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Neighborhood Socioeconomic Disadvantage and Gestational Weight Gain and Loss

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Abstract We explored the relationship between neighborhood socioeconomic disadvantage (NSED) and gestational weight gain and loss and if the association differed by race. A census tract level NSED index (categorized as low, mid-low, mid-high, and high) was generated from 12 measures from the 2000 US Census data. Gestational weight gain and other individual-level characteristics were derived from vital birth records for Allegheny County, PA for 2003–2010 (n = 55,608). Crude and adjusted relative risks were estimated using modified multilevel Poisson regression models to estimate the association between NSED and excessive and inadequate gestational weight gain (GWG) and weight loss (versus adequate GWG). Black women lived in neighborhoods that were more likely to be socioeconomically disadvantaged compared to white women. Almost 55 % of women gained an excessive amount of weight during pregnancy, and 2 % lost weight during pregnancy. Black women were more likely than white women to have inadequate weight gain or weight loss. Mid-high (aRR = 1.3, 95 % CI 1.2, 1.3) and high (aRR = 1.5, 95 % CI 1.5, 1.6) NSED compared to low NSED was associated with inadequate weight gain while NSED was not associated with excessive weight gain. Among black women, high versus low NSED was associated with weight loss during pregnancy (RR = 1.6, 95 % CI 1.1, 2.5). Among white women, each level of NSED compared to low NSED was associated with weight loss during pregnancy. This study demonstrates how neighborhood socioeconomic characteristics can contribute to our understanding of inadequate weight gain and weight loss during pregnancy, having implications for future research and interventions designed to advance pregnancy outcomes.

Keywords Gestational weight gain and loss · Neighborhood socioeconomic disadvantage · Neighborhood conditions · Racial differences

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Introduction

In the US, black women are more likely to gain less weight than recommended by the Institute of Medicine [1] and to lose weight during pregnancy compared to white women [2, 3]. Poor weight gain during pregnancy is associated with adverse birth outcomes, including fetal growth restriction and preterm birth—outcomes that are also more

common among black women in the US [1]. Additionally, weight gain during pregnancy not only influences pregnancy outcomes but may have implications for weight trajectories across the life-course [1, 4]. Individual predictors do not adequately explain the racial and socioeconomic differences in inadequate weight gain, and the increased risk of inadequate weight gain among black women is not well understood [1–3]. Many prior studies have explored how social determinants beyond individual risk factors may play a role in pregnancy health. However, there are only a few empirical studies that investigate the relationship between neighborhood environments and gestational weight gain, in which gestational weight gain could be along the pathway from neighborhood environments and pregnancy outcomes [5–7]. Neighborhood environments and the context in which women live may contribute to inadequate gestational weight gain and provide insight into existing racial disparities [3, 5, 6].

There is an unequal distribution of neighborhood environmental conditions and access to resources that may be important for health by race and socioeconomic status in the US due residential segregation and as a result of institutional polices that reinforce geographic separation [8]. Neighborhood conditions are closely linked with clustering of socioeconomic disadvantage [9]. Low-income and minority communities tend to have less access to supermarkets and healthy food options, more solid waste facilities, limited employment opportunities, inadequate access to transportation, and limited access to healthcare [8, 10]. More specifically, studies show that neighborhood socioeconomic disadvantage is associated with an increased risk of gestational diabetes and pregnancy-related hypertension, outcomes associated with pregnancy-related weight; as well as preterm birth, low birth weight and small-for-gestational-age birth [9, 11–16].

Three studies to date investigated the association between various neighborhood characteristics and gestational weight gain [5–7]. Investigators in each study used a neighborhood audit inventory based on researcher report and found neighborhood 'physical incivilities' (i.e., litter, graffiti, and poor housing conditions) and 'social spaces' (i.e., porches and presence of sidewalks and people) were inversely associated with excessive gestational weight gain [5] and positively associated with inadequate gestational weight gain [5–7]. 'Walkability' (i.e., parks, conditions of sidewalks, and lighted areas) was inversely associated with inadequate weight gain [6, 7]. In addition, two other studies have found that neighborhood food environments and residence in metropolitan areas were associated with pre-pregnancy obesity, but these studies did not focus on weight gain during pregnancy [17, 18].

