prenatal care, and other medical risk factors. After careful consideration of evidence that neighborhood deprivation may have an effect on health behaviors and health status such as prenatal care, cigarette smoking, physical activity, or BMI,[14,22,39] we did not adjust for these variables because they may lie on the causal pathway from neighborhood deprivation to birth outcomes. The model adjusted for education and private insurance status as indicators of individual socioeconomic position, but not individual poverty, avoiding potential bias due to exclusion of individuals with missing information. We were able to account for a non-linear effect of maternal age on birth weight by including a quadratic term for maternal age.[49,50] Mean centering avoided collinearity with maternal age and this quadratic variable. The final multivariate models adjusted for the following confounding variables parity, maternal age, maternal age^2, maternal education, and private insurance status (Appendix B Part 2).

We assessed linearity of the continuous NDI scores in the logit graphically by plotting the estimate of the beta coefficient for SGA against the NDI score and again by graphing the beta coefficient for LGA vs. NDI score for each race/ethnic group. In most cases, NDI did not have a linear relationship with either outcome, so we centered the term and tested the addition of higher order terms to the model containing a priori confounders. A likelihood ratio test (α=0.05) was used to determine whether adding the higher order term significantly added to the fit of the model (Appendix Table A-3). Significant higher order terms varied by buffer size and by race/ethnicity. For example, adding the quadratic term for the 8 km buffer significantly improved model fit (likelihood ratio test p-value <0.05) for all groups except for the Native American group. However, adding the cubic term for the 8 km buffer significantly improved the model only for the White, Hispanic, and Native American groups. Furthermore, the cubic term for the 1 km buffer was significant for all race/ethnic groups, but estimates resulting from the model including the cubic term were unstable for the Native American group. Models included the highest ordered term that improved the model fit significantly as well as each lower-ordered term. For example, if adding the cubic term to the model (with linear and quadratic term included) improved the model fit, the final model included $NDI + NDI^2 + NDI^3$. However, in some cases this model generated very unstable estimates (identified graphically), so the higher ordered terms were removed from the model. The final models for each buffer size and each race/ethnic group are summarized in Table 3.

Table 3: Transformations for NDI variables included in final models.

	White	Black	Asian	Hispanic	Native American
1 km	CUBIC	CUBIC	CUBIC	CUBIC	LINEAR*
3 km	CUBIC	CUBIC	CUBIC	LINEAR*	LINEAR
5 km	CUBIC	QUADRATIC	QUADRATIC	LINEAR*	LINEAR
8 km	CUBIC	QUADRATIC	QUADRATIC	LINEAR*	CUBIC

*Cubic term significantly improved model fit (Likelihood ratio test p-value <0.05), but produced unstable point estimates. The quadratic term did not significantly improve model fit, so only the linear NDI term was retained in the model.

Limited diagnostic tests for complex survey data exist, so diagnostics were performed on weighted data, without taking into account the stratification variable. In order to evaluate model fit and detect potential outliers, each multivariate multinomial model was broken down into two logistic regression models: one comparing appropriate for gestational age to large for gestational age infants, and another comparing AGA and SGA infants. Leverage plots were examined to detect potential influential points. Unrealistic responses had already been excluded from the data during the descriptive analysis to create the final study population, so final multivariate models were re-run excluding potential influential points. This did not change any of the adjusted odds ratio estimates by greater than ten percent, so these observations remain in the final analysis.

The Hosmer-Lemeshow goodness of fit test was used to evaluate model fit. Among Asian, Black, Hispanic, and Native American groups, this test did not detect a poor model fit (p-value >0.20 for both outcomes at all buffer sizes). Within the White group however, this test showed that the model for small compared to appropriate size for gestational age did not fit the data well at any buffer size (p-value <0.001). This result is counter-intuitive because the models for this group explained the most variance of any in this analysis. In this study population, low birthweight infants, who are more likely to be small for gestational age, were oversampled for White women only. This was the only group with significant goodness-of-fit test. The Hosmer-Lemeshow test does not take into account the stratification of the survey sampling and may not be appropriate in this situation. The models were constructed with great care based on prior literature in order to estimate the adjusted association between neighborhood deprivation and size for gestational age.

In order to interpret the non-linear associations represented by linear, quadratic, and cubic terms, an odds ratio was calculated to compare the odds of each outcome for women residing in an area with high deprivation (90th percentile) compared to the odds of the respective outcome for women living in an area with low deprivation (10th percentile). In order to show non-monotonic associations, an odds ratio was also calculated comparing the median deprivation level to the low level. For this purpose, the SURVEYMEANS procedure calculated the value of the index at the 90th percentile, labeled "High Deprivation," and at the 10th percentile, labeled "Low Deprivation."

Below is an example of the estimation of these odds ratios. This was repeated for each model (4 buffer sizes X 5 race/ethnic groups). The multinomial model estimates separate beta-coefficients for each outcome, but just one is shown for the example.

Where:

$\pi(x)$ = Probability of large size for gestational age given NDI score x

g(x) = log-transformed probability of large size for gestational age

β_0 = intercept of g(x)

β_1 = change in logit function when NDI increases by one unit

β_2 = change in logit function when NDI^2 increases by one unit

β_3 = change in logit function when NDI^3 increases by one unit

[covars] = shorthand for beta coefficients and corresponding values for maternal age, parity, private health insurance status, and maternal education.

a = centered NDI score at 90th percentile (a unique value for each radius buffer, given in Appendix Table A-4)

c = centered NDI score at 10th percentile (a unique value for each radius buffer, given in Appendix Table A-4)

The log(odds) of the outcome given NDI score x:

$$g(x) = ln\frac{\pi(x)}{1-\pi(x)} = \beta_0 + \beta_1 \cdot x + \beta_2 \cdot x^2 + \beta_3 \cdot x^3 + [covars] + \varepsilon$$

The log(odds) of the outcome at the 90th percentile of deprivation:

$$\hat{g}(x|x=a) = ln\left[\frac{\pi(a)}{1-\pi(a)}\right] = \beta_0 + a\cdot\beta_1 + a^2\cdot\beta_2 + a^3\cdot\beta_3 + [covars]$$

Exponentiation gives the odds of the outcome at the 90th percentile of deprivation:

$$e^{\beta_0+a\cdot\beta_1+a^2\cdot\beta_2+a^3\cdot\beta_3+[covars]}$$

The log(odds) of the outcome at the 10th percentile of deprivation is represented in the same manner:

$$\hat{g}(x|x=c) = ln\left[\frac{\pi(c)}{1-\pi(c)}\right] = \beta_0 + c\cdot\beta_1 + c^2\cdot\beta_2 + c^3\cdot\beta_3 + [covars]$$

Exponentiation gives the odds of the outcome at the 90th percentile of deprivation:

$$e^{\beta_0+c\cdot\beta_1+c^2\cdot\beta_2+c^3\cdot\beta_3+[covars]}$$

The ratio of the odds at the 90th percentile and 10th percentile of deprivation is the estimate of the odds ratio for high compared to low deprivation:

$$\widehat{OR} = \frac{odds|x=a}{odds|x=c} = \frac{e^{\hat{g}(x|x=a)}}{e^{\hat{g}(x|x=c)}} = \frac{e^{\beta_0+a\cdot\beta_1+a^2\cdot\beta_2+a^3\cdot\beta_3+[covars]}}{e^{\beta_0+c\cdot\beta_1+c^2\cdot\beta_2+c^3\cdot\beta_3+[covars]}}$$

Simplifying the equation:

$$\widehat{OR} = e^{\left(\beta_0+a\cdot\beta_1+a^2\cdot\beta_2+a^3\cdot\beta_3+[covars]-\left[\beta_0+c\cdot\beta_1+c^2\cdot\beta_2+c^3\cdot\beta_3+[covars]\right]\right)}$$

$$= e^{\left(\beta_0-\beta_0+a\cdot\beta_1-c\cdot\beta_1+a^2\cdot\beta_2-c^2\cdot\beta_2+a^3\cdot\beta_3-c^3\cdot\beta_3+[covars]-[covars]\right)}$$

$$= e^{\left(a\cdot\beta_1-c\cdot\beta_1+a^2\cdot\beta_2-c^2\cdot\beta_2+a^3\cdot\beta_3-c^3\cdot\beta_3\right)}$$

$$\widehat{OR} = e^{\left((a-c)\beta_1+\left(a^2-c^2\right)\beta_2+\left(a^3-c^3\right)\beta_3\right)}$$

The values (a-c), (a^2-c^2), and (a^3-c^3) were calculated for each radius buffer and inserted into a CONTRAST statement in the SURVEYLOGISTIC procedure as the values for the corresponding beta-coefficient to estimate the odds ratio and corresponding confidence limits for each outcome comparing women residing in high deprivation (NDI score = a) areas to women residing in low deprivation areas (NDI score = c). The values same contrasts were calculated comparing the 10th percentile value of NDI and the median value (Appendix Table A-4).

Lastly, the model fit was compared for each buffer radius. The change in adjusted R^2 for the model when the neighborhood deprivation index terms were added was assessed. We proposed that the NDI for the buffer size that caused the largest positive change in R^2 could be the most appropriate scale at which to assess neighborhood sociodemographic context. If all buffer sizes provide a similar fit to the data, one buffer size would need to be selected based on theory.

Results

NDI characterization

The neighborhood deprivation index measures at each size buffer were all highly correlated with one another, and the level of correlation between measurements decreased as the buffers covered increasingly different areas (Table 4).

Table 4: Partial Pearson correlation coefficients between neighborhood deprivation indexes measured at each size buffer.

	1 km	**3 km**	**5 km**	**8 km**
1 km	1.0	0.9061	0.7677	0.6237
3 km	0.9061	1.0	0.9402	0.8208
5 km	0.7677	0.9421	1.0	0.9503
8 km	0.6237	0.8281	0.9500	1.0

A scatter plot of each NDI measurement visually shows this trend as well, (Appendix Figure A-3) although this does not reflect the sample weighting and stratified survey design. The plot of 1 km NDI vs 3 km NDI is fairly tight with a positive slope, but the 1km NDI plotted against the 8km NDI shows a much looser relationship while still maintaining a positive slope (Appendix Figure A-3). The repeated ANOVA showed that the mean NDI for at least one buffer radius was different, and the a priori planned pairwise comparisons indicated that each radius buffer captured significantly different mean deprivation levels than the other buffer sizes (Results not shown). Analysis continued to compare the associations between each NDI score and size for gestational age.

