Birth Outcomes in Relation to Neighborhood Food Access and Individual Food Insecurity During Pregnancy in the Environmental influences on Child Health Outcomes (ECHO)-Wide Cohort Study

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Data Availability: Data described in the manuscript, code book, and analytic code will be made available upon request pending approval.

Abbreviations

BW-for-GA: birth weight-for-gestational-age

BMI: body mass index

CRISYS-R: Crisis in Family Systems-Revised

ECHO: Environmental influences on Child Health Outcomes

FARA: Food Access Research Atlas

GA: gestational age

LGA: large-for-gestational-age

LILA: low-income-low-food-access

LILV: low-income-low-vehicle-access

SGA: small-for-gestational-age

Abstract

Background: Limited access to healthy foods, resulting from residence in neighborhoods with low food access or from household food insecurity, is a public health concern. Contributions of these measures during pregnancy to birth outcomes remain understudied.

Objective: We examined associations of neighborhood food access and individual food insecurity during pregnancy with birth outcomes.

Study design: We used data from 53 cohorts participating in the nationwide Environmental influences on Child Health Outcomes (ECHO)-Wide Cohort Study. Participant inclusion required a geocoded residential address or response to a food insecurity question during pregnancy and information on birth outcomes. Exposures include low-income-low-food-access (LILA, where nearest supermarket is >0.5 miles for urban or >10 miles for rural areas) or low-income-low-vehicle-access (LILV, where few households have a vehicle and >0.5 miles from the nearest supermarket) neighborhoods and individual food insecurity. Mixed-effects models estimated associations with birth outcomes, adjusting for socioeconomic and pregnancy characteristics.

Results: Among 22,206 pregnant participants (mean age 30.4 years) with neighborhood food access data, 24.1% resided in LILA neighborhoods and 13.6% in LILV neighborhoods. Of 1,630 pregnant participants with individual-level food insecurity data (mean age 29.7 years), 8.0% experienced food insecurity. Residence in LILA (vs. non-LILA) neighborhoods was associated with lower birth weight (β -44.3 grams; 95% CI -62.9, -25.6), lower birth weight-for-gestational-age z-score (-0.09 SD units; -0.12, -0.05), higher odds of small-for-gestational-age (OR 1.15; 95% CI 1.00, 1.33), and lower odds of large-for-gestational-age (0.85; 95% CI 0.77, 0.94).

Similar findings were observed for residence in LILV neighborhoods. No associations of individual food insecurity with birth outcomes were observed.

Conclusion: Residence in LILA or LILV neighborhoods during pregnancy is associated with adverse birth outcomes. These findings highlight the need for future studies examining whether investing in neighborhood resources to improve food access during pregnancy would promote equitable birth outcomes.

Keywords: Neighborhood Food Access; Food Insecurity; Birth Weight; Gestational Age; Health Disparities; Epidemiology

Introduction

Food insecurity, which is present when households have limited or uncertain access to adequate food because of limited money or other resources, is a persistent and intractable public health threat in the US (1). More than 10% of US families in 2021 (2) and 7% of pregnant females in 2020 (3) experienced food insecurity. While national food insecurity levels decreased from 20.6% in 2019 to 15.5% in 2021 among low-income adults, it rebounded to pre-pandemic levels (20.1%) in 2022 (4). This issue is highly concerning given the strong links between food insecurity and a range of chronic diseases (1). A 2021 meta-analysis of 35 published studies among non-pregnant adults found that food insecurity is significantly associated with greater prevalence of obesity, diabetes, coronary heart disease, and chronic kidney disease (5), likely through psychological distress and behavioral adaptations that result from food insecurity (e.g., eating a diet rich in energy dense but nutritionally poor foods) (6-8). Similarly, food insecurity around the time of pregnancy has been shown to predict adverse maternal health outcomes including poorer mental health, higher rates of obesity, excessive gestational weight gain, and gestational diabetes (9,10). Less is known about the associations of prenatal food insecurity with offspring outcomes, an important topic for study given that pregnancy is a developmentally sensitive period that lays the foundation for long-term health (11).

Many prior studies of prenatal food insecurity and birth outcomes have been performed in international settings, especially Africa (9), which may not be generalizable to the US. In the Chemicals in Our Bodies-2 birth cohort in San Francisco, household food insecurity in the 2nd trimester of pregnancy was associated with lower birth weight-for-gestational-age (BW-for-GA) z-scores, although the study was small (n=510) and based in a single urban setting (12). In the Pregnancy Risk Assessment Monitoring System study (n=50,915 pregnancies from 15 US states), mothers living in food-insecure households had higher odds of delivering a low birth weight infant (13). In a study of 1,124,299 mother-newborn pairs in Ohio, residence in a neighborhood with low food access at the time of birth was associated with higher risk of preterm birth, although the analysis was limited to females who were underweight or normal weight, which is not likely representative given that overweight and obesity are common among those living in neighborhoods with low food access (14). An analysis of births in North Carolina in 2019 reported that county-level rate of food insecurity was the strongest predictor of infant mortality (15). These studies, however, generally examined either household- or neighborhood-level metrics of food insecurity (12-14) but not both, an important aspect to consider given the inextricable relationship between the two variables (16), or did not control for individual-level socioeconomic factors (15).

To further advance knowledge on the relationship of prenatal food insecurity with birth outcomes, we analyzed data from racially, ethnically, and geographically diverse mother-child pairs enrolled in prospective birth cohorts participating in the nationwide Environmental influences on Child Health Outcomes (ECHO)-Wide Cohort Study (17). We aimed to determine the extent to which neighborhood-level food access and individual-level food insecurity during pregnancy contributed to adverse birth outcomes. We hypothesized that mothers residing in low-income and low food access (LILA) neighborhoods and/or experiencing food insecurity during pregnancy would have higher rates of preterm, small- (SGA), and large-for-gestational-age (LGA) birth, independent of individual sociodemographic characteristics.

Methods

Study Population

In its first funding cycle (2016-2023), ECHO comprised a consortium of 69 extant cohorts of children across the US that had collected information on environmental exposures before age 5 years and assessed health outcomes across childhood (17-19). Most ECHO cohorts started enrollment and recruitment from prenatal obstetric clinics or at birth (20). Recruitment of new participants and follow-up of existing cohort participants throughout childhood is ongoing in Cycle 2 (2023-2030). Investigators of participating cohorts implemented the ECHO-wide cohort data collection protocol, which specifies the data elements for new or ongoing data collection as well as extant data to be uploaded onto an ECHO-wide cohort data platform.