Prior studies have not examined the relationship between socioeconomic characteristics of the neighborhood and weight gain and loss during pregnancy and whether this association differs by race. We sought to examine whether a US Census-based index of neighborhood socioeconomic disadvantage (NSED) was associated with gestational weight gain and loss for non-Hispanic black and non-Hispanic white women. In Allegheny County, Pennsylvania, the geographic region of this study, about 12 % of the population was black and 84 % was white as of the year 2000. The city of Pittsburgh population was 27 % black; and there were only slight changes in racial demographics by 2010 according to the US Census Bureau. In addition, 30 % of families in Allegheny County were in poverty with a median household income of $28,588 compared to $40,106 for the state of Pennsylvania. According to the 2000 US Census, the poverty rate among black adults was almost 27 % compared to whites at less than 10 %. Finally, the county has high rates of pre-pregnancy obesity and considerable racial maternal and infant health inequities where black infants are more than twice as likely to die within the first year of life compared to white infants, making this geographic region ideal for understanding neighborhood socioeconomic inequities and its relationship to pregnancy-related weight [19–21].

Methods

Population and Data Sources

Individual-level data, including maternal weight and height data, were obtained from birth records of infants born in Allegheny County, Pennsylvania (PA) from 2003 to 2010. The city of Pittsburgh is the urban center of Allegheny County. In 2003, PA along with several other states adopted the revised US Standard Certificates of Live Birth and Death, which included the collection of maternal weight and height data.

The analytic sample includes all non-Hispanic black and non-Hispanic white women who delivered singleton infants with no congenital anomalies from 20 to 42 week gestation (n = 90,510). We chose these exclusionary criteria due to weight gain differences among multiple births, shorter gestational ages among infants with congenital anomalies, and the viability births before 20 weeks gestation. We excluded records of women with improbable or missing weight changes (weight loss ≥40 pounds or gain ≥100 pounds [19, 22]) (n = 33,201) and missing data on pre-pregnancy BMI [includes height and weight] (n = 144), covariates included in our final models (n = 1,547), and unknown census tracts (n = 10). We did not exclude those missing data on insurance given the amount of missing data, but created a separate category to measure differences in NSED among those with and without insurance status data. We addressed the missing outcome data (weight and height) by applying multiple

imputation (described below) and comparing results with a complete case analysis (n = 55,608). The women with complete data compared with women missing data were more likely to be white (81 vs. 75 %), have private insurance (57 vs. 50 %), and slightly more likely to live in neighborhoods with low socioeconomic disadvantage (26 vs. 23 %).

Individual Outcome Measures

Gestational weight outcomes were inadequate weight gain, excessive weight gain, and weight loss (all compared with adequate weight gain). Gestational weight gain and loss was calculated as weight at delivery minus pre-pregnancy weight. Pre-pregnancy weight and height were self-reported at delivery, and weight at delivery was ascertained at the last prenatal visit before delivery. Adequacy of gestational weight gain was calculated as the ratio of observed gestational weight gain to expected weight gain (based on 2009 Institute of Medicine recommendations (IOM) [1]) at the gestational age of delivery, as described previously [23]. Adequacy of gestational weight gain was defined as inadequate, adequate, or excessive (less than, within, and greater than the pre-pregnancy BMI specific IOM recommended ranges, where pre-pregnancy BMI is calculated as pre-pregnancy weight (kg) divided by height (meters) squared). In a subset of women in this analysis, we compared medical record data with variables in the birth record on pregravid weight and height reported at the first prenatal visit and the last measured weight before delivery and found high correlations [pregravid weight (r = 0.95), height (r = 0.95), and weight at delivery (r = 0.96)].