Description of study population

In our final sample of 3,716 women, about 26% of respondents were White, 25% were Asian, 22% were Hispanic, 20% were Black, and 7% were Native American. The proportion of respondents in each race/ethnicity group after taking into account the weighting to reflect the sampling design and non-response is shown in Table 5.

Table 5: Proportion of study participants in each race/ethnicity group.

	N	Crude Percent	Weighted Percent (95% CI)	
Total	3,716	100	100	
White	980	26.4	65.00	(63.5, 66.5)
Black	746	20.1	3.96	(3.8, 4.2)
Asian	925	24.9	8.92	(8.5, 9.4)
Hispanic	811	21.8	21.20	(20.0, 22.4)
Native American	254	6.8	0.91	(0.8, 1.0)

Outcome

In the total study population, about 6.5% (95% CI: 5.5%, 7.6%) of infants were small for gestational age, and 8.4% (95% CI: 7.0%, 9.8%) were large for gestational age. Native American and Hispanic women had a higher proportion of large for gestational age infants [14.1 (95% CI: 9.9, 18.4) and 12.0 (95% CI: 9.8, 14.2) respectively], and we observed an elevated prevalence of small for gestational age among Black and Asian infants [14.4 (95% CI: 11.8, 16.9) and 13.0 (95% CI: 10.8, 15.2) respectively] (Table 6). In addition to the a priori covariates and outcome, Table 6 also describes the study population's income as percent of the federal poverty line (% FPL) and marital status.

Table 6: Characteristics of study population by race and ethnicity.

	Total (N=3,716)		White (n=980)		Black (n=746)		Asian (n=925)		Hispanic (n=811)		Native American (n=254)	
	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI	%	95% CI
Maternal age (mean yrs)	28.8	(28.5, 29.1)	29.2	(28.8, 29.7)	26.7	(26.3, 27.1)	30.8	(30.5, 31.2)	27.0	(26.6, 27.4)	26.5	(25.8, 27.3)
>12 years education (%)	56.50	(54.0, 59.0)	68.21	(64.5, 71.9)	43.44	(39.9, 47.0)	71.66	(68.6, 74.8)	17.32	(14.7, 19.9)	41.18	(35.1, 47.2)
% of FPL (mean)	213.6	(207, 221)	246.5	(237, 256)	131.8	(124, 140)	251.1	(243, 260)	98.9	(92, 106)	158.2	(143, 173)
Nulliparous (%)	42.86	(40.3, 45.5)	45.71	(41.9, 49.5)	43.23	(39.6, 46.8)	45.56	(42.3, 48.8)	32.85	(29.6, 36.1)	44.02	(37.8, 50.2)
Private health insurance (%)	64.03	(61.7, 66.4)	75.63	(72.3, 79.0)	41.17	(37.6, 44.7)	80.09	(77.4, 82.8)	26.82	(23.8, 29.9)	44.50	(38.3, 50.7)
Married (%)	70.46	(68.1, 72.8)	76.31	(72.9, 79.7)	34.32	(30.9, 37.7)	85.93	(83.6, 88.3)	53.89	(50.4, 57.4)	44.04	(37.9, 50.2)
Size for gestational age (%)												
Small	6.53	(5.5, 7.6)	5.59	(4.1, 7.1)	14.39	(11.8, 16.9)	13.02	(10.8, 15.2)	5.39	(3.8, 7.0)	***	
Appropriate	85.10	(83.4, 86.8)	86.93	(84.5, 89.4)	77.29	(74.2, 80.3)	81.35	(78.8, 83.9)	82.62	(80.0, 85.2)	83.12	(78.5, 87.7)
Large	8.37	(7.0, 9.8)	7.48	(5.5, 9.5)	8.32	(6.3, 10.3)	5.63	(4.1, 7.1)	11.98	(9.8, 14.2)	14.13	(9.9, 18.4)

N's are un-weighted frequencies.

***Too few (n=7) SGA births occurred in the Native American group to make population inferences.

Exposure

The NDI indices for the smaller areas have the most variability, which decreases as the area size increases. The range of NDI score was largest for the smallest (1 km) buffer, extending from -2.44 to 2.02. At the other end of the spectrum, the largest (8 km) radius buffer had the smallest range and the smallest standard error of the mean (Table 7).

Table 7: Description of neighborhood deprivation index in total study population.

	Minimum	Maximum	Range	Mean	Std Error
1 km	-2.441	2.021	4.462	-0.407	0.0240
3 km	-2.174	1.353	3.527	-0.487	0.0191
5 km	-1.962	0.782	2.744	-0.553	0.0165
8 km	-1.733	0.664	2.397	-0.627	0.0141

We further examined the NDI scores stratified on race/ethnic group. Regardless of buffer size, White and Asian groups tend to reside in areas with lower socioeconomic deprivation than Black, Hispanic, and Native American groups (Appendix Table A-5). The absolute differences appear to become less extreme as the buffer radius increases (Figure 2). Despite race/ethnic differences in mean NDI scores, the range of NDI was similar for all race/ethnic groups (Appendix Table A-6).

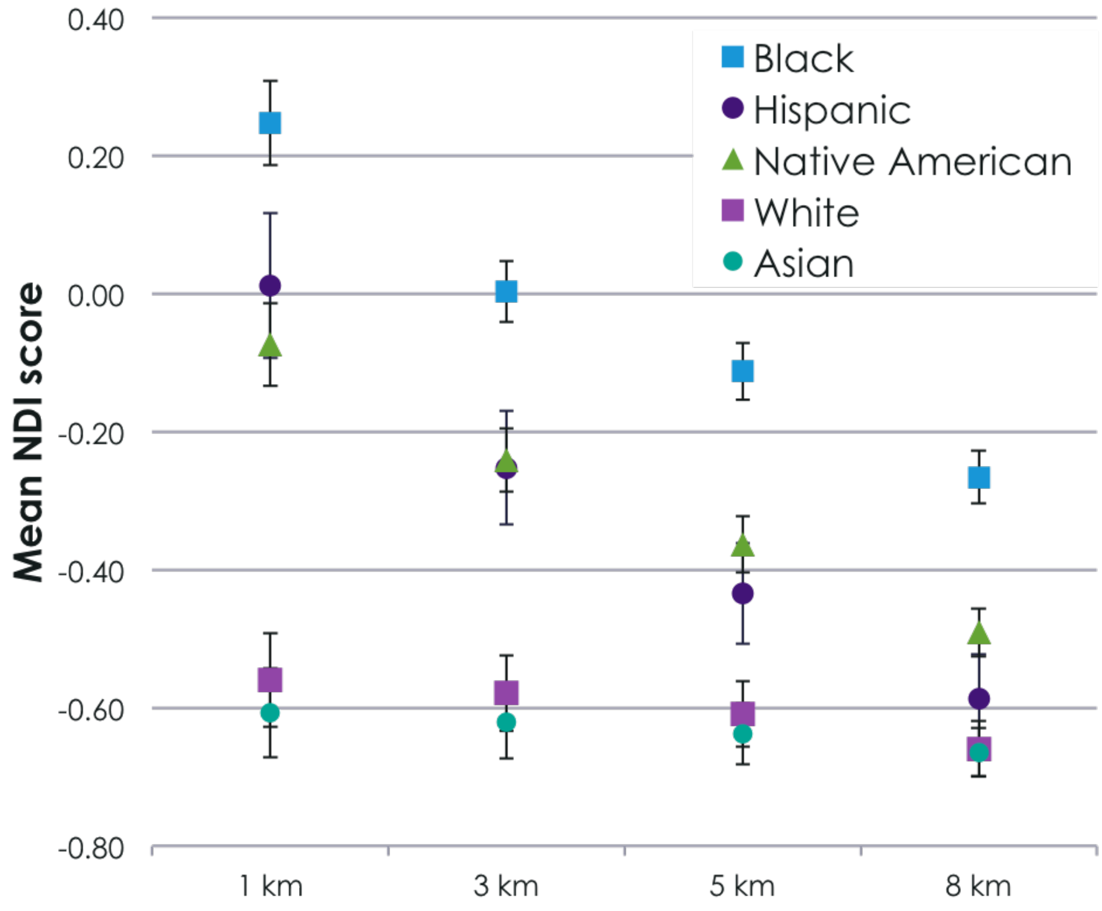

Figure 2: Mean NDI score by race/ethnic group. Whiskers represent 95% confidence intervals. Values appear in Appendix Table A-5.

Confounders

The mean age of women at the time of birth was about 29 years, and over half [56.5% (95% CI: 54.0, 59.0%)] of women had attended at least some post-secondary education (more than 12 years of education) (Table 6). Private health insurance paid for about 64% (95% CI: 61.7%, 66.4%) of births, and public health insurance covered almost all the remaining births. Only 1.85% (95%CI: 1.1%, 2.4%) of births were funded by the individual and not by public or private insurance. Stark racial and ethnic differences stand out in almost all individual socioeconomic position indicators (educational attainment, income, marital status, and health insurance coverage).

Bivariate analysis results

Means or percentages for each covariate within each outcome category are shown in Table 8a. Parity and health insurance status show substantial differences across size for gestational age categories. Of all small for gestational age infants, over half were the mother's first child, while only about 30% of mothers of large for gestational age infants were nulliparous. 56% of small for gestational age births were paid for by private health insurance, whereas private insurance paid for around 65% of both AGA and LGA births. A smaller proportion of mothers of SGA infants have education beyond high school than mothers of AGA or LGA infants, but the confidence intervals suggest this may be a less-meaningful difference in the total population.

Table 8a: Characteristics of study population by size for gestational age.

	SGA (n=490)		AGA (n=2912)		LGA (n=307)	
	% or mean	95% CI	% or mean	95% CI	% or mean	95% CI
Maternal age (mean years)	28.0	(27.1, 29.0)	28.8	(28.4, 29.1)	29.4	(28.5, 30.3)
> 12 years education (%)	51.00	(42.9, 59.1)	56.85	(54.1, 59.6)	57.18	(48.8, 65.6)
% of FPL (mean)	207.6	(182, 233)	215.4	(208, 223)	199.2	(176, 222)
Nulliparous (%)	56.37	(48.4, 64.3)	43.11	(40.2, 46.0)	29.70	(21.7, 37.7)
Private health insurance (%)	55.57	(47.5, 63.6)	64.63	(62.0, 67.2)	64.59	(56.7, 72.4)
Married (%)	67.14	(60.0, 74.3)	70.47	(67.9, 73.1)	72.93	(65.5, 80.4)

Further examination of the study population stratified by race/ethnic group showed that the general patterns within the total population are similar within each race/ethnic group with a few exceptions (Table 8b). Within the Black, Asian, and Hispanic groups, mothers with small for gestational age infants tended to be younger than mothers with AGA infants, and mothers with large for gestational age infants tended to be older. Among the Black and groups, mothers of SGA infants have slightly less education than mothers of AGA or LGA infants. The pattern in parity was different in the Hispanic group where the proportion of nulliparous mothers was similar within small and appropriate for gestational age infants, though these confidence intervals are wide.