For this study, we used data from ECHO Cycle 1 that were harmonized and shared on the ECHO data platform. We selected ECHO cohorts with data collected between January 1, 1997, and March 1, 2023, including participants who had high-quality data on geocoded residential address (i.e., either a point or specific street address) during pregnancy or who responded to a food insecurity question, and had birth outcome data. Pregnant participants, or the child’s parents or guardians, provided written informed consent for participation in the cohort of origin, and institutional review boards (IRB) at each local study site or a central ECHO IRB approved the protocol. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline for cohort studies. The analysis plan for this study has been documented in accordance with established protocols regarding use of ECHO data (19).

Neighborhood-level food access exposure

Using ArcGIS geospatial software (Esri, Redlands, CA), the ECHO Data Analysis Center geocoded each participant’s residential address obtained during pregnancy (year of residence 1997–2022) and assigned a census tract location to each address using the 1990, 2000, 2010, or 2020 US census tract boundaries. The Data Analysis Center linked the resultant census tract location closest in time to the year of residence to census tract–level food access data from the US Food Access Research Atlas (FARA), which is the most comprehensive food environment classification in the US (21). Each census tract record in the dataset includes 16 variables that describe measures of food access in the form of urban/rural status, presence of group quarters, household income, distance to supermarket, and availability of household vehicle. In accordance with FARA definitions, we identified LILA neighborhoods (yes or no) as low-income census tracts (where the federal poverty is rate ≥20% or median family income ≤80% of the state-wide median family income) with low food access (where the nearest supermarket is >0.5 miles for urban areas or >10 miles for rural areas) (22). We also considered other definitions for LILA neighborhoods contained in FARA, including low-income census tracts where the nearest supermarket is: 1) >1 mile for urban areas or >10 miles for rural areas or 2) >1 mile for urban areas or >20 miles for rural areas (21). As vehicle access also is an important factor for determining food access, we additionally examined an indicator for low-income neighborhoods with low food and vehicle access (LILV, yes or no) contained in FARA, defined as low-income census tracts where more than 100 housing units do not have a vehicle and are >0.5 miles from the nearest supermarket.

Individual-level food insecurity exposure

We assessed individual-level food insecurity during pregnancy using the Crisis in Family Systems-Revised (CRISYS-R) questionnaire, a validated measure of contemporary life stress. This questionnaire was originally developed in a population of adult primary caregivers of children residing in low-income urban areas in the US (23), and has since been validated more broadly across US populations (24,25). The CRISYS-R includes 80 items from 12 domains encompassing financial, legal, relationship, medical issues pertaining to one’s self, medical issues pertaining to others, community safety, safety in the home, housing, career, prejudice, authority, and acculturation (24). During late pregnancy (mean 30.5 gestational weeks), mothers responded to the following food insecurity question: "*In the past year, did you go without food because you didn't have the money to pay for it?*". We categorized respondents who answered "yes" to the question as food insecure, and those who responded "no" as food secure.

Birth Outcomes

We obtained information on the following birth outcomes from hospital medical records or self-report, according to the protocol for each cohort: gestational age (GA, in completed weeks), preterm birth (GA <37 weeks), and birth weight (BW, in grams). We do not anticipate any bias from using self-reported birth outcomes, as prior studies (26,27) have shown high agreement for birth outcomes obtained by self-report vs. medical records. We derived sex-specific BW-for-GA z-scores, small-for-GA (SGA; BW-for-GA ≤10th percentile), and large-for-GA (LGA; BW-for-GA ≥90th percentile) using the 2017 US birth weight reference (28). We chose this reference as it reflects nationally representative data on birth weight and obstetric estimates of GA in the US.

Covariates

We obtained information on characteristics of mothers and children from maternal or caregiver reports (maternal age, education level during pregnancy, number of individuals in a household, insurance status, prenatal cigarette smoking or secondhand smoke exposure, race and ethnicity) or medical records (pre-pregnancy body mass index (BMI), parity, and child sex) and categorized them as follows: maternal age (in years) and education level during pregnancy (less than high school, high school diploma or equivalent, some college but no degree, or college degree and above), number of individuals in a household (1-2, 3-4, or 5+), insurance status

(Medicaid, private, any other insurance, or no insurance), pre-pregnancy BMI (in kg/m^2), prenatal cigarette smoking or secondhand smoke exposure (yes or no), parity (0, 1-2, or 3+), and child's sex (male or female), race (American Indian or Alaskan Native, Asian, Black, Native Hawaiian or Pacific Islander, White, multiple races, or other race), Hispanic ethnicity, and year of residential address during pregnancy (1997–2007, 2008–2010, 2011–2019, or 2020–2022). Due to the small sample size, we combined children whose races were reported as American Indian or Alaskan Native, Native Hawaiian or Pacific Islander, multiple races, or other racial groups into a separate category of "Other." We used data on urban/rural status of a census tract contained in FARA, whereby a census tract is considered urban if the tract is in an area with >2,500 people and rural if the tract is in an area with ≤2,500 people.(29) We selected these covariates based on previous publications examining associations between food insecurity and health outcomes.(1,12-14)

Statistical Analysis

In our main analyses, we used multilevel linear and logistic regression models to examine associations of neighborhood-level food access and individual-level food insecurity with continuous (GA, BW, BW-for-GA z-scores) and dichotomous birth outcomes (preterm birth, SGA, LGA), adjusting for the covariates described above except for race and ethnicity. We did so as we view race and ethnicity as societal constructs, rather than deterministic biological causes of disease risk (30). Prior work (31) has suggested that membership in a particular racial group is a measure of structural racism and the resources (or lack thereof) attributed to this assigned membership may have downstream impact on access to residential location, food, and healthcare resources likely associated with health outcomes. Hence, including race and ethnicity as covariates may result in an over-adjustment of the associations of food access or food insecurity with birth outcomes.

We fit separate models for neighborhood-level food access and individual-level food insecurity with each birth outcome. In all models, we included random effects for cohort to account for clustering of children from the same cohort. In models for neighborhood-level food access, we additionally included random effects for census tract to account for clustering of children residing within the same neighborhood.