Neighborhood-Level Exposure

Each mother's home address at delivery was recorded in the birth record, geocoded by the Allegheny County Health Department using ArcGIS software version 9.2 (Redlands, California), and assigned a corresponding census tract. The census tract (a proxy of neighborhood) is a geographic unit defined by the US Census, which includes an average of 4,000 residents (between 1,000 and 8,000) and is typically homogeneous in socioeconomic characteristics compared to larger geographic spaces such as zip codes [24]. Census tracts also have been found to be meaningful geographic units to estimate area level socioeconomic characteristics and other neighborhood indices in the context of maternal and child health [7, 25], and have been used as a proxy for neighborhoods [7, 26]. We used year 2000 US Census data and boundaries for Allegheny County since most the women in our study gave birth before 2010 (our analytic sample gave birth between 2003 and 2010). There were a total of 416 census tracts with a mean of 217 (range 3–799) women per tract and 2 tracts with ≤5 women.

We used 2000 US Census data to create a census-tract level measure of NSED. A composite index was derived using exploratory factor analysis [27] of 12 census-tract level measures (Appendix, Online Version) (Almario Doebler, D. 2009. Developing Composite Area-Level Indicators of Socioeconomic Position for Pittsburgh, Pennsylvania. Master's Thesis, University of Pittsburgh, Pennsylvania) based on indices used in health research that take into account material deprivation and concentrated disadvantage [26, 28, 29]. The measures included in the NSED index were percentages of unemployed individuals, houses with no cars, crowded housing, renters, males not in management and professional occupations, households in poverty, female headed households with dependents, public assistance, earning less than $30,000/year, less than high school education, Black residents, residents under the age of 16. A maximum likelihood extraction method was used, and oblique rotation was applied to allow for correlations among extracted factors. Scree plots helped to ascertain the number of factors to extract. One factor was extracted, and the weighted eigenvalue for the first factor was 36.1, which explained 81 % of the total variance of the data. The NSED was categorized in quartiles as high, mid-high, mid-low, and low.

Individual-Level Covariates

Covariates of interest were maternal race/ethnicity (non-Hispanic black and non-Hispanic white; henceforth called black and white), maternal education (less than high school, high school graduate, some college, or college graduate), marital status (married or unmarried), maternal age (continuous), previous live births (0, 1, ≥2), use of the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) during pregnancy (yes or no), principal source of payment at delivery (private insurance, Medicaid, self-pay, other), and smoking during pregnancy (smoker or nonsmoker). We selected confounders using theory-based causal models and previous studies [4, 9, 14, 23, 30].

Statistical Analysis

To address missing data for pre-pregnancy weight, delivery weight, and height, we imputed 10 datasets (multiple imputation relative efficiency = 98 %) using Markov Chain Monte Carlo with a Fully Conditional Specification (n = 905,100) [31]. We imputed gestational weight gain and loss, which were used in the final multivariable models, by including race/ethnicity, marital status, maternal education, maternal age, receipt of WIC, insurance status, parity, smoking status during pregnancy, gestational age, year of birth, and census tract in the imputed models. The

results from the multiple imputation were obtained by averaging estimates across the 10 imputed datasets. We conducted a sensitivity analysis by comparing the imputed results with the results of the completed dataset. The results from the imputed datasets and the complete datasets were similar (data not shown).

We performed analysis of variance (ANOVA) to determine the mean NSED scores by individual maternal characteristics and gestational weight gain outcomes. We then fit a series of separate multilevel random intercept modified Poisson regression models [32, 33] for each outcome (i.e., inadequate weight gain, excessive weight gain, and weight loss all versus adequate weight gain) in which individuals were nested within census tracts to estimate relative risks of the association between NSED and pregnancy-related weight outcomes. Our multilevel models included 2 levels: level-1 the individual-level variables and level-2 the neighborhood level. We first fit null models to calculate the proportion of variance in each outcome that was attributable to census tract differences. Second, we fit unadjusted models that included NSED alone, and then finally fit models with NSED and individual-level covariates. Previous work has found that the association between neighborhood characteristics and birth outcomes differ for black and white women [6, 30]. As a result, we tested effect measure modification (statistical interaction) between NSED and race by assessing the Log Likelihood χ^2 test and the significance level for the interaction term and found that race modified the association between NSED and weight loss during pregnancy. Hence, we present results for all women and then stratified by race for gestational weight loss.

All analyses were conducted using SAS software version 9.3 (Cary, NC). The University of Pittsburgh Institutional Review Board approved this study.