Table 8b: Characteristics of study population by size for gestational age stratified by race/ethnicity.

	Point estimate	(95% CI)	Point estimate	(95% CI)	Point estimate	(95% CI)
White	SGA (n=222)		AGA (n=702)		LGA (n=56)	
Maternal age (mean yrs)	28.7	(27.1, 30.2)	29.3	(28.8, 29.7)	29.2	(27.7, 30.6)
> 12 years education (%)	61.70	(48.3, 75.1)	67.92	(63.9, 71.9)	76.35	(63.9, 88.8)
% FPL (mean)	242.8	(204, 282)	246.3	(236, 257)	251.9	(219, 285)
Nulliparous (%)	64.37	(51.6, 77.2)	45.70	(41.6, 49.8)	31.95	(18.9, 45.0)
Private health insurance (%)	66.30	(53.2, 79.4)	75.82	(72.2, 79.5)	80.42	(69.1, 91.7)
Married (%)	74.76	(63.7, 85.8)	75.96	(72.3, 79.6)	81.51	(70.2, 92.8)
Black	SGA (n=106)		AGA (n=577)		LGA (n=63)	
Maternal age (mean yrs)	24.4	(23.3, 25.6)	26.9	(26.4, 27.4)	28.4	(27.0, 29.8)
> 12 years education (%)	33.19	(24.3, 42.1)	45.28	(41.2, 49.4)	44.01	(31.6, 56.4)
% FPL (mean)	110.7	(90, 131)	134.7	(125, 144)	139.8	(109, 171)
Nulliparous (%)	56.63	(47.1, 66.2)	41.28	(37.2, 45.4)	38.16	(26.0, 50.3)
Private health insurance (%)	26.90	(18.5, 35.3)	42.99	(38.9, 47.1)	48.98	(36.5, 61.5)
Married (%)	16.56	(9.7, 23.4)	36.18	(32.3, 40.1)	47.71	(35.2, 60.2)
Asian	SGA (n=119)		AGA (n=754)		LGA (n=52)	
Maternal age (mean yrs)	29.8	(28.8, 30.8)	30.9	(30.5, 31.3)	32.0	(30.8, 33.2)
> 12 years education (%)	67.37	(58.5, 76.2)	72.09	(68.7, 75.5)	75.36	(62.8, 87.9)
% FPL (mean)	245.5	(219, 272)	252.7	(243, 262)	240.7	(204, 277)
Nulliparous (%)	58.04	(49.0, 67.1)	44.15	(40.6, 47.7)	37.02	(23.9, 50.2)
Private health insurance (%)	70.88	(62.3, 79.4)	81.30	(78.4, 84.2)	83.90	(73.0, 94.8)
Married (%)	81.76	(74.6, 88.9)	86.28	(83.7, 88.9)	90.42	(82.3, 98.5)
Hispanic	SGA (n=43)		AGA (n=669)		LGA (n=99)	
Maternal age (mean yrs)	26.0	(24.1, 27.8)	26.7	(26.3, 27.1)	29.6	(28.4, 30.7)
> 12 years education (%)	9.52	(0.6, 18.4)	17.53	(14.6, 20.4)	19.43	(11.6, 27.3)
% FPL (mean)	75.8	(53, 98)	101.1	(93, 109)	93.9	(78, 110)
Nulliparous (%)	29.52	(15.6, 43.4)	34.59	(30.9, 38.2)	22.35	(14.1, 30.6)
Private health insurance (%)	20.88	(8.7, 33.1)	26.21	(22.9, 29.6)	33.71	(24.4, 43.0)
Married (%)	53.63	(38.6, 68.7)	53.32	(49.5, 57.1)	58.00	(48.2, 67.8)
Native American	SGA (n=7)		AGA (n=210)		LGA (n=37)	
Maternal age (mean yrs)	**		26.4	(25.5, 27.2)	26.7	(24.7, 28.7)
> 12 years education (%)	**		41.31	(34.6, 48.0)	40.88	(25.1, 56.7)
% FPL (mean)	**		162.2	(145, 179)	143.7	(110, 177)
Nulliparous (%)	**		45.04	(38.2, 51.8)	39.02	(23.3, 54.8)
Private health insurance (%)	**		45.80	(39.0, 52.6)	40.40	(24.7, 56.1)
Married (%)	**		44.50	(37.7, 51.3)	39.93	(24.2, 55.6)

**Too few observations in this category to present estimates.

Table 9: Mean NDI score by size for gestational age group.

	SGA		AGA		LGA	
	mean	95% CI	mean	95% CI	mean	95% CI
Total						
1 km NDI	-0.318	(-0.5, -0.2)	-0.430	(-0.5, -0.4)	-0.233	(-0.4, -0.1)
3 km NDI	-0.421	(-0.5, -0.3)	-0.507	(-0.5, -0.5)	-0.337	(-0.5, -0.2)
5 km NDI	-0.499	(-0.6, -0.4)	-0.567	(-0.6, -0.5)	-0.448	(-0.6, -0.3)
8 km NDI	-0.581	(-0.7, -0.5)	-0.637	(-0.7, -0.6)	-0.563	(-0.7, -0.5)
White						
1 km NDI	-0.481	(-0.7, -0.2)	-0.581	(-0.7, -0.5)	-0.374	(-0.6, -0.1)
3 km NDI	-0.532	(-0.7, -0.3)	-0.598	(-0.7, -0.5)	-0.392	(-0.6, -0.2)
5 km NDI	-0.578	(-0.8, -0.4)	-0.623	(-0.7, -0.6)	-0.467	(-0.7, -0.3)
8 km NDI	-0.642	(-0.8, -0.5)	-0.669	(-0.7, -0.6)	-0.560	(-0.7, -0.4)
Black						
1 km NDI	0.416	(0.3, 0.6)	0.238	(0.2, 0.3)	0.041	(-0.2, 0.3)
3 km NDI	0.069	(0.0, 0.2)	0.017	(0.0, 0.1)	-0.239	(-0.4, -0.1)
5 km NDI	-0.075	(-0.2, 0.0)	-0.091	(-0.1, 0.0)	-0.375	(-0.5, -0.2)
8 km NDI	-0.253	(-0.4, -0.2)	-0.245	(-0.3, -0.2)	-0.491	(-0.6, -0.4)
Asian						
1 km NDI	-0.575	(-0.8, -0.4)	-0.618	(-0.7, -0.5)	-0.524	(-0.8, -0.2)
3 km NDI	-0.590	(-0.7, -0.4)	-0.627	(-0.7, -0.6)	-0.601	(-0.8, -0.4)
5 km NDI	-0.627	(-0.7, -0.5)	-0.638	(-0.7, -0.6)	-0.654	(-0.8, -0.5)
8 km NDI	-0.658	(-0.7, -0.6)	-0.663	(-0.7, -0.6)	-0.694	(-0.8, -0.6)
Hispanic						
1 km NDI	0.089	(-0.2, 0.4)	0.001	(-0.1, 0.1)	0.045	(-0.1, 0.2)
3 km NDI	-0.148	(-0.3, 0.0)	-0.267	(-0.3, -0.2)	-0.201	(-0.3, -0.1)
5 km NDI	-0.334	(-0.5, -0.2)	-0.447	(-0.5, -0.4)	-0.392	(-0.5, -0.3)
8 km NDI	-0.477	(-0.6, -0.3)	-0.598	(-0.6, -0.6)	-0.562	(-0.7, -0.5)
Native American						
1 km NDI			-0.093	(-0.2, 0.0)	0.021	(-0.2, 0.3)
3 km NDI			-0.264	(-0.4, -0.2)	-0.138	(-0.4, 0.1)
5 km NDI			-0.390	(-0.5, -0.3)	-0.239	(-0.4, 0.0)
8 km NDI			-0.514	(-0.6, -0.4)	-0.373	(-0.6, -0.2)

Table 9 shows the mean NDI for each size for gestational age category in the study population as a whole and then stratified by race/ethnicity. In the total population, the mean NDI is highest for large infants and lowest for appropriate for gestational age infants, with small for gestational age in between the two. In other words, appropriate size for gestational age infants were born to mothers living in less deprived areas than infants with either restricted or accelerated fetal growth.

NDI follows a different pattern across these outcomes among mothers in the Black group. As in the total population, mothers of small infants reside in more deprived areas than mothers of appropriate for gestational age infants. However, Black mothers of LGA infants reside in much less deprived areas than Black mothers of AGA or SGA infats, no matter the buffer size. The Black group is the only race/ethnic group for whom the mean deprivation is not lowest in the reference group.

Multivariate analysis results

Stratified by race/ethnic group, one multivariate multinomial logistic regression for each size buffer estimated the adjusted odds of LGA and SGA simultaneously. Due to insufficient umbers of Native American women with SGA births, a multivariate logistic regression was used to estimate odds of LGA in the Native Americans. We analyzed the continuous neighborhood deprivation index with higher order terms to accommodate a non-linear relationship with the log odds of both outcomes. For ease of interpretation, odds ratios are presented as the odds of the outcome in an area with high deprivation (90^{th}

percentile of the continuous index) relative to the odds of the outcome in an area with low deprivation (10^{th} percentile), denoted as OR_H. To represent a non-monotonic relationship between the continuous exposure and multinomial outcome, we also present odds ratios comparing the median level of deprivation to low deprivation (denoted as OR_M).

Large size for gestational age

After controlling for maternal age, education, health insurance status, and parity, there was a positive association between neighborhood deprivation and large size for gestational age for most of the race/ethnic groups (Table 10a, OR_H). The estimates for the OR_M comparing the areas with median deprivation to low deprivation areas for both small and large outcomes tended to be smaller in magnitude than the odds ratio for the high compared to low levels of deprivation, but not always in the same direction as the OR_H (Tables 10a, 10b).