We conducted several secondary analyses. We conducted a series of "leave-one-out" analyses, which repeated the main analysis excluding one cohort at a time to ensure that no single cohort substantially swayed the findings. In a separate model, we additionally adjusted for race and ethnicity to examine whether its inclusion would meaningfully change effect estimates. We restricted our analyses for neighborhood-level food access to residential addresses obtained during or after 2014 to address potential misclassification, as we used FARA measures for the years 2015 and 2019. We explored effect modification by child's sex, race, birth year, and urban/rural status by adding multiplicative interaction terms with neighborhood-level food access. We also explored the extent to which the associations for individual-level food insecurity may be modified by neighborhood-level food access, by including interaction terms between both variables among those with information on both.

We used multiple imputation by chained equations to impute missing covariate data (see **Table 1**). We generated 50 imputed data sets for all participants in the analytic sample. The imputation model included the exposure, outcome, and covariates under study. We combined the imputed data sets using the pool function in R software, version 4.2.2. When interpreting findings, we focused primarily on the direction, strength, and precision of the estimates and used 2-sided α = 0.05 to assess statistical significance.

Results

Of 69 ECHO cohorts, we included 53 with 22,206 participants (mean age 30.4 years, SD 5.7) that had neighborhood-level food access data and information on birth outcomes (**Supplementary Figures 1** and **2**). Among pregnant individuals with neighborhood-level food access data, 3.1% identified as Asian, 13.7% Black, 11.1% Other race, 12.4% unknown race, 59.5% White, 19.3% Hispanic, and 7.2% unknown ethnicity; and 52.6% had at least a college degree (**Supplementary Table 1**). Additionally, 24.1% resided in LILA neighborhoods and 13.6% resided in LILV neighborhoods; the mean (SD) GA at birth was 38.3 (3.0) weeks and BW-for-GA z-score was 0.04 (1.08) SD units. The prevalence of preterm birth was 11.3%, SGA 6.1%, and LGA 16.7%. (**Supplementary Table 2**). Our sample also included 6 cohorts with 1,630 participants (mean age 29.7 years, SD 5.8) that had individual food insecurity data (**Supplementary Figures 1** and **2**), of which 8.0% reported experiencing food insecurity and 98.5% (n=1,606) also had neighborhood-level food access data. Participants residing in LILA neighborhoods or experiencing food insecurity were more likely to identify as Black and were less likely have a college degree or have private insurance (**Table 1**).

In models adjusted for year of residential address only (**Figure 1,** Model 1), residence in LILA (vs. non-LILA) neighborhoods during pregnancy was associated with lower GA, BW, and BW-for-GA z-score. After additionally adjusting for socioeconomic and pregnancy characteristics (**Figure 1,** Model 2), these associations were attenuated but remained statistically significant for BW (β -44.3 grams; 95% CI -62.9, -25.6) and BW-for-GA z-score (β -0.09 SD units; 95% CI -0.12, -0.05) but not for GA. Residence in LILA (vs. non-LILA) neighborhoods during pregnancy also was significantly associated with higher odds of SGA (OR 1.15; 95% CI 1.00, 1.33) and lower odds of LGA (OR 0.85; 95% CI 0.77, 0.94) (**Figure 2**). These associations remained largely similar for alternative definitions of LILA neighborhoods, albeit with wider 95% CI that crossed the null for SGA and LGA outcomes (**Figures 1** and **2**). Residence in LILV (vs. non-LILV) neighborhoods also was significantly associated with lower BW (β -45.6 grams; 95% CI -69.3, -24.4), lower BW-for-GA z-score (β -0.12 SD units; 95% CI -0.16, -0.07), higher odds of SGA (OR 1.26; 95% CI 1.07, 1.48), and lower odds of LGA (OR 0.80; 95% CI 0.71, 0.92) in adjusted models (**Supplementary Table 3**).

In models adjusted for year of residential address only (**Figure 3,** Model 1), point estimates showed that individual-level food insecurity during pregnancy was associated with lower BW (β -63.8 grams; 95% CI -166.3, 38.8) and GA (β -0.30 weeks; 95% CI -0.66, 0.05), lower odds of LGA (OR 0.65; 95% CI 0.36, 1.15), and higher odds of preterm birth (OR 1.39; 95% CI 0.80, 2.41). However, owing to the smaller sample size, these associations were imprecise with wide 95% CI that crossed the null. These associations did not change substantively after adjusting for socioeconomic characteristics (**Figure 3,** Model 2 and **Supplementary Table 3**).

In the “leave-one-out” analyses, the association of residence in LILV neighborhoods with lower BW-for-GA and lower odds of LGA did not substantially differ from our main analyses (**Supplementary Figures 3** and **4**). However, the associations of residence in LILA or LILV neighborhoods with adverse birth outcomes (i.e., lower BW-for-GA and higher odds of SGA) were substantially attenuated to non-significance after additionally adjusting for race and ethnicity (**Figures 1** and **2**, Model 3), except for the association of residence in LILV neighborhoods with lower BW-for-GA z-score (β -0.04 SD units; 95% CI -0.09, 0.00). The association of individual-level food insecurity during pregnancy with birth outcomes did not change after additional adjustment for race and ethnicity (**Figure 3,** Model 3). When restricting analyses to residential addresses obtained during or after 2014, the associations of residence in LILA or LILV neighborhoods with adverse birth outcomes were similar with our main analyses, albeit with wider 95% CI, which might be attributed to the smaller sample size (**Supplementary Table 4**). No clear evidence of effect modification by child sex, race, urban/rural status, and year of residential address was present (**Supplementary Figures 5** to **8**). We did observe that residence in LILV neighborhoods during pregnancy was significantly associated with lower odds of LGA (OR 0.75; 95% CI 0.59, 0.96) among Black mothers only. The association of individual-level food insecurity during pregnancy with birth outcomes also did not appear to be modified by neighborhood-level food access (**Supplementary Figure 9**).

Discussion

In this nationwide study, we observed that residence in LILA or LILV neighborhoods during pregnancy was associated with adverse birth outcomes of lower BW and BW-for-GA z-score, and higher odds of SGA. These associations were independent of socioeconomic and pregnancy characteristics previously associated with adverse birth outcomes. Additional adjustment for race and ethnicity meaningfully attenuated these associations to non-significance. To the extent that the self-reported social constructs of race and ethnicity reflect proxy measures of structural racism (30-33), this finding suggests that structural racism is related to the inequitable distribution of individuals in LILA or LILV neighborhoods, due to the influence of historic and contemporary policies and practices such as race-based residential segregation (34). Moreover, structural racism may be related to differential exposure to factors that would negatively affect birth outcomes, such as access to health care services and resources (35), environmental chemicals (36), violence and crime (37), or other features. In fact, prior studies (38,39) have demonstrated how inclusion of race and ethnicity as a covariate eliminated the predictive value of objectively assessed neighborhood quality and violent crime on child mental health outcomes, potentially misleading researchers to believe the neighborhood does not matter for health outcomes. Altogether, these findings exemplify how adjustment for race and ethnicity may be inappropriate (40,41) and could impede efforts that seek to better understand differences in birth outcomes according to neighborhood food access during pregnancy.