Results

Approximately half of women were normal weight before pregnancy, while 23 % were overweight and 18 % were obese (Table 1). About 18 % of the women included in the study were black. Most women were married, college-educated, had private insurance, and were nulliparous. About 55 % of all the women in our sample gained an excessive amount of weight during pregnancy, and 2.9 % lost weight during pregnancy (Table 2). When we examined maternal characteristics by race, black women were more likely to be overweight or obese before pregnancy, unmarried, have a high school education, use WIC, and use Medicaid compared to white women. Black women were more likely to live in neighborhoods with more socioeconomic disadvantage (higher NSED score) compared to white women ($p < 0.001$) (Table 1).

Individual-Level Covariates, Gestational Weight Gain and Loss, and NSED

Neighborhood socioeconomic disadvantage was highest among women who were obese or underweight before pregnancy, were unmarried women, had low education, used WIC, smoked during pregnancy, and were not privately insured ($p < 0.001$) (Table 2). Black women were more likely than white women to have inadequate weight gain or weight loss. Women with inadequate gestational weight gain or weight loss had higher mean NSED scores compared to women with adequate weight gain.

Multilevel Poisson Regression Results: Neighborhood and Gestational Weight Gain and Loss

The intraclass correlation for the null (empty) models for gestational weight loss, inadequate weight gain, and excessive weight gain were 11, 0.4, and 2.5 % respectively. Mid-high (RR = 1.3, 95 % CI 1.2, 1.3) and high (RR = 1.5, 95 % CI 1.5, 1.6) compared to low NSED was associated with inadequate weight gain in the unadjusted model, and high (RR = 1.2, 95 % CI 1.1, 1.2) versus low NSED was associated with inadequate weight gain in the adjusted model (Table 3). NSED was not associated with excessive weight gain. We found that the association between NSED and weight loss during pregnancy differed by race (Table 4). Among black women, high versus low NSED was associated with weight loss during pregnancy in the unadjusted and adjusted models (RR = 1.6; 95 % CI 1.1, 2.5). Among white women, mid-low, mid-high, and high versus low NSED was also associated with weight loss during pregnancy in the adjusted and unadjusted models, with a greater association with each level of NSED.

Discussion

In this population-based sample of births in an urban county in Allegheny County, Pennsylvania, we found that NSED was associated with inadequate gestational weight gain and weight loss during pregnancy. We also found that the association between NSED and weight loss during pregnancy differed by race. Among black women, high versus low NSED was associated with weight loss while among white women, each level of NSED compared to low NSED was associated with an incremental increase in weight loss. There was no association between NSED and excessive weight gain.

Table 1 Population characteristics by mean neighborhood socioeconomic disadvantage scores (NSED) and race/ethnicity, Allegheny County, PA, 2003–2010