The strongest associations were observed in the White and Black groups. Using the three-kilometer buffers as an example, White women residing in areas of high deprivation had an estimated 2.74 (95% CI 1.12, 6.71) times the odds of having a large for gestational age infant than White women in low deprivation areas. This association is weaker for White women living in areas at median compared to low deprivation ([3km OR_M=1.08 (95% CI: 0.60, 1.95)]. The reverse relationship between NDI score and LGA observed in the bivariate results for the Black group persisted in the multivariate adjusted model, and the odds of having a large for gestational age infant for Black women residing in areas with high neighborhood deprivation were 64% (95% CI: 15%, 85%) lower than the odds of this outcome among Black women residing in the most affluent areas (10^{th}

percentile of NDI). This negative association persisted for all size buffers in the Black women, and the only confidence interval including the null value was for the smallest buffer. Although Black women in the most deprived areas had lower odds of LGA than those in the least deprived areas, Black women in the middle of the range had slightly higher odds of LGA [3km OR_M=1.08 (95% CI: 0.47-2.4)], reflecting the non-monotonic trend.

Native American women had greater odds of LGA with greater neighborhood deprivation [3km OR_H=1.91 (95% CI: 0.57, 6.44)]. However, the confidence intervals are wide and contain the null value at each size buffer. The association for Native American women residing at median compared to low deprivation was weaker [3km OR_M=1.34 (95% CI: 0.77, 2.31)] Among Hispanic women, the odds of large size for gestational age were higher at high levels of deprivation [3km OR_H=1.39 (95% CI: 0.76, 2.53)], but again the confidence limits included the null value. The association for the Asian group was the smallest in magnitude, and was not statistically significant.

Table 10a: Adjusted odds ratio for large size for gestational age for women residing in a high or median deprivation area compared to a low deprivation area.

	White (n=980)		Black (n=746)		Asian (n=925)		Native American (n=254)		Hispanic (n=811)	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
1 km										
Med/Lo	1.49	(0.85, 2.6)	1.36	(0.54, 3.5)	0.87	(0.50, 1.5)	1.21	(0.73, 2.0)	1.69	(0.65, 4.4)
Hi/Lo	2.63	(1.01, 6.8)	0.54	(0.21, 1.38)	1.34	(0.57, 3.1)	1.57	(0.47, 5.2)	1.85	(0.74, 4.7)
3 km										
Med/Lo	1.08	(0.60, 1.9)	1.08	(0.47, 2.4)	0.94	(0.51, 1.7)	1.34	(0.77, 2.3)	1.16	(0.89, 1.5)
Hi/Lo	2.74	(1.12, 6.7)	0.36	(0.15, 0.85)	1.10	(0.49, 2.5)	1.91	(0.57, 6.4)	1.39	(0.76, 2.5)
5 km										
Med/Lo	0.84	(0.47, 1.5)	1.06	(0.51, 2.2)	1.21	(0.74, 2.0)	1.41	(0.88, 2.3)	1.10	(0.87, 1.4)
Hi/Lo	2.15	(0.96, 4.8)	0.34	(0.15, 0.80)	1.01	(0.44, 2.3)	2.32	(0.72, 7.5)	1.26	(0.71, 2.2)
8 km										
Med/Lo	0.98	(0.57, 1.7)	1.17	(0.61, 2.3)	1.54	(0.90, 2.6)	0.58	(0.25, 1.3)	1.05	(0.85, 1.3)
Hi/Lo	2.12	(0.94, 4.8)	0.39	(0.17, 0.88)	0.94	(0.40, 2.2)	2.23	(0.75, 6.7)	1.14	(0.65, 2.0)

Adjusted for maternal age, education, insurance status, and parity.
"Med/Lo" OR compares odds of LGA at median deprivation to odds of LGA at low (10th percentile) of deprivation (OR_M). "Hi/Lo" compares odds of LGA at high (90^{th} percentile) deprivation to low deprivation (OR_H).

Small size for gestational age

The adjusted association between small size for gestational age and neighborhood deprivation is in the positive direction, but weaker than the association with the large outcome and all confidence intervals include the null value (Table 10b, OR_H). The Asian group is an exception to this with all point estimates smaller than one, although the confidence limits still include the null value. The non-montonic relationship was most obvious in Asian women at the 8 km buffer, where women in median deprived areas had higher odds of SGA than women in areas with low deprivation [8km OR_M= 1.37 (95% CI: 0.90, 2.08)], but women in areas with high deprivation had lower odds of SGA than those in low deprivation areas [8km OR_H= 0.84 (95% CI: 0.46, 1.52)]. The point estimates for White and Black women measuring NDI at the 8km buffer also fell below one, but the confidence limits stretched well above and below the null value. Limited observations with the SGA outcome prevented the construction of a multinomial model to estimate odds of small size for gestational age for Native American women.

Table 10b: Adjusted odds ratio for small size for gestational age for women residing in a high or median deprivation area compared to a low deprivation area.

	White (n=980)		Black (n=746)		Asian (n=925)		Hispanic (n=811)	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
1 km								
Med/Lo	1.13	(0.64, 2.0)	1.09	(0.50, 2.4)	0.61	(0.42, 0.89)	1.29	(0.28, 6.0)
Hi/Lo	1.28	(0.52, 3.2)	1.15	(0.50, 2.6)	0.67	(0.37, 1.23)	1.25	(0.29, 5.3)
3 km								
Med/Lo	0.92	(0.49, 1.7)	1.35	(0.73, 2.5)	0.60	(0.39, 0.92)	1.20	(0.79, 1.8)
Hi/Lo	1.24	(0.53, 2.9)	1.23	(0.57, 2.7)	0.76	(0.42, 1.4)	1.51	(0.60, 3.8)
5 km								
Med/Lo	0.72	(0.39, 1.3)	1.38	(0.71, 2.7)	0.92	(0.64, 1.30)	1.22	(0.85, 1.7)
Hi/Lo	1.12	(0.52, 2.4)	1.14	(0.51, 2.5)	0.79	(0.45, 1.4)	1.62	(0.67, 4.0)
8 km								
Med/Lo	0.58	(0.34, 1.0)	0.98	(0.58, 1.7)	1.37	(0.90, 2.08)	1.24	(0.92, 1.7)
Hi/Lo	0.90	(0.42, 1.9)	0.83	(0.42, 1.6)	0.84	(0.46, 1.5)	1.81	(0.79, 4.1)

Adjusted for maternal age, education, insurance status, and parity.
"Med/Lo" OR compares odds of SGA at median deprivation to odds of SGA at low (10th percentile) of deprivation (OR_M). "Hi/Lo" compares odds of SGA at high (90^{th} percentile) deprivation to low deprivation (OR_H).

Area comparisons

The strength of the association changed a small amount from one buffer to the next, and no consistent patterns arose favoring one buffer size over the others (Tables 10a, 10b). For Hispanic, and Asian women, the strongest associations between LGA and NDI were found at the 1 km buffer. For White women, the strongest association with LGA was observed at the 3 km buffer, and the 5 km buffer produced the strongest associations with LGA for Black and Native American women. The strongest association between SGA and NDI was observed at the 1 km buffer for White women and Asian women, the 3 km buffer for Black women, and the 8 km buffer for Hispanic women. However, the magnitude and direction of the associations were relatively consistent from one buffer size to the next. The largest differences were observed between the 1 and 3 km buffer for LGA and between the 5 and 8 km buffers for SGA. In most cases, the 3 and 5km buffers provided similar estimates.

We compared R^2 with the goal of determining which radius buffer provides the model that explains most of the variance. All neighborhood definitions provided a similar fit with the data. The most drastic differences in change in adjusted R^2 are between different race/ethnicity groups rather than across neighborhood size (Figure 3, Appendix Table A-7). Within each group, the area taken into account for measuring NDI does not seem to have much effect on the model fit (Figure 3, Appendix Table A-7).

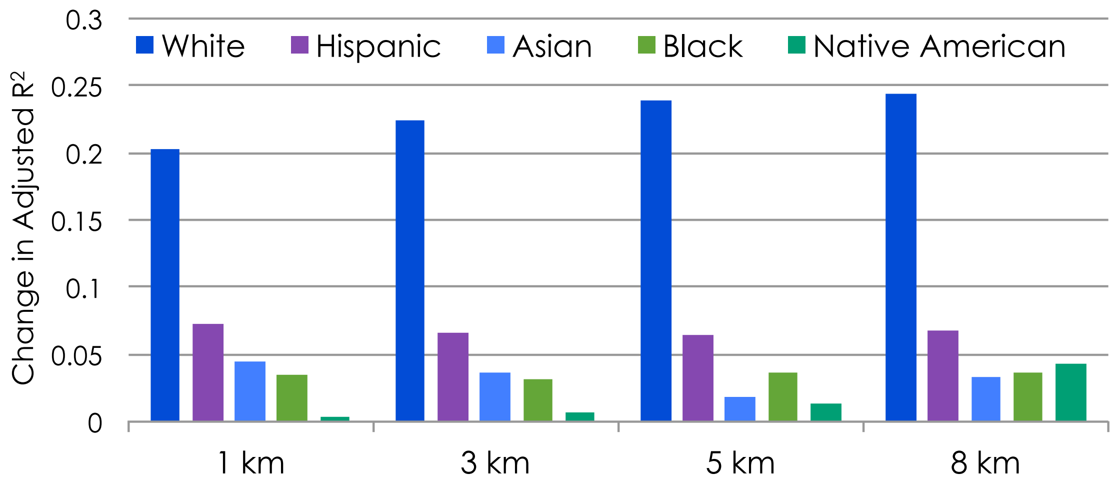

Figure 3: Change in adjusted R^2 resulting from addition of NDI term(s) to the multivariate model. Small trends in increasing or decreasing change in R^2 across buffer sizes may exist, but the most substantial differences are between the race/ethnicity groups rather than buffer size.

Discussion

Oregon PRAMS (2004-2007) respondents in Washington, Clackamas, and Multnomah counties exhibited racial and ethnic disparities in small- and large-size for gestational age, as well as disparities in multiple measures of individual socioeconomic position. Multivariate multinomial regression estimated a strong positive association between neighborhood deprivation and large size for gestational age among White women and a weaker positive association for Native American and Hispanic women, whereas Black women residing in high deprivation areas had lower odds of delivering a large for gestational age infant. The odds of small size for gestational age were also higher at high levels of deprivation, except among Asian women. The magnitude and direction of the associations changed little from one buffer size to the next, and the most stable estimates came from the 3 and 5 km buffers. Furthermore The changes in R^2 as the neighborhood deprivation index was added to the multivariate model without a neighborhood component were very slight and did not favor one size buffer over another.

Other studies that have attempted to distinguish between neighborhood definitions using model fit had similar inconclusive results.[44] In fact, Spielman and Yoo (2009) simulated environmental and health data and found, on average, the correct buffer size provided the best model fit, but the differences in R^2 were very small. They concluded that model fit has minimal utility as a selection criteria for area size, and stress that division of space should be based on theory about how the environment influences health.[39] The very subtle differences in adjusted R^2 from our results support this conclusion.