Our results for neighborhood food access during pregnancy and birth outcomes generally align with prior studies from both developed and developing countries, although specific neighborhood food access metrics have varied. In the US, two studies in South Carolina (42) and New York (43) showed that residence in neighborhoods with greater access to unhealthy foods was associated with lower BW and GA and higher risk of SGA. Lane *et al*. reported that in New York, females who resided in neighborhoods without a supermarket within 1.5-miles were three times more likely to have low BW newborns (44). In Canada, Savard *et al*. reported that the odds of SGA birth were higher in neighborhoods with a high proportion of residents who were experiencing food insecurity (45). In Brazil, females living in municipalities with limited access to healthy foods had higher risk of having SGA or low BW newborns (46). These studies and others, however, were largely cross-sectional in study design (42,43,45,46), limited by smaller sample sizes (12,44), or lacked geographical diversity (12,14,15,42-44) as they were conducted only within a single US state. Our study directly addressed these key research gaps by assembling a large and geographically diverse cohort of participants that is more generalizable to the US population (see **Supplementary Figure 1**). Taken together, our findings contribute substantially to the small but growing body of evidence linking neighborhood food environment in early life with birth outcomes.

We did not observe significant associations of individual-level food insecurity with birth outcomes, although effect estimates were in the hypothesized directions for GA and BW. This observation could likely be because the sample size for the analysis of individual-level food insecurity was smaller and thus, statistical power and precision may have been limited. Moreover, the lack of association between individual-level food insecurity and birth outcomes might stem from the fact that we ascertained food insecurity from only a single question in the CRISYS-R questionnaire. This question likely excludes individuals with less severe forms of food insecurity and may be less sensitive than the 18-item US Household Food Security Survey (47), which assesses food insecurity more comprehensively.

Several potential mechanisms could explain our observations. First, the neighborhood food environment (i.e., availability and/or accessibility of healthy and unhealthy foods) plays an important role in influencing the diet quality of pregnant females (48) which may subsequently affect birth outcomes. Notably, a previous study in ECHO reported higher risk of inadequate micronutrient intake during pregnancy among participants of non-White race or Hispanic ethnicity or those with less than a high school education (49), a demographic previously shown to more likely reside in neighborhoods with unhealthy food environments (43). Substantive evidence has shown that fetal growth is vulnerable to dietary deficiencies of nutrients during pregnancy (50). Second, neighborhoods with low access to supermarkets, supercenters, or large grocery stores might, in turn, have greater access to smaller convenience stores (51), which implies greater access to and consumption of other harmful substances that are known to negatively affect fetal growth, including highly processed foods that contain endocrine disrupting chemicals, alcohol, and tobacco (52-54). Finally, low-income neighborhoods with low food access could simply reflect disadvantaged neighborhood environments with higher rates of other social (e.g., poverty and violent crime) and environmental (e.g., toxic chemicals, traffic-related air pollutants) stressors that can affect pregnancy health and wellbeing. Hence, beyond affecting diet quality of pregnant females, it is possible that residence in LILA or LILV neighborhoods may negatively affect birth outcomes through increased psychological stress (55), increased exposure to environmental pollutants (56), or other factors. While this is beyond the scope of the current study, future studies in ECHO or other settings could be done to explore these potential mechanisms.

Strengths of our study include the large sample size and wide range of covariates. We used neighborhood food access indices that have been validated for a wide range of health outcomes (22,57,58). We were also able to control for individual-level factors (e.g., mother's education level and insurance status) that may likely influence residential selection. This study, however, has several limitations. First, we used residential census tracts as a marker of exposure, which may not capture the relevant areas where pregnant females spend most of their time. Second, certain covariates (e.g., education level during pregnancy) had a substantial percentage of missing data, which may have impacted our findings. However, we used flexible multiple imputation techniques that reduce bias and likelihood of spurious results. Third, despite our efforts to adjust for multiple covariates, we cannot exclude the possibility that residual confounding by unmeasured risk factors of birth outcomes could explain our observations. Fourth, we used FARA information for 2015 and 2019 which may be misclassified for residential addresses during the 1990s or 2000s. However, results for LILA or LILV restricted to residential addresses obtained during or after the year 2014 were similar to our main findings.

Fifth, our findings may not be generalizable to other ethnic groups and populations from different countries, since all participants in this study were from the US. Finally, this study did not consider how residential mobility during pregnancy may influence changes in neighborhood food access over time and whether such changes may alter birth outcomes. Although this question is beyond the scope of the current study, follow-up studies in ECHO investigating these associations will be considered to evaluate its impact on birth outcomes.

Conclusion

The results of this cohort study of over 20,000 pregnancies enrolled in more than 50 cohorts across the US suggest that residence in low-income neighborhoods with low food access or low vehicle access during pregnancy is associated with adverse birth outcomes. These findings suggest that developing strategies to improve healthful food access during pregnancy, a sensitive period for maternal and fetal health, may promote equitable birth outcomes in the US. A variety of strategies might be needed, such as improving neighborhood food access, policies directed at those living in low access neighborhoods to improve food affordability, or efforts to directly provide healthful food during pregnancy. Given the long-term effects of adverse birth outcomes on later cardiovascular disease risk in adolescence (59) and adulthood (60,61), additional research is warranted to evaluate interventions and policies that would be most effective in improving birth outcomes and promoting child health.

Author Contributions

The authors' responsibilities were as follows – IMA, PDL, EO: developed the concept and design; IMA, PDL: acquired or analyzed the data; IMA, EO: drafted the manuscript and had primary responsibility for the final content; AJW, DD, BML, RJW, MRK, JMK, ALD, CLMJ, CACJ, JMG, RJS, RSS, CTM, AEH, TMO, LAM, LEM, ZN, AF, YZ, RFC, EWK, NRB, RHNN, KNC, ESB, KL, LMS-T, LT, JMB, CVB, MAP, BC, NA-O, MRK, TJT :contributed to the interpretation of the findings; and all authors: read and approved the final manuscript.