	All (n = 55,608)		Non-hispanic blacks [n = 10,222 (18.4 %)]	Non-hispanic whites [n = 45,386 (81.6 %)]
	N (%)	Mean NSED (SD)	N (%)	N (%)
Married (yes)	35,577 (64)	17.4 (5.6)	1,857 (18.2)	33,720 (74.3)
No		25.8 (9.9)	8,365 (81.8)	11,666 (25.7)
		$p < 0.001$		
Maternal Education				
No diploma	4,504 (8.1)	27.8 (10.4)	2,016 (19.7)	2,488 (5.5)
HS/GED	11,496 (20.7)	24.1 (9.7)	3,564 (34.9)	7,932 (17.5)
Some college	16,524 (29.7)	21.1 (8.0)	3,478 (34)	13,046 (28.7)
College grad and beyond	23,084 (41.5)	16.7 (5.3)	1,164 (11.4)	21,920 (48.3)
		$p < 0.001$		
Used WIC (yes)	17,001 (30.6)	25.7 (9.7)	6,802 (66.5)	10,199 (22.5)
No		18.1 (6.6)	3,420 (33.5)	35,187 (77.5)
		$p < 0.001$		
Insurance status				
Private insurance	31,739 (57.1)	18.0 (6.2)	2,582 (25.3)	29,157 (64.2)
Medicaid	11,357 (20.4)	26.2 (10.1)	4,795 (46.9)	6,562 (14.5)
Self-pay	355 (0.6)	22.4 (8.5)	74 (0.7)	281 (0.6)
Other	1,267 (2.3)	25.2 (10.1)	502 (4.9)	765 (1.7)
Missing	10,890 (19.6)	20.9 (8.8)	2,269 (22.2)	8,621 (19)
		$p < 0.001$		
Number of previous live births				
Zero	28,354 (51)	20.4 (8.2)	4,849 (47.4)	23,505 (51.8)
One	23,150 (41.6)	20.0 (8.3)	4,066 (39.8)	19,084 (42)
Two or more	4,104 (7.4)	23.1 (10.5)	1,307 (12.8)	2,797 (6.2)
		$p < 0.001$		
Cigarettes use During pregnancy (yes)	10,202 (18.4)	23.7 (8.7)	2,307 (22.6)	7,895 (17.4)
No		19.7 (8.2)	7,915 (77.4)	37,491 (82.6)
		$p < 0.001$		
Maternal age				
<20	4,130 (7.4)	27.5 (10.7)	2,117 (20.7)	2,013 (4.4)
20–29	25,450 (45.8)	22.0 (8.7)	5,888 (57.6)	19,562 (43.1)
30+	26,028 (46.8)	17.7 (6.5)	2,217 (21.7)	23,811 (52.5)
		$p < 0.001$		
Neighborhood characteristics				
Neighborhood disadvantage (M, SD)		20.8 (8.7)	31.2 (10.6)	18.0 (5.5)
			$p < 0.001$	
Neighborhood disadvantage [quartiles (N, %)]				
Low (0–15)	14,439 (26)		268 (2.6)	14,171 (31.2)
Mid-low (>15–19)	16,616 (29.9)		876 (8.6)	15,740 (34.7)
Mid-high (>19–26)	14,746 (26.5)		2,555 (25)	12,191 (26.9)
High (>26)	9,807 (17.6)		6523 0.8)	3,284 (7.2)

Higher score indicates greater disadvantage

To our knowledge, our study is the first to examine a social determinant of weight loss during pregnancy. Weight loss occurs rarely but is associated with markedly elevated risk in adverse birth outcomes [19, 23]. Our results highlight the potential for NSED to be an important factor for pregnancy-related weight that warrants further exploration. Additionally, our novel method for operationalizing NSED status can be applied in future work.

Table 2 Gestational weight gain, weight loss, and mean neighborhood socioeconomic disadvantage (NSED) by race/ethnicity, Allegheny County, PA 2003–2010

	All (n = 55,608)		Blacks (n = 10,222)		Whites (n = 45,386)	
	N (%)	Mean NSED (SD)	N (%)	Mean NSED (SD)	N (%)	Mean NSED (SD)
Pre-pregnancy BMI						
Underweight	2,277 (4.1)	21 (8.4)	370 (3.6)	31.9 (10.9)	1,907 (4.2)	18.9 (5.9)
Normal weight	30,544 (54.9)	19.5 (8.0)	4,449 (43.5)	30.9 (10.7)	26,095 (57.5)	17.5 (5.4)
Overweight	12,636 (22.7)	21 (8.6)	2,743 (26.8)	30.9 (10.5)	9,893 (21.8)	18.1 (5.4)
Obese	10,151 (18.3)	22.6 (9.2)	2,660 (26.0)	32 (10.6)	7,491 (16.5)	19.2 (5.7)
		$p < 0.001$		$p < 0.001$		$p < 0.001$
Gestational weight gain						
Adequate weight gain	15,543 (28)	19.8 (8.0)	2,473 (24.2)	30.9 (10.3)	13,070 (28.8)	17.7 (5.3)
Inadequate weight gain	9,446 (17)	22.1 (9.6)	2,431 (23.8)	32.1 (10.9)	7,015 (15.5)	18.6 (5.9)
Excessive weight gain	30,619 (55)	20.2 (8.2)	5,318 (52.0)	30.9 (10.6)	25,301 (55.8)	18.0 (5.4)
		$p < 0.001$		$p < 0.001$		$p < 0.001$
Weight Loss[a]	941 (1.7)	24.6 (10.1)	334 (3.3)	32.9 (10.5)	607 (1.3)	20.1 (6.3)
		$p < 0.001$		$p < 0.001$		$p < 0.001$