Spielman and Yoo (2009) noted an inflated measure of association using buffers that were too small and also using buffers that were much larger than the correct size.[39] In their simulation, the correct buffer size gave an unbiased estimate, and buffers that were slightly larger resulted in similar measures of association.[39] Our estimated associations were most stable for the 3 and 5 km buffers, which could indicate that the 3-5 km radius falls within the "correct" or slightly larger buffer size.

The effective neighborhood size will likely be different from one city to the next and from one subgroup of the population to another.[17,39,42] Neighborhood deprivation is proposed to impact individual health through stress and access to resources. Stress can originate from many sources within a neighborhood, making an appropriate buffer size difficult to propose. In an urban area like Portland, people access resources mostly by car, but also via foot, public transit, or bicycle. Access to resources on foot might be most convenient within a one-kilometer radius, and car, public transit, or bicycle, would increase the area with easy access. However, Portland is not a very dense city, and the study sample includes suburban and urban fringe areas where resources are more spread out. The majority of examples given throughout this paper pull from the three-kilometer buffer for these reasons. It might be more appropriate to use the 3 km buffer for women residing in urban areas and the 5 km or 8 km buffer in suburban and rural areas, but this was out of the scope of investigation for this project.

Neighborhood deprivation can be a marker of many unmeasured exposures, which limits the specificity of the association. Social factors in the study area that are associated with area socioeconomic position, such as ongoing gentrification, could mean that living in a more affluent neighborhood is actually more stressful for Black women than living in a more deprived neighborhood. However, stress is a contributor to both accelerated and restricted fetal growth, and we did not observe the same association with small size for gestational age. Another limitation stems from the fact that the area has undergone rapid change within the last few decades, including the study period, but our cross-sectional data only capture one point in time. Ending the study period in 2007 reduces the impact of the changing socioeconomic environment by excluding the national financial crisis that began in 2008.

NDI not as strongly associated with small size for gestational age as it was with large size for gestational age, but the magnitude of association with the small outcome remained within the range documented by existing literature in other regions of the United States[23,49,51] and in the Netherlands.[52] No studies of neighborhood deprivation and size for gestational age have stratified on racial or ethnic groups other than White, Black, and Hispanic, so our results for the Asian group add new information to the literature. One previous study of neighborhood deprivation and low birthweight stratified analysis on diverse racial and ethnic groups and identified substantial heterogeneity between groups in a similar manner as our findings for small size for gestational age.[29]

Our results revealed heterogeneity across race/ethnicity groups and identified distinct relationships with neighborhood deprivation for each outcome. Failing to distinguish between large for gestational age and appropriate for gestational age infants may over-simplify the association. Dichotomizing size for gestational age requires grouping large with appropriate size for gestational age infants in spite of evidence that accelerated fetal growth has long-term adverse health outcomes and causes similar to restricted fetal growth.[8,12,13] Aggregating these distinct outcomes would bias the observed association between neighborhood deprivation and small size for gestational age toward the null for all groups in this study population except for the Black group, for whom the observed association between NDI and small size for gestational age would have been biased away from the null. Distinguishing between diverse racial and ethnic groups and including the large size for gestational age outcome are two important strengths of this study.

Conclusions

This study identified marked heterogeneity in the association between large size for gestational age and neighborhood deprivation across diverse race/ethnic groups. Future studies of neighborhood deprivation and large size for gestational age would be helpful to understand the consistency and inconsistencies of this relationship across diverse racial and ethnic groups and in other regions. Examination of other more specific contextual factors in addition to neighborhood deprivation could explain some of the heterogeneity between racial and ethnic groups or suggest a more specific pathway. The associations between NDI and size for gestational age were most stable for the 3 and 5 km buffers, and a 3 km buffer is a plausible distance for an effective neighborhood deprivation exposure. Decisions about appropriate area size for a neighborhood-level exposure should be chosen based on theory specific to the proposed mechanism and the population under study rather than by measures of model fit.

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Appendix A

Table A-1: Details on Oregon birth certificate variables

Coding	Comments/instructions
Race of Mother	
1=White (includes Mexican, Puerto Rican, Caucasian) 2= Black, African American 3=Indian (North, Central, South American, Eskimo, Aleut) 4=Chinese 5=Japanese 6=Hawaiian (includes part Hawaiian) 7=Other entries 8=Filipino 9=Unknown or not classifiable 0=Other Asian or Pacific Islander If the racial entry is "Asian," "Yellow," "Oriental," or "Mongolian," and birthplace is given as China, Japan, Hawaii, or the Philippines, code 4, 5, 6, or 8 based on birthplace information. If birthplace is not China, Japan, Hawaii, or the Philippines, code 0 (Other Asian or Pacific Islander). If the racial entry is "Indian" and birthplace is not in North, South or Central America code "0" (Other Asian or Pacific Islander).	Precoded except for (1) White code. See Appendix D for race entries. For uncoded race, enter 1. If a mixture of Hawaiian and any other race, code Hawaiian. If more than one race is reported (except Hawaiian), code to the first race listed. If more than one race is reported with percentages or fractions given (except Hawaiian), code the race having the higher percentage or fraction. If equal, code the first listed. If more than one race is reported with a hyphen but without percentages (except Hawaiian), code the first listed. If a racial entry is reported that cannot be coded to your state codes, 1-6,8,0, code to "Other Race" entries (Code 7). If "Part" is given in relation to race, ignore the qualification and code to stated race. If the entry Is "Col.," "N," "Negro," "Color(ed)," "B," "Brown," "A.A.," "Afro-american," code 2 (African American).
Hispanic Origin	
0 = Non-Hispanic 1 = Mexican 2 = Puerto Rican 3 = Cuban 4 = Central or South American 5 = Other or Unknown Hispanic 9 = Not Classifiable, Unknown	See Appendix Q (Refers to NHS Instruction Manual Part 3a, Appendix G).

Table A-1 (continued): Details on Oregon birth certificate variables

Coding	Comments/instructions
Marital Status	
1-married/separated 2-unmarried/divorced/ annulled/ Not Reported (Oregon Births Only) Blank = Not Reported, (Out-of-State)	If Oregon birth and marital status is not reported, use code 2 (unmarried). Can be blank only for out-of-state occurrence. If marital status = 2 (unmarried) and father's name is present, then there must be a sealed file number. Queried if Oregon occurrence and item is left blank
Mother's Education	
00=None 01-12=Elementary and Secondary 13=1 Year of College 14=2 Years of College 15=3 Years of College 16=4 Years of College 17=5 or More Years of College 99=unknown	Age of mother minus mother's education must >3. Two-digit code from 00-17. If education is designated in some way as "Unknown," Code 99. If education is blank, refer to registration for verification. If two or more levels of education are reported, code the highest level classifiable. If year is given with a fraction or symbol, such as +, ', ?, etc., ignore fraction or symbol and code year as stated. If entry of "All" is reported in the elementary or secondary block, code 12. If entry "All" is reported in the college block, code 16. If entry of +, ', ?, or / is reported in both blocks, code 99. If entry in college block is "AA," or "AS," Code 14. If entry in college block is "BBA," "BA," or "BS," Code 16. If entry in college block is "AM," "MA," "MSC," "MD," "DVM," "DDS," "DDM," "DO," "LLB," "Phd," or other advanced degree, code 17. If entry Is R.N. or B.S. in nursing, Code as Follows: R.N. = 14, 2 R.N. = 14; 3 R.N. = 15; 4 R.N. = 16; B.S. in Nursing = 16

Table A-2: Sociodemographic variables for NDI generation from year 2000 Census by sociodemographic domain.

Variable	Raw / Normalizing data description
Poverty	
% Households (HH) in poverty*	Total households with 1999 income below poverty level / Total Households
% Families with female head & dependent children	Total families with female householder, no husband present with own children under 18 / Total families
% HH with income < $30000*	Total HH with income < $30K (<10, 10-14.9, 15-19.9, 20-24.9,25-29.9) / Total HH
% HH with public assistance income*	Total HH with public assistance income / Total HH
% HH with no car	Total occupied housing units with no vehicle available (owner occupied & renter occupied) / Total occupied housing units
% HH with income >150% of FPL	Total HH with income to poverty level ratio 1.50 + / Total HH
% individuals with income < FPL	Total with income 0 to 0.99 poverty status / Total pop for whom poverty status is determined
Housing	
%HH rented	Total renter occupied housing units / Total occupied housing units
%HH vacant	Total vacant housing units / Total housing units
% HH with > 1 person per room	Total occupied HH with 1.01+ occupants per room (owner occupied: 1.01-1.5, 1.51-2.0, 2.01+; renter occupied: 1.01-1.5, 1.51-2.0, 2.01+) / Total occupied housing units
% renter costs >50% of income	Specified renter-occupied housing units with gross rent ≥ 50% of HH income / Total specified renter- occupied housing units– not computed
% owner costs >50% of income	Total owner occupied housing units (with a mortgage and without a mortgage) where owner costs are ≥ 50% of the HH income / Total occupied housing units – total not computed (with a mortgage and without a mortgage)
Median HH value*	Median value (dollars) for all owner-occupied housing units

*variables with factor loading >0.25

Table A-2 (Continued): Sociodemographic variables for NDI generation from year 2000 Census by sociodemographic domain.