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References

1. Gundersen C, Ziliak JP. Food Insecurity And Health Outcomes. *Health Aff (Millwood).* 2015;34(11):1830-1839.

2. US Department of Agriculture Economic Research Service. Key Statistics & Graphics. https://www.ers.usda.gov/topics/food-nutrition-assistance/food-security-in-the-u-s/key-statistics-graphics/. Published 2021. Accessed March 1st, 2023.

3. Hinkle SN, Dolin CD, Keddem S, Kinsey EW. Patterns in Food Insecurity During Pregnancy, 2004 to 2020. *JAMA Netw Open.* 2023;6(7):e2324005.

4. Troy AL, Ahmad I, Zheng Z, Wadhera RK. Food Insecurity Among Low-Income U.S. Adults During the COVID-19 Pandemic. *Ann Intern Med.* 2024.

5. Te Vazquez J, Feng SN, Orr CJ, Berkowitz SA. Food Insecurity and Cardiometabolic Conditions: a Review of Recent Research. *Curr Nutr Rep.* 2021;10(4):243-254.

6. Seligman HK, Schillinger D. Hunger and socioeconomic disparities in chronic disease. *N Engl J Med.* 2010;363(1):6-9.

7. Hails KA, Zhou Y, Shaw DS. The Mediating Effect of Self-Regulation in the Association Between Poverty and Child Weight: A Systematic Review. *Clin Child Fam Psychol Rev.* 2019;22(3):290-315.

8. Palakshappa D, Ip EH, Berkowitz SA, Bertoni AG, Foley KL, Miller DP, Jr., et al. Pathways by Which Food Insecurity Is Associated With Atherosclerotic Cardiovascular Disease Risk. *J Am Heart Assoc.* 2021;10(22):e021901.

9. Augusto ALP, de Abreu Rodrigues AV, Domingos TB, Salles-Costa R. Household food insecurity associated with gestacional and neonatal outcomes: a systematic review. *BMC Pregnancy Childbirth.* 2020;20(1):229.

10. Laraia BA, Siega-Riz AM, Gundersen C. Household food insecurity is associated with self-reported pregravid weight status, gestational weight gain, and pregnancy complications. *J Am Diet Assoc.* 2010;110(5):692-701.

11. Aris IM, Fleisch AF, Oken E. Developmental Origins of Disease: Emerging Prenatal Risk Factors and Future Disease Risk. *Curr Epidemiol Rep.* 2018;5(3):293-302.

12. Goin DE, Izano MA, Eick SM, Padula AM, DeMicco E, Woodruff TJ, et al. Maternal Experience of Multiple Hardships and Fetal Growth: Extending Environmental Mixtures Methodology to Social Exposures. *Epidemiology.* 2021;32(1):18-26.

13. De Silva DA, Thoma ME, Anderson EA, Kim J. Infant Sex-Specific Associations between Prenatal Food Insecurity and Low Birthweight: A Multistate Analysis. *J Nutr.* 2022;152(6):1538-1548.

14. Madzia J, McKinney D, Kelly E, DeFranco E. Influence of Gestational Weight Gain on the Risk of Preterm Birth for Underweight Women Living in Food Deserts. *Am J Perinatol.* 2021;38(S 01):e77-e83.

15. Cassidy-Vu L, Way V, Spangler J. The correlation between food insecurity and infant mortality in North Carolina. *Public Health Nutr.* 2022;25(4):1038-1044.

16. Shaker Y, Grineski SE, Collins TW, Flores AB. Redlining, racism and food access in US urban cores. *Agric Human Values.* 2023;40(1):101-112.

17. Knapp EA, Kress AM, Parker CB, Page GP, McArthur K, Gachigi KK, et al. The Environmental influences on Child Health Outcomes (ECHO)-wide Cohort. *Am J Epidemiol.* 2023;192(8):1249-1263.

18. Blaisdell CJ, Park C, Hanspal M, Roary M, Arteaga SS, Laessig S, et al. The NIH ECHO Program: investigating how early environmental influences affect child health. *Pediatr Res.* 2022;92(5):1215-1216.

19. LeWinn KZ, Caretta E, Davis A, Anderson AL, Oken E, program collaborators for Environmental influences on Child Health O. SPR perspectives: Environmental influences on Child Health Outcomes (ECHO) Program: overcoming challenges to generate engaged, multidisciplinary science. *Pediatr Res.* 2022;92(5):1262-1269.

20. Gillman MW, Blaisdell CJ. Environmental influences on Child Health Outcomes, a Research Program of the National Institutes of Health. *Curr Opin Pediatr.* 2018;30(2):260-262.

21. U.S. Department of Agriculture Economic Research Service. Food Access Research Atlas. https://www.ers.usda.gov/data-products/food-access-research-atlas/documentation/. Published 2019. Accessed March 1st, 2023.

22. Berkowitz SA, Karter AJ, Corbie-Smith G, Seligman HK, Ackroyd SA, Barnard LS, et al. Food Insecurity, Food "Deserts," and Glycemic Control in Patients With Diabetes: A Longitudinal Analysis. *Diabetes Care.* 2018;41(6):1188-1195.

23. Shalowitz MU, Berry CA, Rasinski KA, Dannhausen-Brun CA. A new measure of contemporary life stress: development, validation, and reliability of the CRISYS. *Health Serv Res.* 1998;33(5 Pt 1):1381-1402.

24. Berry C, Shalowitz M, Quinn K, Wolf R. Validation of the Crisis in Family Systems-Revised, a contemporary measure of life stressors. *Psychol Rep.* 2001;88(3 Pt 1):713-724.

25. Sherlock P, Shalowitz MU, Berry C, Cella D, Blackwell CK, Cowell W, et al. A short form of the Crisis in Family Systems (CRISYS) in a racially diverse sample of pregnant women. *Curr Psychol.* 2023;42(10):8393-8401.

26. Dietz P, Bombard J, Mulready-Ward C, Gauthier J, Sackoff J, Brozicevic P, et al. Validation of self-reported maternal and infant health indicators in the Pregnancy Risk Assessment Monitoring System. *Matern Child Health J.* 2014;18(10):2489-2498.

27. Wise LA, Wang TR, Wesselink AK, Willis SK, Chaiyasarikul A, Levinson JS, et al. Accuracy of self-reported birth outcomes relative to birth certificate data in an Internet-based prospective cohort study. *Paediatr Perinat Epidemiol.* 2021;35(5):590-595.