Higher score indicates greater disadvantage

[a] p-value for weight loss compared to adequate weight gain

Table 3 Relative risks (RR) for the adjusted and unadjusted association between neighborhood socioeconomic disadvantage (NSED) and inadequate weight gain and excessive weight gain, Allegheny County, PA, 2003–2010

	Inadequate weight gain[b] RR (95 % CI)		Excessive weight gain[a]	
	Unadjusted	Adjusted[c]	Unadjusted	Adjusted[b]
NSED				
Low (ref)	–	–	–	–
Mid-Low	1.1 (1.1, 1.1)	1.0 (1.0, 1.1)	1.0 (1.0, 1.0)	1.0 (1.0, 1.0)
Mid-High	1.3 (1.2, 1.3)	1.1 (1.0, 1.1)	1.0 (1.0, 1.0)	1.0 (1.0, 1.0)
High	1.5 (1.5, 1.6)	1.1 (1.1, 1.2)	1.0 (1.0, 1.0)	(1.0, 1.0)

Higher NSED values indicate more disadvantage

[a] Compared with adequate weight gain; ICC (intraclass correlation): inadequate weight gain = 0.4 %, excessive weight gain = 2.5 %

[c] Adjusted for individual characteristics: maternal race, maternal education, marital status, maternal age, parity, use of the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) during pregnancy, principal source of payment at delivery (i.e., insurance type), and smoking during pregnancy

Table 4 Relative risks (RR) for the adjusted and unadjusted association between neighborhood socioeconomic disadvantage (NSED) and gestational weight loss separately for non-Hispanic black and white women, Allegheny County, PA, 2003–2010

	Weight Loss[a]			
	Black[c]		White[c]	
	RR (95 % CI			
	Unadjusted	Adjusted[b]	Unadjusted	Adjusted[b]
NSED				
Low (ref)	–	–	–	–
Mid-low	1.3 (0.8, 2.1)	1.3 (0.8, 2.0)	1.4 (1.2, 1.6)	1.2 (1.1, 1.4)
Mid-high	1.2 (0.8, 1.8)	1.2 (0.8, 1.9)	2.2 (2.0, 2.5)	1.6 (1.4, 1.8)
High	1.6 (1.1, 2.4)	1.6 (1.1, 2.5)	3.2 (2.8, 3.7)	2.0 (1.7, 2.4)

[a] Compared with adequate weight gain. ICC = 10 %

[b] Adjusted for individual characteristics: maternal race, maternal education, marital status, maternal age, parity, use of the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) during pregnancy, principal source of payment at delivery (i.e., insurance type), and smoking during pregnancy

[c] Due to effect measure modification (EMM) for weight loss as an outcome, we evaluate the effect of NSED separately for black and white women

We are unaware of other studies that examine inadequate or excessive gestational weight gain in association with a Census-based measure of NSED. One previous study in Europe found that pre-pregnancy obesity was associated with living in a poor area [34]. Other studies have found that neighborhood food environments and residence in metropolitan areas were associated with pre-pregnancy obesity [17, 18]. Previous studies examining neighborhood factors and gestational weight gain used a neighborhood inventory of street audit data collected by researchers to measure a variety of neighborhood conditions [5–7]. One study found that neighborhood physical incivilities (i.e., litter, graffiti, and poor housing conditions) and social spaces (i.e., porches and presence of sidewalks and people) were inversely associated with excessive gestational weight gain among a clinic-based sample of 703 black and white women in North Carolina [5]. Two other studies using North Carolina birth certificate data of 39,000 births among black and white women found that physical incivilities and social spaces were positively associated with inadequate and excessive

and weight gain, and 'walkability' (i.e., parks, conditions of sidewalks, and lighted areas) was inversely associated with inadequate weight gain [6, 7]. Because two of the past studies could not account for pre-pregnancy weight or gestational length in their assessment of gestational weight gain [6, 7], inferences are difficult to draw based on these findings [35].

Taken together, our work and previous research suggests that women who reside in socioeconomically disadvantaged neighborhoods are susceptible to poor weight gain during pregnancy. Socioeconomically disadvantaged neighborhoods have less access to important neighborhood resources that are essential for health before and during pregnancy [9]. NSED may influence pregnant women's health due to less healthy food options or grocery stores, limited healthcare options, and other neighborhood stressors such as crime and violence. Geographic clustering of health-promoting and health-adverse factors have an influence on reproductive and perinatal health as well as important health behaviors such as smoking, diet quality, and physical activity [5, 6, 9, 17, 36–38].

Birth records in Pennsylvania include residence at the time of delivery. Long-term histories of women's residential environments would be important for understanding their neighborhood contexts before women become pregnant, and residential mobility during pregnancy could be a potential source of exposure misclassification [39, 40]. However, within Allegheny County where this study is based, there is limited migration in and out of the region [41], potentially mitigating confounding or exposure misclassification by a change in residence.

Socioeconomic measures of neighborhood context are important but do not capture all aspects of a woman's neighborhood context and do not take into account other social exposures such as place of work, other environments, and how social networks within and between neighborhoods within a lareger geographic region may influence health. Also, as a result of racial residential segregation, the overlap in the racial distributions of neighborhood environments, including neighborhood poverty, is limited [42]. In our study, we also found less variability in NSED where black women were overrepresented in the high neighborhood disadvantage group. Structural confounding as a result of social stratification and 'selection' into certain neighborhoods is an important consideration for this study [42–44]. Also, there may be unobserved or unmeasured neighborhood factors that may influence gestational weight gain for specific racial/ethnic groups that we did not measure in this study [11].

Although 36 % of records were missing data on key outcome variables, the similarity between the multiple imputation results and the complete case analysis suggests that selection bias is unlikely in our study. Misreporting of pre-pregnancy weight, height, and weight at delivery occurs in pregnant mothers, but results from a validation study in our population highlights the accuracy of these data in our cohort. Additionally, we did not have adequate sample size to examine other racial/ethnic groups other than non-Hispanic black and non-Hispanic white women. Data on individual or family income and alcohol use were not available on the birth record and could not be included in the analysis. The birth record also does not include information about health behaviors or other maternal risks that may be important for understanding pregnancy-related weight outcomes. Nevertheless, our use of a large, diverse population-based cohort of births in US county with some geographic diversity (urban and suburban) provided us with an adequate sample size to study associations with pregnancy-related weight outcomes including weight loss within racial/ethnic groups while adjusting for multiple individual level confounders. We also used a measure of gestational weight gain that accounts for BMI and gestational age based on 2009 Institute of Medicine recommendations. Finally, we applied novel methods such as exploratory factor analysis to create a single neighborhood socioeconomic index based various US Census measures to capture the social and demographic environment.

The intersection of race and place, particularly how socioeconomic conditions may play a role in racial/ethnic differences in health, is of importance in shaping pregnancy outcomes such as gestational weight gain. Differential access to resources and neighborhood conditions as a result of institutional racism and residential segregation is also of great importance [8, 45, 46], particularly in understanding racial inequities in pregnancy outcomes such as gestational weight gain. Residential segregation has been cited as a fundamental cause of racial/ethnic disparities in health due to differential access to neighborhood resources as well as other opportunities in employment, housing, and education by race [8]. Research studies investigating neighborhood effects should consider how residential segregation and institutional racism could be integrated [46]. Future studies should also examine how neighborhood and social contexts influence potential mediators in the relationship between neighborhood and gestational weight gain such as health behaviors (e.g., diet, physical activity, smoking). In understanding potential racial/ethnic inequities in gestational weight gain, researchers should consider the simultaneous influences of residential racial segregation, neighborhood disadvantage, and specific attributes of the neighborhood such as proximity to and the quality of parks, food establishments, and other health-promoting services. Place-based policies and interventions can be critical in understanding pregnancy health and racial disparities as well as associated behaviors that may be on the pathway from neighborhood

environments to pregnancy outcomes. Finally, understanding how access to "opportunity neighborhoods" for all racial groups is imperative in addressing racial/ethnic disparities in health [46].

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