Variable	Raw / Normalizing data description
Occupation	
% Males in management*	Total employed civilian population 16+ males in management, professional & related occupations / Total employed civilian pop 16+ males
% Males in professional occupations	Total employed civilian population 16+ males in professional and related occupations / Total employed civilian pop 16+ males
% females in management	Total employed civilian population 16+ females in management occupations, except farmers and farm managers / Total employed civilian pop 16+ males
% females in professional occupations	Total employed civilian population 16+ females in professional and related occupations / Total employed civilian pop 16+ females
Employment	
% males and females who are unemployed	Total population 16+ unemployed (civilians) / Total population 16+ in labor force
% males no longer in work force	Total males 16+ not in labor force / Total males 16+
Education	
% males and females without diploma/GED*	Total population 25+ without diploma/GED (M/F) (no school, to 4th, 5th & 6th, 7th & 8th, 9th, 10th, 11th, 12th no diploma) / Total population 25+ (M/F)
% males & females with college +	Total population 25+ with Bachelor's, Master's, Professional, or Doctorate degree (M/F) / Total population 25+ (M/F)
Residential Stability	
% in same residence for 5 yrs prior	Total population 5+ who lived in same house in 1995 / Total population 5+
% residents aged 65+	Total aged 65+ (M/F: 65&66, 67 to 69, 70 to 74, 75 to 79, 80 to 84, 85 and over) / Total population 5+
Racial Composition	
% White	Total Non-Hispanic or Latino, White alone / Total population
% Black	Total Non-Hispanic or Latino, Black or African American alone / Total population
% Hispanic	Total Hispanic or Latino / Total population

*variables with factor loading >0.25

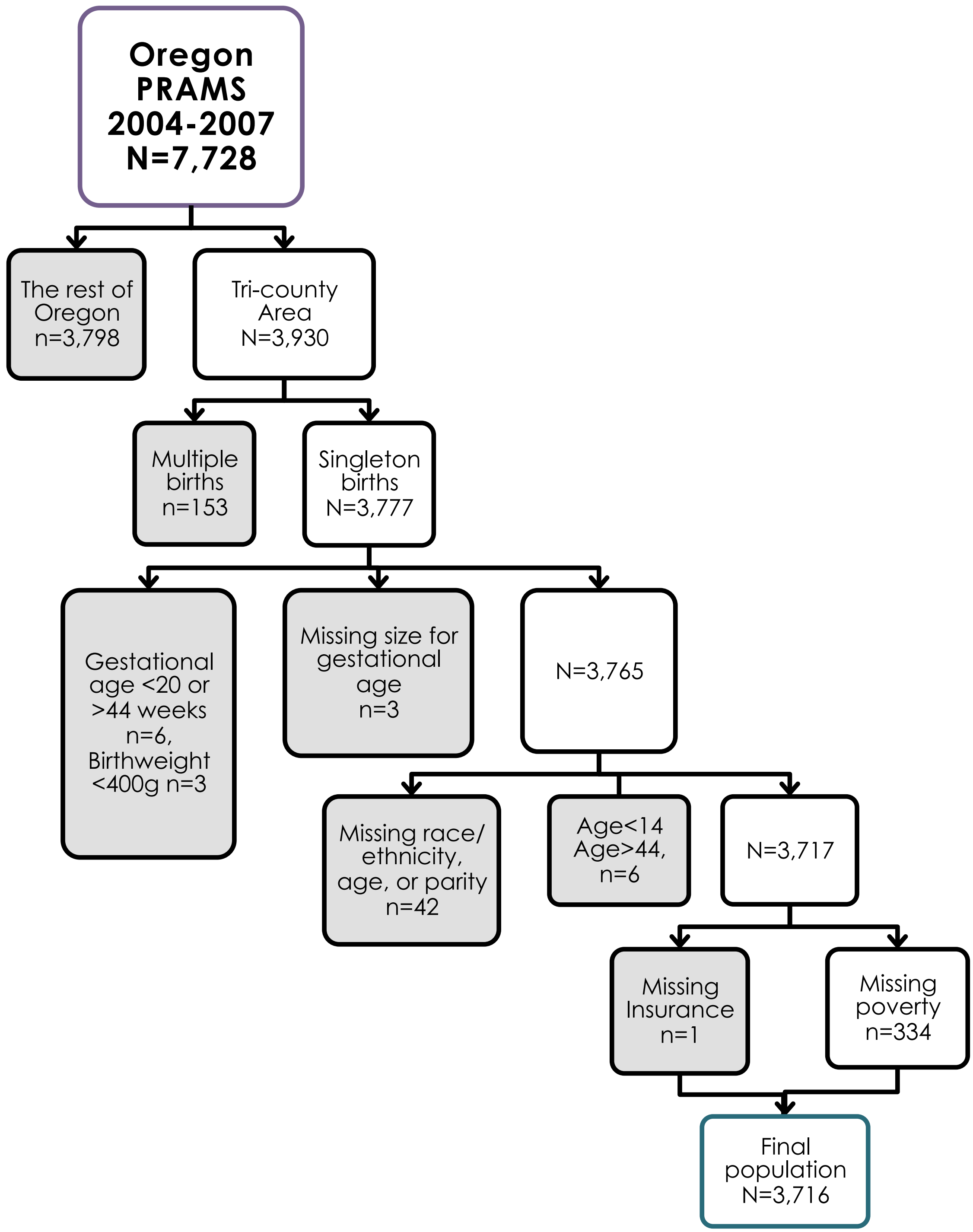

Figure A-1: Study population and selection criteria.

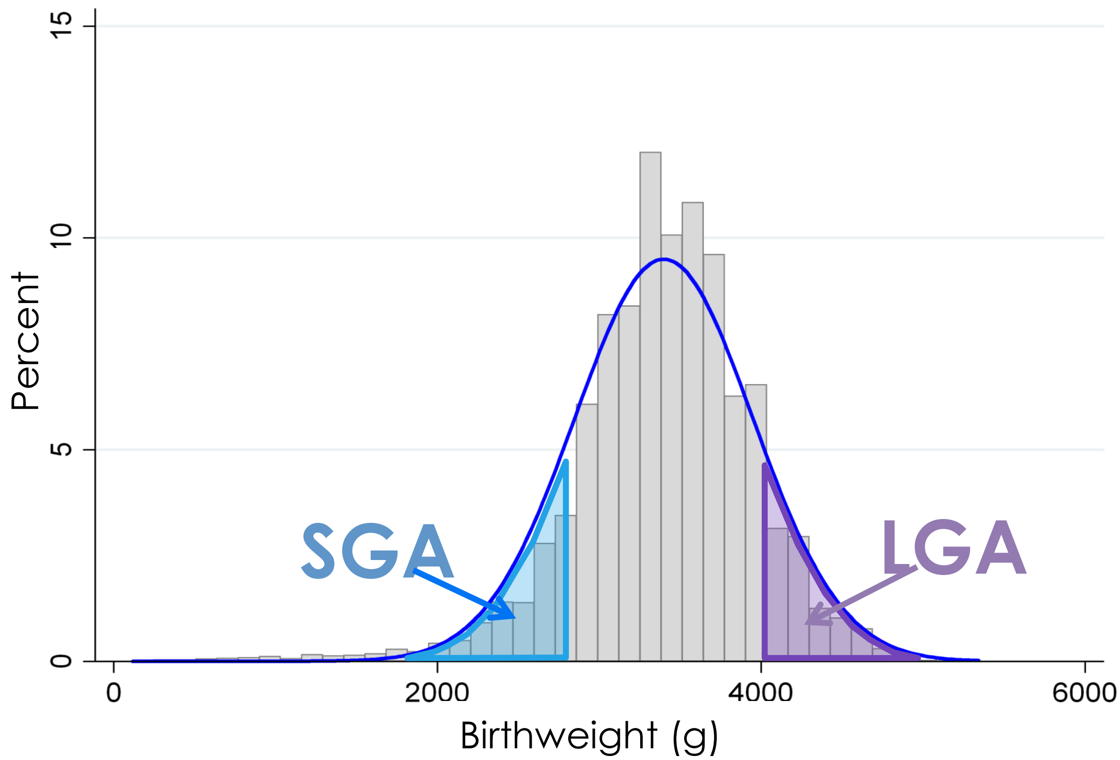

Figure A-2: Size for gestational age: Distribution of birthweight at 40 weeks gestation with approximate cut-off points for large for gestational age (LGA) and small for gestational age (SGA).

Table A-3: Likelihood Ratio Test results for higher order NDI terms.

	White (n=980)		Black (n=746)		Asian (n=925)		Hispanic (n=811)		Native American (n=254)	
Main exposure terms	G	p<G	G	p<G	G	p<G	G	p<G	G	p<G
1 km										
NDI	315.62	< 0.001	23.34	< 0.001	14.39	< 0.001	1.76	0.184	13.70	< 0.001
NDI + NDI^2	0.21	0.644	8.77	0.003	42.59	< 0.001	0.26	0.608	46.51	< 0.001
NDI + NDI^2 + NDI^3	144.54	< 0.001	28.68	< 0.001	46.11	< 0.001	12.34	< 0.001	5.53	0.019
3 km										
NDI	409.71	< 0.001	34.23	< 0.001	6.57	0.010	3.76	0.053	33.31	< 0.001
NDI + NDI^2	169.83	< 0.001	12.69	< 0.001	13.18	< 0.001	0.62	0.432	79.88	< 0.001
NDI + NDI^2 + NDI^3	6.83	0.009	6.55	0.010	52.77	< 0.001	0.41	0.667	28.69	< 0.001
5 km										
NDI	311.58	< 0.001	50.08	< 0.001	6.15	0.013	6.85	0.009	31.70	< 0.001
NDI + NDI^2	322.05	< 0.001	18.31	< 0.001	4.65	0.031	1.71	0.191	108.07	< 0.001
NDI + NDI^2 + NDI^3	41.99	< 0.001	0.14	0.708	2.84	0.092	3.55	0.060	90.52	< 0.001
8 km										
NDI	205.83	< 0.001	49.26	< 0.001	4.56	0.033	7.46	0.006	41.66	< 0.001
NDI + NDI^2	397.81	< 0.001	18.70	< 0.001	55.13	< 0.001	3.44	0.064	28.23	< 0.001
NDI + NDI^2 + NDI^3	107.65	< 0.001	0.55	0.460	1.41	0.234	11.87	< 0.001	103.35	< 0.001

G= change in deviance (Likelihood Ratio Statistic) for addition of highest order term to the model including lower-ordered terms and covariates Maternal age, maternal age2, parity, private health insurance status, and maternal education.. DF=1.

Table A-4: Definitions of Low, Median, and High NDI for odds ratios.