28. Aris IM, Kleinman KP, Belfort MB, Kaimal A, Oken E. A 2017 US Reference for Singleton Birth Weight Percentiles Using Obstetric Estimates of Gestation. *Pediatrics.* 2019;144(1).

29. Hall SA, Kaufman JS, Ricketts TC. Defining urban and rural areas in U.S. epidemiologic studies. *J Urban Health.* 2006;83(2):162-175.

30. Flanagin A, Frey T, Christiansen SL, Committee AMAMoS. Updated Guidance on the Reporting of Race and Ethnicity in Medical and Science Journals. *JAMA.* 2021;326(7):621-627.

31. Howe CJ, Bailey ZD, Raifman JR, Jackson JW. Recommendations for Using Causal Diagrams to Study Racial Health Disparities. *Am J Epidemiol.* 2022;191(12):1981-1989.

32. Nuriddin A, Mooney G, White AIR. Reckoning with histories of medical racism and violence in the USA. *Lancet.* 2020;396(10256):949-951.

33. Bryant BE, Jordan A, Clark US. Race as a Social Construct in Psychiatry Research and Practice. *JAMA Psychiatry.* 2022;79(2):93-94.

34. Bailey ZD, Krieger N, Agenor M, Graves J, Linos N, Bassett MT. Structural racism and health inequities in the USA: evidence and interventions. *Lancet.* 2017;389(10077):1453-1463.

35. Fong KC, Yitshak-Sade M, Lane KJ, Fabian MP, Kloog I, Schwartz JD, et al. Racial Disparities in Associations between Neighborhood Demographic Polarization and Birth Weight. *Int J Environ Res Public Health.* 2020;17(9).

36. Bloom MS, Wenzel AG, Brock JW, Kucklick JR, Wineland RJ, Cruze L, et al. Racial disparity in maternal phthalates exposure; Association with racial disparity in fetal growth and birth outcomes. *Environ Int.* 2019;127:473-486.

37. Holaday LW, Tolliver DG, Moore T, Thompson K, Wang EA. Neighborhood Incarceration Rates and Adverse Birth Outcomes in New York City, 2010-2014. *JAMA Netw Open.* 2023;6(3):e236173.

38. Ahmad SI, Rudd KL, LeWinn KZ, Mason WA, Murphy L, Juarez PD, et al. Maternal childhood trauma and prenatal stressors are associated with child behavioral health. *J Dev Orig Health Dis.* 2022;13(4):483-493.

39. Norona-Zhou A, Coccia M, Sullivan A, O'Connor TG, Collett BR, Derefinko K, et al. A Multi-Cohort Examination of the Independent Contributions of Maternal Childhood Adversity and Pregnancy Stressors to the Prediction of Children's Anxiety and Depression. *Res Child Adolesc Psychopathol.* 2023;51(4):497-512.

40. Kuban KCK, Boynton-Jarrett R, Heeren T, O'Shea TM. A Consideration of Racism in Pediatric Epidemiologic Studies. *J Pediatr.* 2021;239:225-227.

41. Duncan AF, Montoya-Williams D. Recommendations for Reporting Research About Racial Disparities in Medical and Scientific Journals. *JAMA Pediatr.* 2024.

42. Ma X, Liu J, Hardin JW, Zhao G, Liese AD. Neighborhood Food Access and Birth Outcomes in South Carolina. *Matern Child Health J.* 2016;20(1):187-195.

43. Kinsey EW, Widen EM, Quinn JW, Huynh M, Van Wye G, Lovasi GS, et al. Neighborhood Food Environment and Birth Weight Outcomes in New York City. *JAMA Netw Open.* 2023;6(6):e2317952.

44. Lane SD, Keefe RH, Rubinstein R, Levandowski BA, Webster N, Cibula DA, et al. Structural violence, urban retail food markets, and low birth weight. *Health Place.* 2008;14(3):415-423.

45. Savard N, Levallois P, Rivest LP, Gingras S. Impact of individual and ecological characteristics on small for gestational age births: an observational study in Quebec. *Chronic Dis Inj Can.* 2014;34(1):46-54.

46. Victor A, Gotine ARM, Falcao IR, Ferreira AJF, Flores-Ortiz R, Xavier SP, et al. Association between food environments and fetal growth in pregnant Brazilian women. *BMC Pregnancy Childbirth.* 2023;23(1):661.

47. Radimer KL, Radimer KL. Measurement of household food security in the USA and other industrialised countries. *Public Health Nutr.* 2002;5(6A):859-864.

48. Laraia BA, Siega-Riz AM, Kaufman JS, Jones SJ. Proximity of supermarkets is positively associated with diet quality index for pregnancy. *Prev Med.* 2004;39(5):869-875.

49. Sauder KA, Harte RN, Ringham BM, Guenther PM, Bailey RL, Alshawabkeh A, et al. Disparities in Risks of Inadequate and Excessive Intake of Micronutrients during Pregnancy. *J Nutr.* 2021;151(11):3555-3569.

50. Kheirouri S, Alizadeh M. Maternal dietary diversity during pregnancy and risk of low birth weight in newborns: a systematic review. *Public Health Nutr.* 2021;24(14):4671-4681.

51. Farley TA, Mason K, Rice J, Habel JD, Scribner R, Cohen DA. The relationship between the neighbourhood environment and adverse birth outcomes. *Paediatr Perinat Epidemiol.* 2006;20(3):188-200.

52. Dejong K, Olyaei A, Lo JO. Alcohol Use in Pregnancy. *Clin Obstet Gynecol.* 2019;62(1):142-155.

53. Abraham M, Alramadhan S, Iniguez C, Duijts L, Jaddoe VW, Den Dekker HT, et al. A systematic review of maternal smoking during pregnancy and fetal measurements with meta-analysis. *PLoS One.* 2017;12(2):e0170946.

54. Zota AR, Phillips CA, Mitro SD. Recent Fast Food Consumption and Bisphenol A and Phthalates Exposures among the U.S. Population in NHANES, 2003-2010. *Environ Health Perspect.* 2016;124(10):1521-1528.

55. Shannon MM, Clougherty JE, McCarthy C, Elovitz MA, Nguemeni Tiako MJ, Melly SJ, et al. Neighborhood Violent Crime and Perceived Stress in Pregnancy. *Int J Environ Res Public Health.* 2020;17(15).

56. Padula AM, Ning X, Bakre S, Barrett ES, Bastain T, Bennett DH, et al. Birth Outcomes in Relation to Prenatal Exposure to Per- and Polyfluoroalkyl Substances and Stress in the Environmental Influences on Child Health Outcomes (ECHO) Program. *Environ Health Perspect.* 2023;131(3):37006.