NDI	Percentile		Score
1 km	10%	Low	-1.174
	50%	Median	-0.109
	90%	High	1.318
3 km	10%	Low	-0.928
	50%	Median	-0.046
	90%	High	1.036
5 km	10%	Low	-0.821
	50%	Median	-0.131
	90%	High	0.879
8 km	10%	Low	-0.620
	50%	Median	-0.109
	90%	High	0.764

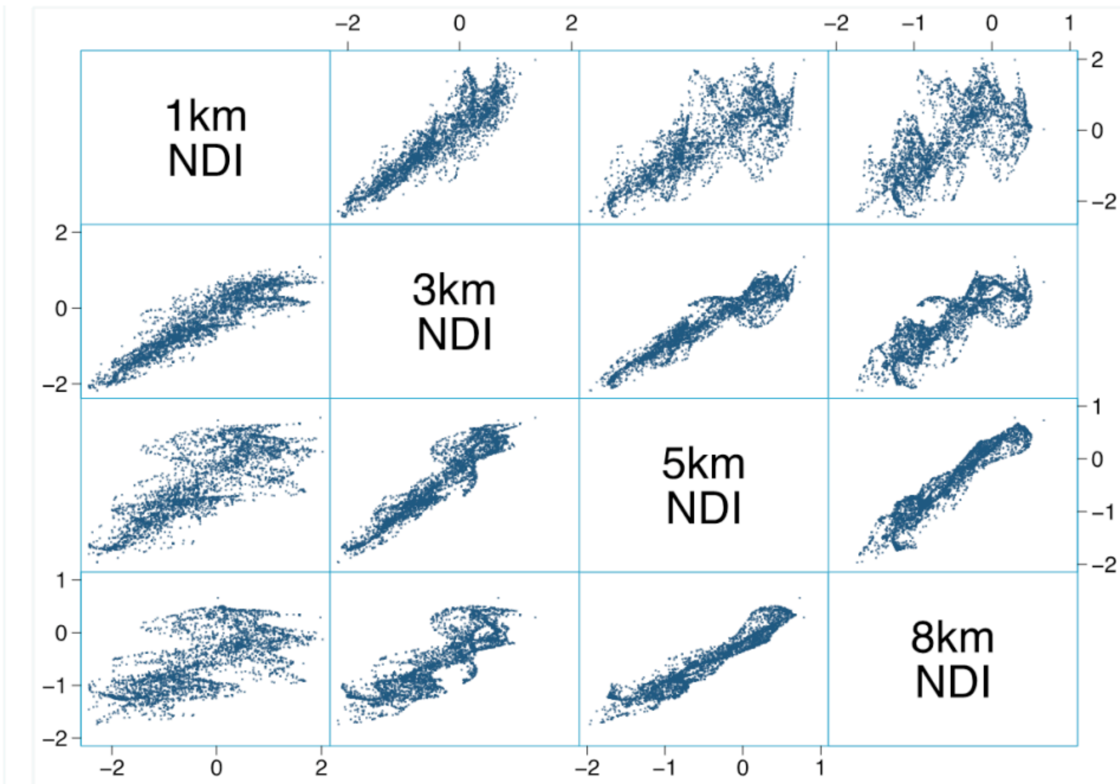

Figure A-3: Scatter plots showing pairwise comparisons of NDI measurements at each buffer size. Buffers that are closer in size are more strongly correlated with one another.

Table A-5: Mean NDI by race/ethnicity group.

	1 km NDI		3 km NDI		5 km NDI		8 km NDI	
	mean	(95% CI)	mean	(95% CI)	mean	(95% CI)	mean	(95% CI)
White	-0.56	(-0.63, -0.49)	-0.58	(-0.63, -0.52)	-0.61	(-0.66, -0.56)	-0.66	(-0.70, -0.62)
Black	0.25	(0.19, 0.31)	0.00	(-0.04, 0.05)	-0.11	(-0.15, -0.07)	-0.27	(-0.30, -0.23)
Asian	-0.61	(-0.67, -0.54)	-0.62	(-0.67, -0.57)	-0.64	(-0.68, -0.59)	-0.66	(-0.70, -0.63)
Hispanic	0.01	(-0.05, 0.07)	-0.25	(-0.30, -0.21)	-0.43	(-0.48, -0.39)	-0.59	(-0.62, -0.55)
Native American	-0.07	(-0.18, 0.03)	-0.24	(-0.32, -0.16)	-0.36	(-0.44, -0.29)	-0.49	(-0.56, -0.43)

Table A-6: NDI range by race/ethnicity group (minimum and maximum values).

	1 km NDI		3 km NDI		5 km NDI		8 km NDI	
	Min	Max	Min	Max	Min	Max	Min	Max
White	-2.441	1.829	-2.061	0.901	-1.876	0.646	-1.703	0.501
Black	-2.279	1.983	-2.174	1.353	-1.950	0.782	-1.668	0.503
Asian	-2.435	1.805	-2.166	1.080	-1.962	0.672	-1.733	0.495
Hispanic	-2.038	2.021	-1.948	1.080	-1.706	0.728	-1.647	0.664
Native American	-2.001	1.669	-1.911	0.946	-1.767	0.644	-1.547	0.496

Table A-7: Adjusted R^2 for each full multivariate model.

	White	Black	Asian	Hispanic	Native American
1 km	0.3507	0.0829	0.0787	0.1491	0.0092
3 km	0.3715	0.0802	0.0704	0.1419	0.0129
5 km	0.3858	0.0856	0.0535	0.1416	0.0186
8 km	0.3914	0.0854	0.0669	0.1438	0.0481
no NDI	0.1472	0.0484	0.0343	0.0763	0.0057

Appendix B

Part 1: Measuring Gestational Age

The birth certificate provided two estimates of gestational age, one of which was used to calculate the outcome variable size for gestational age. The last menstrual period (LMP) estimate of gestational age is calculated from a woman's recall of her last normal menses date and the birth date. The second estimate is a clinical estimate of gestational age and is made by a physician based on the integration of various sources of information available to the clinician.[53,54] Error in the estimation of gestational age may impact our classification of large or small for gestational age.

The LMP gestational age is missing in about ten percent of our sample. Not all race/ethnicity groups are missing at the same frequency, with about 15% missing in the Native American group, and only 8% missing in the Asian group. The most likely reason for this missingness is inability to recall the date of last menses. Many women in the US do not keep careful records of their menstrual cycles and simply do not know what date their last menses started. Furthermore, a reported LMP can be inaccurate if a woman recalls the date inaccurately, has an irregular menstrual cycle, or misinterprets early pregnancy bleeding as normal menses.[53-56] Inaccuracies of LMP have been noted especially among lower-income individuals.[54]

The clinical estimate of gestational age is also not a perfect measure and it becomes less accurate the later prenatal care begins.[53,54] Lazariu, Davis, and McNutt (2013) compared LMP and clinical estimates of gestational age among low income women in New York and concluded that infants born to mothers with high risk indicators were more likely to have a preterm clinical estimate and full term LMP estimate, indicating that reliance on CE of gestational age could result in overestimation of the importance of risk factors for preterm birth.[54] If a birth with known risk factors is classified as preterm rather than full term, this could result in infants that truly are small for gestational age being classified as appropriate for gestational age, which could bias results toward the null. Because studies that compare estimates of gestational age focus on preterm birth, it is less clear what the effect might be on our large for gestational age associations. One clear advantage of using the clinical estimate of gestational age is that there is no missing information for this variable. Rather than exclude women who were missing the LMP estimate, I chose to use the clinical estimate of gestational age and risk biasing the observed association toward the null.

Part 2: Covariates in the Literature

The published papers surveyed for use of covariates are summarized in Table B-1. Five papers used a multivariate model to assess a neighborhood poverty exposure and small size for gestational age or percentile of birthweight for gestational age,[23,27,49,51,52] and eight additional papers with a similar exposure examined low birthweight, continuous birthweight, or preterm birth as an outcome.[28,29,47,57-61] One systematic review with outcome low birthweight was identified,[21] and no papers were identified that modeled the association between this exposure and large size for gestational age or high birthweight. All studies identified in this process either adjusted for or stratified on the mother's race and/or ethnicity, and we have stratified all analysis by race/ethnicity group.

Table B-1: Abridged evidence table for covariate literature search. Covariates that were included in a model are shaded gray.

Study Characteristics			Covariates included										
First Author, year	Neighborhood Exposure	Outcome	Race	Mom's Age	Mom's Edu	Parity	Marital Status	Individual SES	Prenatal care	Infant sex	BMI	smoking	Medical Risk Factors
Elo, 2009	1 sd increase in census tract NDI	term SGA	Stratified					not avail					
Zeka, 2008	1sd change in HH income	SGA	SGA definition					not avail					
Agyemang, 2009	Q1/Q4 income unemployment or public assistance	SGA							only early PC				
Masi, 2007	Economic disadvantage	SGA	Stratified	quadratic				not avail					
Schempf, 2011	NDI, racial composition	LBW, PTB term SGA				gravidity		not avail					
Subramanian, 2005	40-100% of CT < HS education 20-100% CT < FPL	continuous birthweight	Mother & Father		Mother & Father		(father missing info?)	not avail					
Urquia, 2009	Tertile of material deprivation	continuous birthweight	immigrant population					immigrant class					
Schempf, 2009	1SD of index of race, poverty, crime, incivilities	continuous birthweight					live w father	Several measures					
Janevic, 2010	NDI Q4/Q1	PTB Term LBW PTB	Ethnicity + nativity Stratified					not avail			weight		
NKansah-Amankra,'10	Poverty, Edu., HH crowding	LBW											
Cubbin, 2007	CT Townsend Deprivation index	LBW			Mother & Father								
O'Campo, 2007	NDI Q5/Q1	PTB	Stratified					not avail					
Messer, 2008	Several SES domains	PTB	Stratified					not avail					

Maternal age

All identified studies adjusted the association for maternal age. Our multivariate model adjusts for maternal age as a continuous variable centered at the mean age. Mean centering avoided collinearity with the quadratic variable that was included to take into account a non-linear effect of maternal age on birth weight.[49,50]

Parity

As a whole, the papers were divided on including parity as a covariate. Nearly all studies with small size for gestational age as the outcome did adjust for parity,[27,49,51,52] while those that did not tended to be the papers focused on continuous birthweight as the outcome.[57-59] Because parity does appear to be important for the outcome small size for gestational age, it is included in the multivariate models in this paper as a dichotomous variable of nulliparous vs. one or more previous births.

Marital Status

Some papers also adjusted for marital status.[27,49,58-61] On the Oregon birth certificate, (Appendix Table A-1) a woman is classified as single if she is married and living with the husband or married but separated. All women who have never been married, who are divorced, who have had a marriage annulled, and women for whom marital status was not reported are considered unmarried. Marital status could be associated with birth outcomes as an indicator of social support or financial support, but different effects have been observed for women who are married and living with their partner than those who are separated or never married.[62] Furthermore, among unmarried women the quality of the relationship with the infant's father may also play an important role in birth outcomes.[63] Marital status was used in the calculation of percent of federal poverty level for this analysis. The final models did not adjust for marital status because it is likely to be differentially reported by race/ethnic group, which may be reflected in Table 5, and also because the way it is reported in Oregon combines categories with important distinctions (Appendix Table A-1).

Less-common covariates

Other variables included as covariates in these studies included prenatal care, infant sex, pre-pregnancy body mass index (BMI), smoking, and other medical risk factors.[23,29,49,51,52,57,58] After careful consideration of evidence that neighborhood deprivation may have an effect on health behaviors and health status such as prenatal care, cigarette smoking, physical activity, or BMI,[14,22] I did not adjust for these variables because they may lie on the causal pathway from neighborhood deprivation to birth outcomes.

Individual socioeconomic position

All identified studies included maternal education as a covariate. In this analysis, education was dichotomized at less than or equal to 12 years vs. any education beyond high school. Categories with more than two education levels were considered, but due to stratification on race/ethnicity cell counts were too low to divide education into smaller bins. For example, the sample contained only two White and three Asian women with large for gestational age infants and fewer than 12 years of education, and only four

Hispanic women who had small for gestational age infants and 13 or more years of education. Furthermore, additional race-specific educational categories did not change the magnitude of association between NDI and size for gestational age.

Very few of the identified papers adjusted for individual socioeconomic position with a measure of income, poverty, or wealth in addition to education. The majority of these studies acquired data from sources like the state birth record where education was the only available measure of individual socioeconomic position. One advantage of using PRAMS data is that income and family size are both self-reported on the survey. Income, number of persons per household, and marital status allowed us to calculate individual poverty as a percent of the federal poverty level for each year stratum separately using federal poverty level guidelines specific to the year data were collected. With the goal of adjusting for individual socioeconomic position as completely as possible, we considered including private insurance status (as a marker of employment and income) and percent of the federal poverty level as covariates in the multivariate model in addition to education.

334 of 3,716 individuals with otherwise complete information on covariates were missing poverty information (income or, more rarely, number of persons per household). Other available markers of socioeconomic position, private insurance and education, were both strongly associated with percent of federal poverty level and indicated that poverty was not missing at random (Table B-2). About 36% of those missing poverty information were covered by private insurance, compared to 66% of observations with complete information. Similarly, of the group that was missing poverty information, 78%

had a high school education or lower, while only 41% of those with complete information were in the ≤12 years of education group (Table B-2).

Table B-2: Distribution of SES indicators by poverty information missingness.

	FPL missing (n=334)		FPL observed (n=3382)	
	n	%	n	%
Private insurance				
Yes	120	35.5%	2038	66.0%
No	214	64.5%	1344	34.0%
Education				
≤12 years	231	78.0%	1491	41.1%
>12 years	103	22.0%	1891	58.9%

All percentages are weighted. Ns are unweighted.

Other available markers of socioeconomic position, private insurance and education, were both strongly associated with percent of federal poverty level. For the purpose of comparing these markers of socioeconomic position, income as a percent of the federal poverty level is broken into categories of less than 100% FPL, 100-199% FPL, 200-300% FPL, and greater than 300% FPL. 78% of those with private insurance fell above 200% of the federal poverty level, and 94% of those not covered by private insurance were below 200% of the federal poverty level. Similarly, 80% of those with a high school degree or less were below 200% of the federal poverty level and 78% of those with education beyond high school were above 200% of the federal poverty level. (Table B-3).

Table B-3: Distribution of income as percent of the federal poverty level by SEP indicators.

Federal Poverty Level	Private insurance				Education			
	Yes (n=2038)		No (n=1344)		≤12 years (n=1491)		>12 years (n=1891)	
	n	%	n	%	n	%	n	%
<100%	211	7.4%	1003	74.1%	954	60.3%	260	9.0%
100-199%	342	14.2%	258	19.5%	299	19.5%	301	13.5%
200-300%	431	20.0%	57	4.9%	118	8.8%	370	19.0%
>300%	1054	58.5%	26	1.5%	120	11.3%	960	58.5%

All percentages are weighted. N's are unweighted.

Figure B-1 and the information in tables B-2 and B-3 suggest that individuals who are missing poverty information are more similar to low SEP groups than higher groups, and excluding those with missing data would bias our results. In order to assess this potential bias, we performed a single multivariate imputation of percent of federal poverty level as a continuous variable and created preliminary multivariate models for each race/ethnicity group with each size NDI while controlling for each combination of covariates shown in Table B-4.

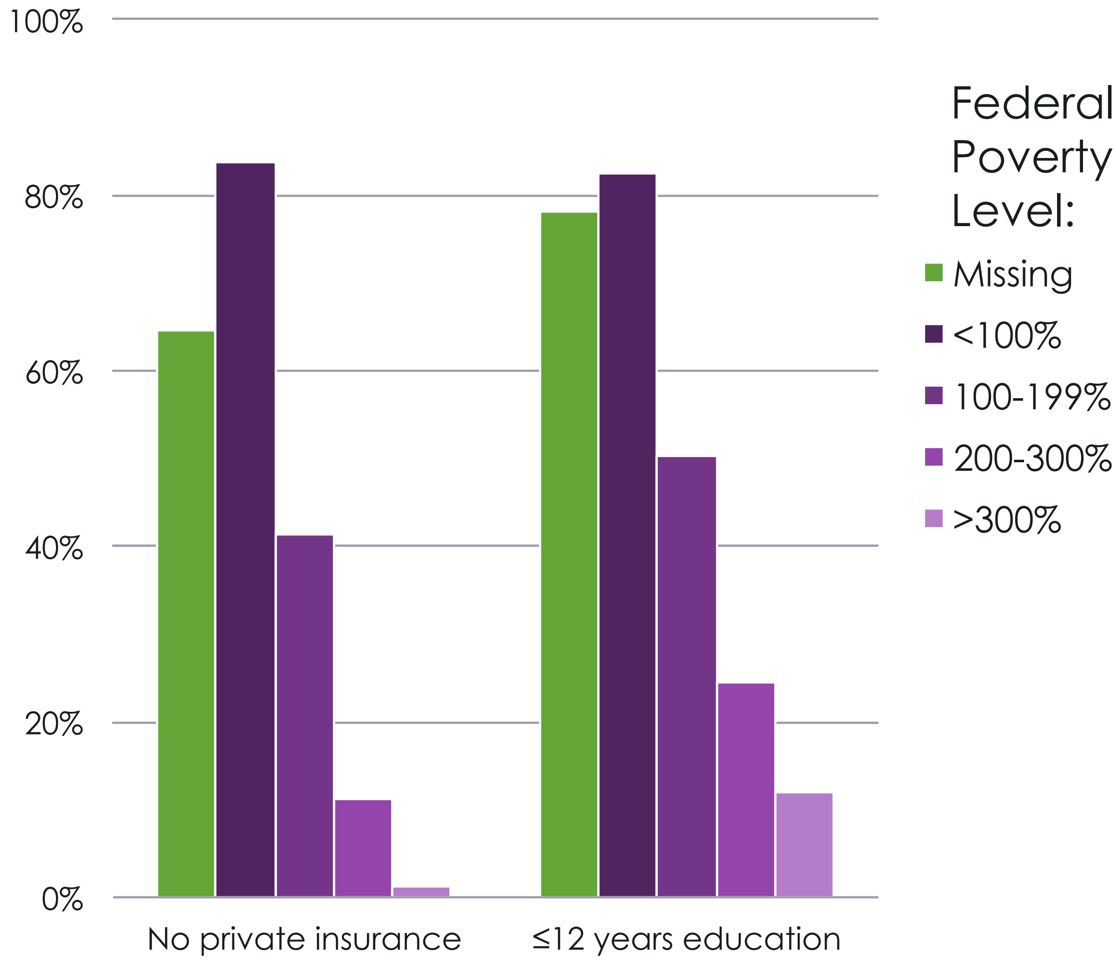

Figure B-1: Individual socioeconomic position and unreported income. Proportion of individuals within each income category (%FPL) who have no private health insurance or who have 12 or fewer years of education. Income is presented as percent of the federal poverty level and a missing category (in green) is provided for the purpose of this figure only. Individuals with unreported income are more similar to those in the lowest poverty bracket than those at higher income levels.

Table B-4: Covariates included in multivariate models to assess bias due to unreported income.

	1	2	3	4	5	6
Parity	X	X	X	X	X	X
Maternal age + (maternal age)^2	X	X	X	X	X	X
Maternal education	X	X	X	X	X	X
Private insurance status	X		X	X		X
% FPL		X	X			
% FPL with imputed values					X	X
N =	3,382	3,382	3,382	3,716	3,716	3,716

N is the sum of observations included in total for that model. Each individual model included fewer observations due to stratification by race/ethnicity group.

Table B-5: Odds of LGA and SGA for one-unit increase in NDI for models 1-3 in Table B-5

	1 km			**3 km**			**5 km**			**8 km**		
SES indicator:	ins	inc	ins+inc	ins	inc	ins+inc	ins	inc	ins+inc	ins	inc	ins+inc
Model #	1	2	3	1	2	3	1	2	3	1	2	3
NH White												
LGA	1.416	1.418	1.426	1.64	1.646	1.651	1.653	1.647	1.66	1.637	1.62	1.64
SGA	1.076	1.099	1.092	1.071	1.093	1.087	1.058	1.082	1.069	1.035	1.063	1.042
NH Black												
LGA	0.719	0.703	0.704	0.518	0.501	0.503	0.418	0.405	0.407	0.372	0.365	0.366
SGA	1.332	1.325	1.318	1.12	1.111	1.101	0.898	0.893	0.883	0.753	0.752	0.743
NH Asian												
LGA	1.149	1.097	1.093	1.1	1.033	1.034	1.038	0.962	0.968	0.984	0.901	0.91
SGA	0.966	0.981	0.983	0.986	1.011	1.007	0.957	0.987	0.978	0.975	1.009	1
Hispanic												
LGA	1.172	1.115	1.12	1.167	1.108	1.126	1.104	1.058	1.082	1.03	0.995	1.022
SGA	1.078	1.047	1.048	1.255	1.223	1.227	1.301	1.276	1.281	1.44	1.418	1.425
Native American												
LGA	1.247	1.231	1.232	1.486	1.467	1.471	1.855	1.825	1.836	2.034	2.004	2.014

***Brutally honest note: The output from the comparisons using imputed data (4-7 in table 5) includes NDI as a categorical variable, so we cannot compare those results with these. Briefly though, those results also did not change with or without income in the model.

Observations with missing income were excluded from the analysis for model 1 in tables B-4 and B-5 so that we could compare models with the same observations. The estimated odds of small for gestational age and large for gestational age for a one-unit increase in NDI from each of these models were compared (Table B-5). Estimates did not change by more than 10% between covariate sets 1, 2, or 3. The estimates were also nearly constant across covariate sets 4, 5, and 6. However, many of the estimated odds ratios produced by models excluding individuals with missing poverty information (1-3) were stronger than those that included the maximum number of observations (4-6). Therefore, the simplest model that maximized the sample size was chosen, and the final multivariate models are adjusted for a priori confounding variables parity, maternal age, maternal age^2, maternal education, and private insurance status.