57. Moughames E, Woo H, Galiatsatos P, Romero-Rivero K, Raju S, Tejwani V, et al. Disparities in access to food and chronic obstructive pulmonary disease (COPD)-related outcomes: a cross-sectional analysis. *BMC Pulm Med.* 2021;21(1):139.

58. Isokpehi RD, Johnson MO, Campos B, Sanders A, Cozart T, Harvey IS. Knowledge Visualizations to Inform Decision Making for Improving Food Accessibility and Reducing Obesity Rates in the United States. *Int J Environ Res Public Health.* 2020;17(4).

59. Gamborg M, Byberg L, Rasmussen F, Andersen PK, Baker JL, Bengtsson C, et al. Birth weight and systolic blood pressure in adolescence and adulthood: meta-regression analysis of sex- and age-specific results from 20 Nordic studies. *Am J Epidemiol.* 2007;166(6):634-645.

60. de Mendonca E, de Lima Macena M, Bueno NB, de Oliveira ACM, Mello CS. Premature birth, low birth weight, small for gestational age and chronic non-communicable diseases in adult life: A systematic review with meta-analysis. *Early Hum Dev.* 2020;149:105154.

61. Mohseni R, Mohammed SH, Safabakhsh M, Mohseni F, Monfared ZS, Seyyedi J, et al. Birth Weight and Risk of Cardiovascular Disease Incidence in Adulthood: a Dose-Response Meta-analysis. *Curr Atheroscler Rep.* 2020;22(3):12.

Table 1: Participant characteristics according to neighborhood food access (non-LILA vs. LILA) and individual food insecurity status (no vs. yes).

	Neighborhood-level food access (N=22,206)		**Individual-level food insecurity (N=1,630)**	
	Non-LILA[a] (N=19,196)	**LILA[a] (N=3,010)**	**No[a] (N=1,501)**	**Yes[a] (N=129)**
Child sex				
Female	48.4%	48.3%	48.4 %	51.6%
Male	51.6%	52.7%	51.6%	48.4%
Ethnicity				
Hispanic	19.6%	17.2%	35.2%	45.0%
Non-Hispanic	72.8%	78.1%	54.3%	33.3%
Unknown	7.6%	4.7%	10.5%	21.7%
Race				
Asian	3.4%	1.4%	2.1%	1.6%
Black	9.6%	40.2%	22.6%	25.6%
Other (American Indian or Alaskan Native, Native Hawaiian or Pacific Islander, multiple races, or other race)	10.8%	13.1%	11.6%	9.3%
Unknown	13.2%	7.5%	26.7%	38.8%
White	62.9%	37.8%	37.0%	24.8%
Education level during pregnancy				
Less than high school	7.5%	14.3%	17.1%	35.7%
High school degree or equivalent	14.8%	31.5%	21.2%	25.8%
Some college, no degree	21.6%	26.7%	27.1%	26.6%
College degree and above	56.1%	27.5%	34.6%	11.9%
Prenatal smoking or secondhand smoke exposure				
No	74.9%	58.7%	74.1%	70.4%
Yes	25.1%	41.3%	25.9%	29.6%
Insurance status during pregnancy				
Medicaid	10.5%	21.9%	31.1%	44.8%
Private	87.5%	76.2%	63.6%	50.7%
Any other insurance	1.3%	0.6%	3.9%	3.4%
No insurance	0.6%	1.3%	1.3%	1.1%
Year of residential address				
1997-2007	12.2%	20.2%	26.1%	27.1%
2008-2010	11.4%	15.2%	1.0%	1.6%
2011-2019	64.7%	57.7%	62.8%	53.5%
2020-2022	11.7%	6.8%	10.2%	17.8%
Urban/rural status				
Rural	21.0%	6.1%	8.1%	5.7%
Urban	79.0%	93.9%	91.9%	94.3%
Parity				
0	76.4%	64.6%	68.8%	68.6%
1-2	19.5%	27.1%	24.4%	23.6%

3+	4.2%	8.2%	6.8%	7.8%
No. of individuals in household				
1-2	65.5%	61.0%	54.3%	50.1%
3-4	27.0%	24.3%	31.8%	35.2%
5+	7.5%	14.7%	13.8%	14.7%
Maternal age (years)	30.8 (5.6)	27.6 (5.7)	29.8 (5.8)	28.3 (5.6)
Pre-pregnancy BMI (kg/m^2)	26.8 (6.8)	29.1 (8.4)	28.1 (7.4)	28.8 (8.1)

Abbreviations: BMI – body mass index; LILA – low income, low food access.

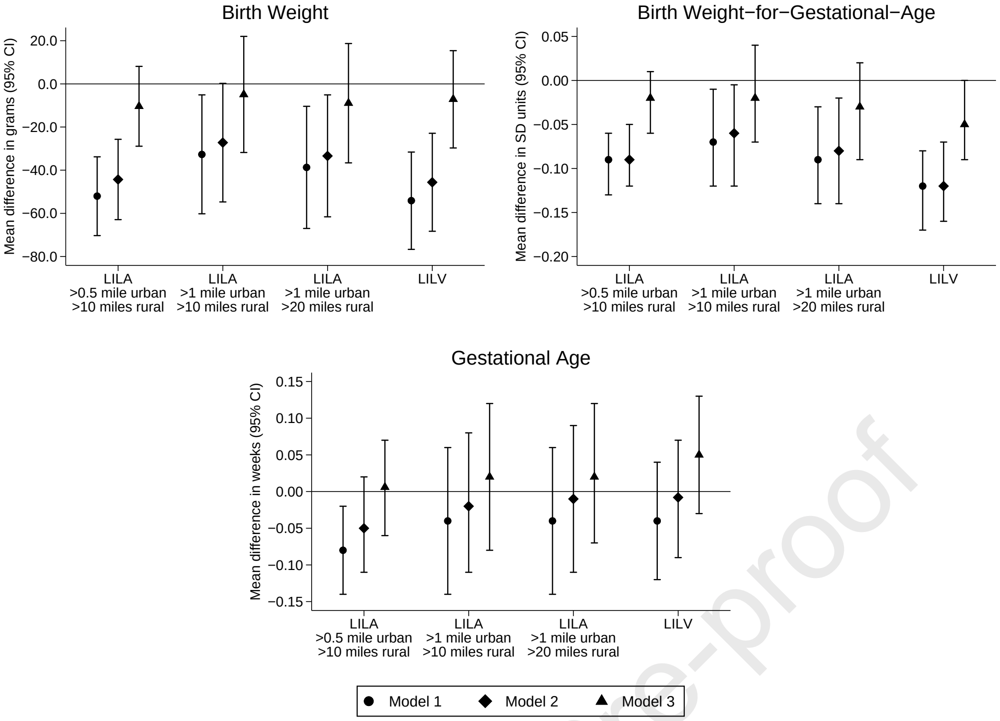
[a] % calculated using imputed data

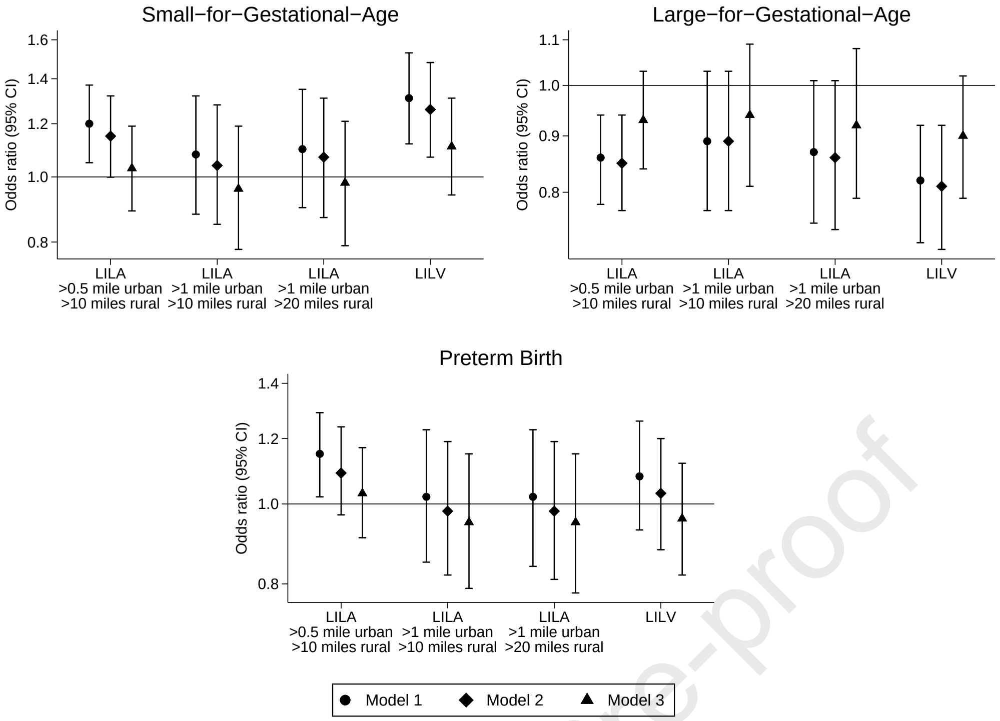
Figure Legends

Figure 1: Associations of neighborhood-level food access with birth weight, birth weight-for-gestational-age, and gestational age. LILA = low-income, low food access. LILV = low-income, low food and vehicle access. Model 1: adjusted for year of residential address during pregnancy. Model 2: Model 1 + age, educational level during pregnancy, number of individuals in a household, insurance status, pre-pregnancy body mass index, prenatal cigarette smoking or secondhand smoke exposure, parity, and child sex. Model 3: Model 2 + race and ethnicity.

Figure 2: Association of neighborhood-level food access with small-for-gestational-age, large-for-gestational-age, and preterm birth. LILA = low-income, low food access. LILV = low-income, low food and vehicle access. Model 1: adjusted for year of residential address during pregnancy. Model 2: Model 1 + age, educational level during pregnancy, number of individuals in a household, insurance status, pre-pregnancy body mass index, prenatal cigarette smoking or secondhand smoke exposure, parity, and child sex. Model 3: Model 2 + race and ethnicity.

Figure 3: Association of individual-level food insecurity with birth outcomes. Model 1: adjusted for year of residential address during pregnancy. Model 2: Model 1 + age, educational level during pregnancy, number of individuals in a household, insurance status, pre-pregnancy body mass index, prenatal cigarette smoking or secondhand smoke exposure, parity, and child sex. Model 3: Model 2 + race and ethnicity.


Birth Weight
Mean difference in grams (95% CI)
20.0
0.0
−20.0
−40.0
−60.0
−80.0
LILA >0.5 mile urban >10 miles rural
LILA >1 mile urban >10 miles rural
LILA >1 mile urban >20 miles rural
LILV
Birth Weight−for−Gestational−Age
Mean difference in SD units (95% CI)
0.05
0.00
−0.05
−0.10
−0.15
−0.20
LILA >0.5 mile urban >10 miles rural
LILA >1 mile urban >10 miles rural
LILA >1 mile urban >20 miles rural
LILV
Gestational Age
Mean difference in weeks (95% CI)
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
LILA >0.5 mile urban >10 miles rural
LILA >1 mile urban >10 miles rural
LILA >1 mile urban >20 miles rural
LILV
● Model 1
◆ Model 2
▲ Model 3


Small−for−Gestational−Age
Large−for−Gestational−Age
Preterm Birth
Odds ratio (95% CI)
1.6
1.4
1.2
1.0
0.8
1.1
0.9
LILA
>0.5 mile urban
>10 miles rural
LILA
>1 mile urban
>10 miles rural
LILA
>1 mile urban
>20 miles rural
LILV
● Model 1
◆ Model 2
▲ Model 3

Birth Weight
Mean Difference in grams (95% CI)
100.0
0.0
−100.0
−200.0
Model 1
Model 2
Model 3
Birth Weight−for−Gestational−Age
Mean Difference in SD units (95% CI)
0.4
0.2
0.0
−0.2
Model 1
Model 2
Model 3
Gestational Age
Mean Difference in weeks (95% CI)
0.2
0.0
−0.2
−0.4
−0.6
Model 1
Model 2
Model 3
Small−for−Gestational−Age
Odds Ratio (95% CI)
2.0
1.5
1.0
0.5
Model 1
Model 2
Model 3
Large−for−Gestational−Age
Odds Ratio (95% CI)
1.2
1.0
0.8
0.6
0.4
Model 1
Model 2
Model 3
Preterm Birth
Odds Ratio (95% CI)
2.5
2.0
1.5
1.0
Model 1
Model 2
Model 3

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: