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Racial/Ethnic Disparities in Inadequate Gestational Weight Gain Differ by Pre-pregnancy Weight

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Abstract Pre-pregnancy body mass index (BMI) varies by race/ethnicity and modifies the association between gestational weight gain (GWG) and adverse pregnancy outcomes, which disproportionately affect racial/ethnic minorities. Yet studies investigating whether racial/ethnic disparities in GWG vary by pre-pregnancy BMI are inconsistent, and none studied nationally representative populations. Using categorical measures of GWG adequacy based on Institute of Medicine recommendations, we investigated whether associations between race/ethnicity and GWG adequacy were modified by pre-pregnancy BMI [underweight (<18.5 kg/m^2), normal weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2), or obese (≥ 30.0 kg/m^2)] among all births to Black, Hispanic, and White mothers in the 1979 USA National Longitudinal Survey of Youth cohort (n = 6,849 pregnancies; range 1–10). We used generalized estimating equations, adjusted for marital status, parity, smoking during pregnancy, gestational age, and multiple measures of socioeconomic position. Effect measure modification between race/ethnicity and pre-pregnancy BMI was significant for inadequate GWG (Wald test p value = 0.08). Normal weight Black [risk ratio (RR) 1.34, 95 % confidence interval (CI) 1.18, 1.52] and Hispanic women (RR 1.33, 95 % CI 1.15, 1.54) and underweight Black women (RR 1.38, 95 % CI 1.07, 1.79) experienced an increased risk of inadequate GWG compared to Whites. Differences in risk of inadequate GWG between minority women, compared to White women, were not significant among overweight and obese women. Effect measure modification between race/ethnicity and pre-pregnancy BMI was not significant for excessive GWG. The magnitude of racial/ethnic disparities in inadequate GWG appears to vary by pre-pregnancy weight class, which should be considered when designing interventions to close racial/ethnic gaps in healthy GWG.

Keywords Health status disparities · Minority health · Overweight · Pregnancy · Weight gain

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Introduction

Black and Hispanic women and children in the United States (US) have disproportionately more adverse birth outcomes and obesity [1–3]. Gestational weight gain (GWG) disparities may be one explanation. The US Institute of Medicine (IOM) recently issued guidelines for optimal ranges of GWG (Table 1) for four categories of pre-pregnancy body mass index (BMI) to promote maternal and infant health [4]. Yet in 2011, only 31 % of women gained within the recommended IOM GWG range [5]. Non-Hispanic Black women had the highest prevalence of

Table 1 Institute of Medicine gestational weight gains in 2009 by weight class

Pre-pregnancy BMI	2009 IOM standards	
	BMI (kg/m^2)[a]	Total weight gain range (lbs)
Underweight	<18.5	28–40
Normal weight	18.5–24.9	25–35
Overweight	25.0–29.9	15–25
Obese (all classes)	≥30.0	11–20

[a] Based on World Health Organizations BMI classification guidelines

weight gain below these guidelines, or inadequate GWG (23.2 %; Hispanics: 22.6 %, Whites: 18.5 %). Over half (52 %) of White women gained excessively, or above the IOM guidelines, as well as almost half of Blacks (48 %) and Hispanics (44 %) [5]. Other studies confirm that Black and Hispanic women have lower GWG during pregnancy than Whites [6–11].

Given rising obesity and growing evidence that GWG may contribute to setting the trajectory for poor health throughout life [12], the association between excessive GWG and large for gestational age and macrosomic infants has raised concern about children's subsequent increased risks for metabolic disorders and obesity [12–14], early menarche [15], and cardiovascular disease in adulthood [16]. In mothers, excessive GWG is associated with antenatal and intra-partum complications [4] and obesity postpartum [4, 13, 14] and later in life [17, 18]. Many of these outcomes are also more common in Black and Hispanic populations [3, 19]. At the other extreme, inadequate GWG is associated with small for gestational age (SGA) infants [4, 13, 14], and preterm deliveries [4, 14, 20]. These outcomes are also more common among Black mothers than White mothers [1, 2, 21].

Overall, while minority women appear to gain less weight than White women, they are still not protected from excessive GWG [19]. However, knowledge is limited in several ways. First, few studies consider whether associations between race/ethnicity and GWG vary by pre-pregnancy BMI (e.g. [6–8, 10]); many only adjusted for BMI. Persistent racial/ethnic disparities in BMI among women of childbearing age make this an important consideration: currently, Black women age 20–39 have over twice the prevalence of obesity as White women (56.2 vs 26.9 %), and Hispanic women have a 1.2 times higher prevalence (34.4 %) [22]. If, counter to current research assumptions, racial/ethnic disparities in GWG vary across pre-pregnancy weight classes (e.g., if Black–White differences in risk of excessive GWG are present among normal weight women but not among obese women), then current interventions to reduce racial/ethnic disparities may not target appropriate subgroups. Additionally, existing studies vary in their racial heterogeneity and may be underpowered to detect interaction by pre-pregnancy BMI among racial/ethnic groups. Sample characteristics of these studies ranged from small local samples [6, 8, 9] to regionally defined samples of economically disadvantaged women [10] to one study by Chu et al. [7] conducted in a sample from a national surveillance study. They also used different measures of GWG, including continuous and categorical overall GWG [6, 7, 10], trimester-specific GWG [23], and a combined measure of GWG and postpartum weight loss [9].

The IOM identified minority women as important targets for intervention to promote healthy weight gain but noted that limited national data and few studies that considered pre-pregnancy BMI prevented "drawing any conclusions about the influence of race ethnicity on GWG" [4, p. 123]. To address this gap, we analyzed data from the US 1979 National Longitudinal Survey of Youth (NLSY79) to determine whether racial/ethnic differences in inadequate and excessive GWG vary by pre-pregnancy weight class.

Methods

Sample

The US Bureau of Labor Statistics' NLSY79 [24] has followed a nationally representative sample of 12,686 men and women since 1979, when they were aged 14–22 years. Participants were interviewed annually from 1979 to 1994 and biennially to 2010. Participants were weighted to account for: non-response; oversampling of Blacks, Hispanics, and low-income non-Black, non-Hispanic individuals; and the national population. Female participants reported on pregnancies prospectively beginning in 1986, and retrospectively for earlier pregnancies [25]. Our analysis included all singleton births to mothers occurring from 1979 to 2010, excluding births with implausible values for gestational age (<22 and >44 weeks; n = 45) [26]. We further restricted to pregnancies with complete data on GWG, mother's race/ethnicity, and covariates of interest; Asian mothers (n = 78) were excluded due to small sample size. The complete case sample size totaled 6,849 pregnancies among 3,835 mothers (Fig. 1). Mothers contributed 1–10 pregnancies to our analysis (mean 1.97; SD 1.11). Our analysis was exempt from full human subjects review by the University of California, Berkeley Center for the Protection of Human Subjects as the data used are unidentifiable and publicly available online.

Analytic Variables

Main Outcome

For each pregnancy, women self-reported their pre-pregnancy and pre-delivery weights. At the interview following

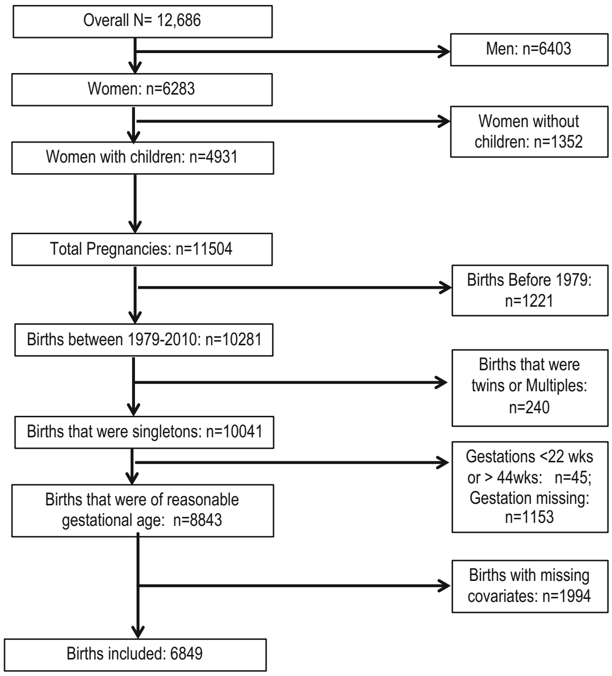

Fig. 1 Observations from the NLSY79 complete cohort remaining in analytic sample based on inclusion and exclusion criteria

the index pregnancy, women were asked, "What was your weight just before you became pregnant with [index child]?" and, "What was your weight just before you delivered?" for pre-pregnancy and pre-delivery weight, respectively. Because more than 10 % of the sample had deliveries before term, and GWG is partially a function of gestational age, we calculated GWG adequacy, an estimated ratio of a woman's observed and expected amounts of weight gain at each week of gestation [27, 28]. Expected GWG was calculated based on IOM recommendations for amount of weight gain during the first trimester, which varied by pre-pregnancy BMI (underweight: 2 kg; normal weight: 2 kg; overweight: 1 kg; obese: 0.5 kg; [4]), and rate of weight gain during the second and third trimester: expected GWG = recommended first trimester gain + (gestational age − 13) × (rate of weight gain during the second and third trimesters). Observed GWG was the difference between a woman's weight right before delivery and her weight prior to pregnancy. We then divided observed GWG by expected GWG and used this ratio to classify women as gaining inadequately, adequately, or excessively. Recommendations were based on the 2009 IOM report and were pre-pregnancy BMI specific: 28–40 lbs for underweight (<18.5 kg/m^2), 25–35 lbs for normal weight (18.5–24.9 kg/m^2), 15–25 lbs for overweight (25–29.9 kg/m^2), and 15–20 lbs for obese (≥30.0 kg/m^2) [4]. Although GWG recommendations changed over our study period [4, 29] and most NLSY pregnancies occurred before 2009, we utilized the 2009 categories which provide a range of weight gain for obese women. Ninety-four percent of pregnancies were classified identically when using the 2009 and 1990 recommendations. Our reference group in statistical models was women who gained adequately, e.g. when comparing women who gained excessively to women who gained adequately, we excluded women who gained inadequately from that model and vice versa.

Covariates

Self-reported race/ethnicity (Hispanic, Black, and White) was our main independent variable of interest. We also included covariates widely considered to be confounders (e.g. [19, 30]): pre-pregnancy BMI, mother's age at birth, parity (prior to the index pregnancy), marital status, smoking during pregnancy, gestational age of child, and infant's birth year. All covariates were collected at the time of pregnancy to capture any changes across pregnancies. We calculated pre-pregnancy BMI by dividing self-reported pre-pregnancy weight (kg) by height (m) self-reported closest to the pregnancy, squared. Height was reported in 1981, 1982, 1985, 2006, and 2008. We regression-calibrated height measures using correction factors derived from National Health and Nutrition Examination Study (NHANES) III data to account for self-reporting bias [31]. While error from weight self-reporting also exists (e.g. [32, 33]), similar regression calibration techniques for pregnancy-related weight do not exist. BMI was categorized into the weight classes described above [4, 34]. Parity, maternal age at the time of the child's birth, and the birth year of the child were continuous variables. Models testing alternative function forms of these covariates (parity as categorical, maternal age squared, and child's birth year as categorical) did not change our findings, so we kept them as continuous to retain power. Self-reported smoking during pregnancy (smoker/non-smoker) and marital status (married/never married or other) were both binary variables.

Since race and socioeconomic status (SES) are highly correlated in the US, it is often difficult to remove confounding effects of SES when investigating racial disparities in health outcomes [35, 36]. We used NLSY79's detailed socioeconomic data to control for several socioeconomic measures. Past-year employment measured as unemployed (<10 h/week), part-time employed (10–34 h/week), and full-time employed (≥35 h/week). Participant's mother's years of education were reported at baseline and participant's years of education attained were reported at each interview. Both were classified as less than high school graduation (<12 years), high school graduation but not college graduation (12–15 years), and college graduation or more (≥16 years). We used a measure of income that accounted for family size, dividing total family income (in year 2000 dollars) by family size, raising it to the 0.38 power [37], and log transforming it to normalize the distribution.

Statistical Analysis

We calculated means, standard deviations, and percentages to describe the distribution of outcomes and covariates in our analytic sample. We assessed bivariable associations between covariates and race/ethnicity using *t* tests for categorical and continuous variables and Chi squared tests for categorical variables. We used generalized estimating equations (GEE) with log link functions to estimate risk ratios for race and GWG that accounted for clustering of pregnancies within women (using an exchangeable correlation structure and robust standard errors). We estimated crude associations, adjusted associations controlling for relevant covariates, and interaction models to determine whether racial/ethnic differences in GWG varied by pre-pregnancy weight class. In all models, continuous variables were median-centered. We set type I error thresholds at 0.05 for main association parameters. We used Wald tests to assess the significance of interaction for all cross-product interaction terms at the $p \leq 0.10$ level, since assessment is underpowered at the 0.05 level [38]. If significant interaction was detected, we reported the magnitude of racial differences within each stratum of pre-pregnancy weight class. We conducted a sensitivity analysis to determine whether bias from missing data impacted estimated associations. Missing values in our covariates ranged from 0.3 to 14.4 % (Appendix Table 3), and those excluded from our complete case analysis were more likely to be non-White, underweight, less educated, unemployed, unmarried, have lower parity, have lower income, have children earlier and at younger ages (Appendix Table 4). We used Stata 11.0's multiple imputation package to predict missing values for covariates. We then estimated the crude, adjusted, and interaction models using the imputed data sets. All models were estimated using Stata 11.0 (StataCorp LP, College Station, TX, 2009–2011).

Results

Table 2 shows the distribution of variables in the final weighted analytic sample and by race/ethnicity. The mean GWG was 14.1 kilograms (31.1 pounds); on average, women gained 127 % of their expected GWG for BMI and gestational age (corresponding to 40 pounds for a normal weight woman at 40 weeks gestation). A plurality of women (44.4 %) gained excessively, with 32.5 % gaining adequately and 23.1 % gaining inadequately. Most women began pregnancy at a normal BMI; only 25.5 % started pregnancy overweight or obese. Black women gained the highest percent of their expected weight gain, while Hispanic women achieved the lowest. However, inadequate weight gain was still more common in Black and Hispanic women than in White women. Also, a larger percent of minority women began their pregnancies overweight or obese, had lower educational attainment at the start of pregnancy, and had mothers who were less likely to have graduated from high school.

Inadequate GWG

The risk of inadequate GWG differed significantly by race/ethnicity. Crude analysis indicated that Black [risk ratio (RR) 1.41; 95 % confidence interval (95 % CI) 1.28, 1.55] and Hispanic women (RR 1.27; 95 % CI 1.13, 1.43) had an increased risk of inadequate GWG compared to White women. After adjusting for socioeconomic, demographic, and maternal characteristics, this risk was somewhat attenuated (Black RR 1.26, 95 % CI 1.13, 1.41; Hispanic RR 1.22, 95 % CI 1.07, 1.40), but remained significant.

Racial/ethnic differences in risk of inadequate GWG varied by pre-pregnancy BMI (Wald $p = 0.08$). Thus, we report relative risks for racial differences in inadequate GWG by pre-pregnancy weight class category. For normal weight women, the risk of inadequate GWG was higher for Blacks (RR 1.34; 95 % CI 1.18, 1.52; Fig. 2) and Hispanics (RR 1.33; 95 % CI 1.15, 1.54; Fig. 2) than Whites. Among underweight women, Blacks also had a significantly higher risk (RR 1.38; 95 % CI 1.07, 1.79) of inadequate GWG than Whites; Hispanic women's risk did not significantly differ from Whites. For overweight and obese women, risk of inadequate GWG did not vary by race/ethnicity (Fig. 2).

Excessive GWG

Crude analysis indicated that Black (RR 1.12; 95 % CI 1.05, 1.20) and Hispanic (RR 1.09; 95 % CI 1.01, 1.18) women were significantly more likely to gain excessively compared White women, but adjusted risk ratios were attenuated and no longer significant (Black RR 1.06; 95 % CI 0.99, 1.14; Hispanic RR 1.03; 95 % CI 0.95, 1.12). There was no interaction between race/ethnicity and pre-pregnancy weight class for excessive GWG (Wald $p = 0.17$). Estimates of racial differences in excessive GWG by pre-pregnancy weight class are shown in Fig. 3.

Table 2 Descriptive statistics for analytic variables overall and by race/ethnicity

	Total (births n = 6,849; mothers n = 3,835)			White (births n = 4,134; mothers n = 2,375)		Black (births n = 1,624; mothers n = 907)		Hispanic (births n = 1,091; mothers n = 553)		*p* value
	Un-weighted N	Weighted mean (SD)	Weighted %	Weighted mean (SD)	Weighted %	Weighted mean (SD)	Weighted %	Weighted mean (SD)	Weighted %	
Race[a]										
White	2,375		82.4	–	–	–	–	–	–	–
Black	907		12.5	–	–	–	–	–	–	–
Hispanic	553		5.1	–	–	–	–	–	–	–
GWG	6,849	14.1 (6.6)		14.3 (6.3)		13.5 (7.8)		13.3 (7.0)		<0.001
GWG Ratio	6,849	1.3 (0.7)		1.3 (0.7)		1.3 (1.0)		1.2 (0.8)		0.02
GWG Adequacy										<0.001
Inadequate	1,721		23.1		21.7		30.1		28.3	
Adequate	2,067		32.5		34.0		24.9		28.1	
Excessive	3,061		44.4		44.4		45.1		43.6	
Pre-pregnancy weight										<0.001
Underweight	514		7.7		8.0		7.0		5.4	
Normal	4,524		66.8		68.0		60.0		63.9	
Overweight	1,190		16.4		15.4		20.1		21.9	
Obese	621		9.1		8.6		12.9		8.8	
Parity										<0.001
0	2,705		42.3		44.5		30.9		35.0	
1	2,408		35.4		35.5		35.6		33.4	
2	1,145		15.2		14.2		20.2		17.8	
≥3	591		7.1		5.8		13.3		13.9	
Education										<0.001
Less than high school	1,407		14.0		11.4		21.1		36.5	
High school	4,437		66.4		66.4		70.7		56.5	
College	1,005		19.6		22.2		8.2		7.1	
Participant's mother's education										<0.001
Less than high school	1,104		29.8		25.2		48.1		79.6	
High school	1,417		60.8		64.5		46.2		18.7	
College	192		9.4		10.2		5.7		1.6	
Equivalized income[b]	6,849	9.8 (1.2)		10.0 (1.1)		8.9 (1.3)		9.3 (1.3)		<0.001
Employment										<0.001
Unemployed	2,392		30.1		28.2		39.1		37.8	
Part-time	2,060		30.6		31.2		27.8		28.2	

Table 2 continued

	Total (births n = 6,849; mothers n = 3,835)			White (births n = 4,134; mothers n = 2,375)		Black (births n = 1,624; mothers n = 907)		Hispanic (births n = 1,091; mothers n = 553)		*p* value
	Un-weighted N	Weighted mean (SD)	Weighted %	Weighted mean (SD)	Weighted %	Weighted mean (SD)	Weighted %	Weighted mean (SD)	Weighted %	
Full-time	2,397		39.3		40.6		33.1		34.0	
Married	4,800		78.7		85.3		37.6		73.2	<0.001
Smoking during pregnancy	1,939		28.4		29.4		28.2		14.5	<0.001
Gestational age	6,849	38.6 (2.0)		38.7 (2.0)		38.4 (2.4)		38.6 (2.0)		<0.001
Preterm birth	6,849		11.7		11.5		14.1		10.0	0.03
Child's birth year	6,849	1988 (5.4)		1988 (5.4)		1987 (5.2)		1987 (5.5)		<0.01
Mother's age at birth	6,849	26.74 (5.1)		27.0 (5.1)		25.5 (5.1)		26.0 (5.3)		<0.001

[a] N represent mothers in the data set (N = 3,835)

[b] Equivalized income was calcluated to adjust for family size. For a family of 4 in year 2000 (the year to which all incomes in our data set are standardized to) our mean equivalized income of 9.8 corresponds to an aggregate houshold income of $30,540

Sensitivity Analysis

Point estimates after multiple imputation of missing covariates were similar to our complete case results (Appendix Tables 5, 6), but some standard errors differed, affecting statistical significance. Point estimates changed anywhere from 0.1 to 21 %. Differences in standard errors are expected as multiply imputed data sets have larger sample sizes and account for uncertainty inherent in the imputation process [39]. Overall, Wald tests supported significant interaction for inadequate GWG (Wald $p = 0.01$) and not for excessive GWG (Wald $p = 0.20$). For inadequate GWG, the interaction term for Hispanic underweight women became significant, but the interaction term for Hispanic obese women was no longer significant. Although these differences reflect changes in estimates considered "statistically significant," the magnitude of changes in p values were small.

Discussion

In this large, nationally representative, multi-ethnic cohort, racial/ethnic differences in GWG varied by pre-pregnancy weight class. Like others [6, 7, 9–11, 23], we observed racial/ethnic differences in inadequate GWG, independent of sociodemographic, maternal, and pregnancy characteristics. These significant associations were limited to women with pre-pregnancy BMI < 25 kg/m^2, whereby risk of inadequate GWG was higher in Black and Hispanic compared to White women. We found no evidence of racial/ethnic differences in risk of excessive GWG overall or by BMI subgroups.

Our findings are consistent with three previous studies [9, 10, 23] that found variation by pre-pregnancy BMI. Hickey et al. [10] used 1994 Alabama WIC and birth records of 19,017 births and found that odds of inadequate GWG for Black women compared to White women was higher within the non-obese pre-pregnancy weight stratum than for the overall cohort. From studying 427 singleton births to adolescents and young adults in New Haven, CT from 2001 to 2004, Gould Rothberg et al. [9] found that among normal and overweight women, Black women had lower weight gain compared to their White counterparts, while this was not the case among obese women. Fontaine et al. [23], who analyzed 2,760 births to Minneapolis-St. Paul-area women in 2008, similarly found that among normal weight and overweight women, Black women gained less across all trimesters compared to their white counterparts. They additionally found that this difference was significant among obese women as well [23]. However, each of these studies assessed GWG differently, making direct comparison of subgroup-

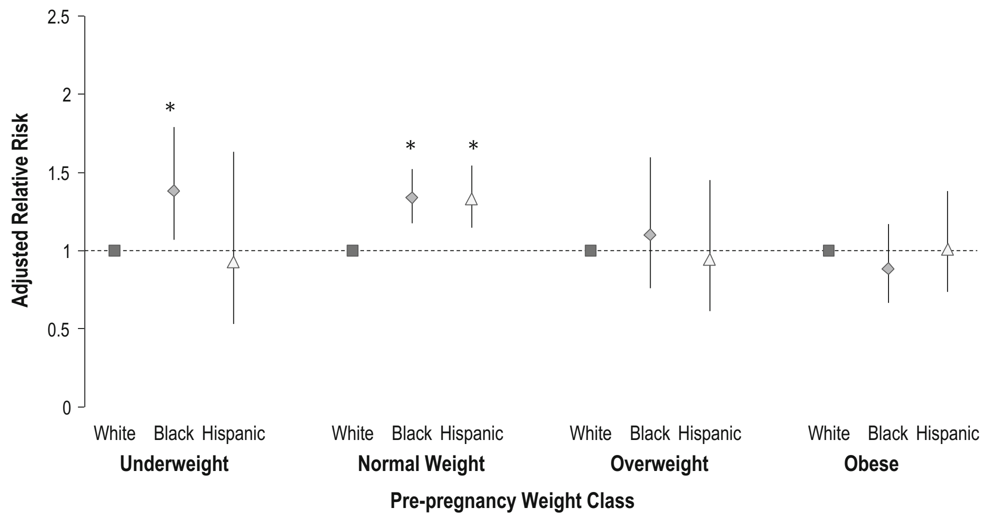

Fig. 2 Racial differences in inadequate gestational weight gain by pre-pregnancy weight class (births n = 3,788; moms n = 2,440). Stratum specific point estimates for each weight class were derived from the full adjusted model including interaction terms using the lincom command in Stata 11.1. Comparisons of Black or Hispanic women are to White women in that weight class. Point estimates for all strata are shown for completeness, but interaction terms were only significant for the obese pre-pregnancy weight class (Black: $p = 0.01$; Hispanic: $p = 0.10$). p values for interaction terms for underweight and overweight Black women were $p = 0.81$ and $p = 0.32$, respectively. p values for interaction terms for underweight and overweight Hispanic women were $p = 0.22$ and $p = 0.14$, respectively. *Significant associations at the $p \leq 0.05$ level

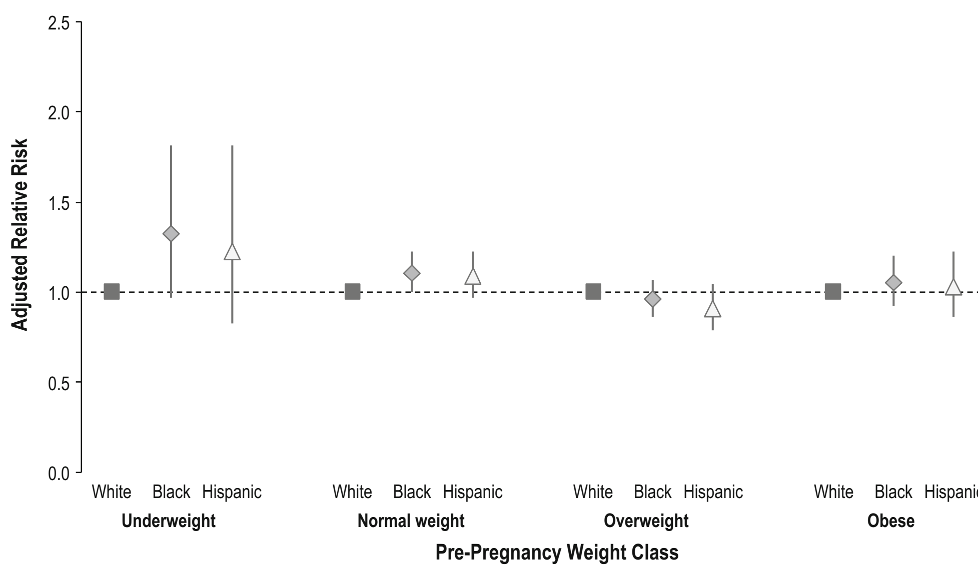

Fig. 3 Racial differences in excessive gestational weight gain by pre-pregnancy weight class (births n = 5,128; moms n = 3,190). Stratum specific point estimates for each weight class were derived from the full adjusted model including interaction terms using the lincom command in Stata 11.1. Comparisons of Black or Hispanic women are to White women in that weight class. Point estimates for all strata are shown for completeness, but interaction, overall, was not significant based on a Wald test ($p = 0.17$)

specific findings across studies difficult. Gould Rothberg et al. [9] used a trajectory of gain over pregnancy and into the postpartum period, making it difficult to determine whether weight gained during pregnancy or weight retained after pregnancy were driving results. Fontaine et al. [23] reported race-specific prevalence of inadequate GWG by trimester for each pre-pregnancy weight class, but did not adjust for covariates in overall estimates. Hickey et al. [10] closely reflected our measure of inadequate GWG, but the authors only reported stratum-specific Black–White differences for non-obese (i.e. normal weight and overweight together) women. Furthermore, while all studies were racially and ethnically diverse, racial/ethnic subgroups were not all equally balanced. Similar to our population, Fontaine et al. [23] had a population that was majority White (74 %), whereas Gould Rothberg et al. [9] studied a majority Black (59 %) population. Hickey et al. [10] was the most evenly balanced between Whites and Blacks, but had no Hispanics. These studies showed similar distributions of pre-pregnancy weight class, although Hickey et al. [10] had a higher prevalence of underweight women and our study had a lower prevalence of pre-pregnancy obesity. Despite these differences, these studies generally supported our findings.

Our findings differed from two studies investigating variation of racial/ethnic differences in inadequate GWG by pre-pregnancy BMI. Both [6, 11] tested for interaction between race/ethnicity and numerous characteristics and did not find evidence of variation in racial/ethnic differences in GWG by pre-pregnancy weight class. However, Caulfield et al. [6], who studied 3,870 singleton births to Black and White mothers between 1987 and 1989, controlled for pregnancy complications that vary in prevalence across racial/ethnic groups and pre-pregnancy weight classes [4]. This likely attenuated differences across cross-classified groups. For example, if women with pregnancy complications, like gestational diabetes or preeclampsia, experience increased monitoring by their prenatal care providers, their weight gain may also be more closely monitored and intervened upon. Differences between our findings and those of Pawlak et al. [11], who analyzed birth certificate data from 2007 to 2010 on 230,698 births to women in Colorado, are likely explained by their use of "clinically significant" criteria (a 20 % change in the odds ratio) and our use of more common, statistical criteria for assessing interaction. Additionally, they had a much lower Black population (3.9 %) than any other study, likely limiting their power to detect further interaction by pre-pregnancy weight class [11].

Notably, whereas most prior studies focused on Black–White differences, ours also included Hispanics. Of the two studies that considered all three racial/ethnic groups, Gould Rothberg et al. [9] found variation of racial/ethnic difference in GWG by pre-pregnancy BMI, while Pawlak et al. [11] did not. Direct comparison of these findings are limited due to differences in the assessment of weight gain [9] and criteria for significant interaction [11]. Future researchers should not only include Hispanic women but also consider ethnic subgroups, since other studies [21, 40, 41] have found that many birth outcomes vary by Hispanic subgroup (e.g., Puerto Rican).

Our findings are important because the association between low GWG and low birth weight (LBW) and SGA outcomes is more pronounced among underweight and normal weight women [13, 42, 43]. Since LBW affects health across the lifecourse and is more prevalent among Blacks [4, 13, 28, 43–47], these findings that racial/ethnic disparities in inadequate GWG are also most pronounced for normal weight women are of potential concern. However, it is also unclear whether racial differences in SGA or preterm birth vary by pre-pregnancy BMI, since the sparse existing literature has not yet reached a consensus [44, 48–54]. Future researchers should consider how racial/ethnic disparities in inadequate GWG may contribute to perpetuating existing disparities in LBW outcomes [20, 49, 55, 56]. Furthermore, while low GWG can be moderately improved through interventions like energy supplementation [57], the positive impact of increasing GWG through such interventions for reducing LBW and SGA outcomes is tenuous [57, 58]. However, weight gains that meet or exceed IOM recommendations may increase infant birth weight [55, 59]. Future research should examine these possible pathways to fully understand how best to intervene through GWG to improve LBW and SGA outcomes.

Psychosocial stress is a possible mechanism for differences in racial disparities in GWG by pre-pregnancy weight. Minority populations are exposed to more stress over the life course [60], and stress, due to things such as financial strain, emotional stressors, and traumatic events, is in turn associated with lower GWG [30, 61, 62], but only among underweight and normal weight women [62]. Investigating the relationship between race, pre-pregnancy BMI, and inadequate GWG in conjunction with structural and environmental stressors may be an important next step to address racial disparities in GWG and associated adverse maternal and child health outcomes.

Excessive GWG is currently more prevalent than adequate GWG [5]. Consistent with others [6, 8, 9, 11, 23], we found no evidence of racial/ethnic disparities, even after assessing differences by pre-pregnancy weight. This suggests that excessive GWG needs to be addressed in all women, however, there is evidence that, key barriers to and perceptions of GWG vary by race/ethnicity [63–65]. In particular, Black [64, 65] and Hispanic [66, 67] women are more influenced by familial perceptions of weight gain and lack of provider advice. Minority women also report less physical activity during pregnancy due to less social support [63, 64, 68] and fear of hurting the baby [64, 67]. Additionally, women with lower acculturation rely more heavily on family members' recommendations [63, 66], who advise gaining more weight than health care providers recommend. We recommend developing more culturally sensitive interventions that acknowledge these types of barriers to help women achieve healthy weight gains during pregnancy.

Our study had some limitations. First, all information was self-reported. Self-reported pre-pregnancy weight by pregnant women is highly correlated with medically recorded weight, but may be biased depending on amount of GWG and sociodemographic characteristics, especially when women are asked to recall this weight years after their pregnancy [32, 69–73]. Nonetheless, virtually all published studies depend on self-reported pre-pregnancy weight. Misreporting error is generally small and trends toward underreporting pregnancy-related weight, although this also varied by maternal characteristics [69, 74]. The literature suggests 30–40 % of women may be misclassified when grouped by IOM GWG recommendations (although this varies depending on population and subgroup), and while this misclassification does not affect associations between GWG and birth outcomes [32, 69], the impact on our particular study is unknown. Future studies using measured weight are needed to address this limitation and confirm our findings.

The IOM GWG categories are relevant only for women delivering at term. Since more than 10 % of women in NLSY delivered before 37 weeks, and gestational age differs by race-ethnicity, we used a measure of GWG adequacy to assign an appropriate category of GWG according to both BMI and gestational age. This method does not perfectly account for the non-linear relationship between length of gestation and GWG when modeling associations with birth outcomes affected by gestational age, [75] and a new approach has been published, though only for normal weight women. [76]. Nonetheless, using weight gain adequacy reduces misclassification in GWG due to length of gestation, which is a strength of our study.

While the NLSY collected a wide array of information about pregnancies occurring to participants, they did not include a number of factors on complications experienced during pregnancy that may impact GWG, such as gestational diabetes and edema. This may be a source of unmeasured confounding that we were unable to address in the current study.

Finally, interaction analyses are widely known to have limited power [77]. We thus set a more conservative type I error threshold, but we may still have been underpowered, particularly in our underweight (n = 185) and obese groups (n = 137), due to small sample size. While we still were able to detect variation of racial/ethnic differences in inadequate GWG among obese women, future analyses should aim to include more underweight women so that this relationship can be further studied.

Importantly, our study had many strengths. First, the study was longitudinal in nature and included virtually all births to women over their lifetime, which may better characterize their GWG experience. Given that many individual characteristics, such as marital status and income, can change over time, the inclusion of multiple pregnancies for women allowed us to capture these changes. Second, our data are from a large, nationally representative population of the women. This makes our findings generalizable to the external population of US women who were 14–22 in 1979, although it may be less generalizable to current populations in which prevalence of pre-pregnancy overweight and obesity have increased as well as the number of minority women of childbearing age [4]. Finally, the NLSY79 includes a comprehensive set of SES variables beyond single indicators of education and income. This is particularly important when studying racial/ethnic disparities because, beyond the known entrenched racial/ethnic differences in socioeconomic environments, historical trends that shaped and constrained the social and economic mobility of individuals' parents continue to strongly impact the socioeconomic status that the individual is able to achieve [78].

In summary, we found racial/ethnic differences in inadequate GWG among normal and underweight women. Future studies are required in large, diverse populations with measured weight and a wider array of covariates to confirm this finding and to investigate underlying mechanisms. Taking nuances in racial/ethnic disparities into account, particularly for inadequate GWG, may become particularly relevant in creating culturally relevant interventions to promote adequate GWG and potentially improving short- and long-term health outcomes of both mothers and their infants.

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Appendix

See Tables 3, 4, 5 and 6.

Table 3 Prevalence of missing values for analytic variables

Variable name	Percent missing
Gestational weight gain	2.8
Prepregnancy weight	2.1
Education	3.9
Income	14.4
Employment	2.3
Marital Status	3.7
Smoking during pregnancy	0.4

Table 4 Descriprive statistics for analytic variables between the complete case and full study sample

	Weighted percentages		p value
	In complete case (births = 6,849; mothers = 3,835)	Excluded from complete case (births = 1,994; mothers = 834)	
Race (%)[a]			<0.001
White	72.84	86.23	
Black	20.98	9.15	
Hispanic	6.18	4.62	
GWG [mean (SD)]	14.50 (7.27)	14.10 (6.58)	0.8
GWG ratio [mean (SD)]	1.26 (0.76)	1.27 (0.73)	0.06
GWG adequacy (%)		0.06	
Inadequate	26.04	23.07	
Adequate	28.53	32.5	
Excessive	45.43	44.43	
Pre-pregnancy weight (%)			<0.001
Underweight	11.39	7.74	
Normal	66.89	66.77	
Overweight	14.64	16.35	
Obese	7.09	9.14	
Parity (%)			<0.001
0	47.35	42.31	
1	30.13	35.38	
2	14.88	15.18	
3	5.19	4.95	
4	1.37	1.47	
5	0.86	0.38	
6	0.1	0.15	
7	0.09	0.12	
8	0.00	0.04	
9	0.04	0.02	
Education (%)			<0.001
Less than high school	34.03	14	
High school	53.73	66.38	
College	12.24	19.62	
Participant's mother's education (%)		<0.001	
Less than high school	43.89	29.84	
High school	49.56	60.75	
College	6.55	9.42	
Equivalized income [mean (SD)][b]	9.68 (1.31)	9.83 (1.18)	0.003
Household income [y2000 dollars; mean (SD)]	16,955.93	44,872.73	<0.001
Family size [mean (SD)]	3.74	3.27	<0.001
Employment (%)			<0.001
Unemployed	64.90	30.09	
Part-time	17.38	30.59	
Full-time	17.72	39.32	
Married (%)	60.55	78.68	<0.001
Smoking during pregnancy (%)	27.84	28.43	0.44
Gestational age [mean (SD)]	38.60 (2.23)	38.63 (2.02)	0.83
Child's birth year [mean (SD)]	1987 (5.75)	1988 (5.38)	<0.001
Mother's age at birth [mean (SD)]	25.52 (5.87)	26.74 (5.12)	<0.001

[a] N represent mothers in the data set (N = 3,835)

[b] Equivalized income was calcluated to adjust for family size. For a family of 4 in year 2000 (the year to which all incomes in our data set are standardized to) our mean equivalized income of 9.68 corresponds to an aggregate houshold income of $27,086

Table 5 Racial/ethnic differences in inadequate gestational weight gain (2009 IOM Recommendations): complete case compared to multiple imputation[a]

	Model 4: Crude association				Model 5: Adjusted main effects[b]				Model 6: Adjusted effect modification[b]			
	Complete case		Multiple imputation		Complete case		Multiple imputation		Complete case		Multiple imputation	
	RR (95 % CI)	p value	RR (95 % CI)	p value	RR (95 % CI)	p value	RR (95 % CI)	p value	RR (95 % CI)	p value	RR (95 % CI)	p value
Black	1.41 (1.28, 1.55)	<0.001	1.40 (1.28, 1.52)	<0.001	1.26 (1.13, 1.41)	<0.001	1.25 (1.13, 1.39)	<0.001	1.34 (1.18, 1.52)	<0.001	1.35 (1.20, 1.51)	<0.001
Hispanic	1.27 (1.13, 1.43)	<0.001	1.22 (1.10, 1.36)	<0.001	1.22 (1.07, 1.40)	<0.001	1.16 (1.02, 1.31)	0.02	1.33 (1.15, 1.54)	<0.001	1.26 (1.10, 1.44)	<0.01
									Wald test: p value = 0.08		Wald test: p value = 0.01	
Underweight[c]												
Black	1.43 (1.07, 1.92)	0.02	1.36 (1.08, 1.71)	0.01	–	–	–	–	1.38 (1.11, 1.72)	0.01	1.25 (0.98, 1.59)	0.07
Hispanic	0.72 (0.38, 1.35)	0.30	0.85 (0.52, 1.39)	0.51	–	–	–	–	1.10 (0.81, 1.50)	0.80	1.20 (0.49, 1.35)	0.43
Normal weight[c]												
Black	1.56 (1.37, 1.78)	<0.001	1.51 (1.37, 1.67)	<0.001	–	–	–	–	–	–	–	–
Hispanic	1.41 (1.19, 1.67)	<0.001	1.35 (1.20, 1.53)	<0.001	–	–	–	–	–	–	–	–
Overweight[c]												
Black	1.30 (0.85, 1.99)	0.22	1.34 (0.99, 1.82)	0.06	–	–	–	–	0.88 (0.70, 1.12)	0.61	0.82 (0.87, 1.66)	0.27
Hispanic	1.31 (0.83, 2.09)	0.25	1.03 (0.70, 1.51)	0.89	–	–	–	–	0.93 (0.58, 1.49)	0.79	0.82 (0.61, 1.36)	0.64
Obese[c]												
Black	0.93 (0.64, 1.36)	0.72	0.90 (0.70, 1.15)	0.40	–	–	–	–	0.94 (0.66, 1.36)	0.39	0.91 (0.64, 1.07)	0.14
Hispanic	1.20 (0.78, 1.85)	0.41	1.04 (0.78, 1.38)	0.79	–	–	–	–	1.01 (0.77, 1.31)	0.96	1.01 (0.75, 1.35)	0.95

[a] Complete cases sample: 3,788 births to 2,440 mothers; multiple imputation sample: 4,615 births to 2,861 mothers

[b] Models adjusted for pre-pregnancy weight class, parity, participant's education, participant's mother's education, equivalized income, employment, marital status, smoking during pregnancy, child's birth year, and mother's age at birth

[c] Point estimates for racial/ethnic differences within strata of pre-pregnancy weight

Table 6 Racial/ethnic differences in excessive gestational weight gain (2009 IOM Recommendations): complete case compared to multiple imputation[a]

	Model 7: Crude association				Model 8: Adjusted main effects[b]				Model 9: Adjusted effect modification[b]			
	Complete case		Multiple imputation		Complete case		Multiple imputation		Complete case		Multiple imputation	
	RR (95 % CI)	p value	RR (95 % CI)	p value	RR (95 % CI)	p value	RR (95 % CI)	p value	RR (95 % CI)	p value	RR (95 % CI)	p value
Black	1.12 (1.05, 1.20)	<0.001	1.09 (1.03, 1.16)	<0.01	1.06 (0.99, 1.14)	0.11	1.05 (0.98, 1.12)	0.18	1.11 (1.00, 1.23)	0.05	1.09 (0.99, 1.20)	0.07
Hispanic	1.09 (1.01, 1.18)	0.04	1.08 (1.01, 1.16)	0.02	1.03 (0.95, 1.12)	0.51	1.02 (0.95, 1.11)	0.55	1.09 (0.97, 1.23)	0.16	1.08 (0.97, 1.20)	0.15
									Wald test: p value = 0.17		Wald test p value = 0.20	
Underweight[c]												
Black	1.16 (0.79, 1.70)	0.44	1.23 (0.95, 1.59)	0.12	–	–	–	–	1.32 (0.97, 1.81)	0.08	1.22 (0.96, 1.57)	0.11
Hispanic	1.44 (0.92, 2.23)	0.11	1.04 (0.71, 1.53)	0.85	–	–	–	–	1.22 (0.82, 1.81)	0.32	0.96 (0.67, 1.44)	0.93
Normal Weight[c]												
Black	0.93 (0.83, 1.04)	0.19	1.09 (1.00, 1.18)	0.05	–	–	–	–	–	–	–	–
Hispanic	0.99 (0.87, 1.14)	0.92	1.10 (1.00, 1.21)	0.06	–	–	–	–	–	–	–	–
Overweight[c]												
Black	0.93 (0.84, 1.05)	0.24	0.99 (0.91, 1.08)	0.87	–	–	–	–	0.96 (0.87, 1.07)	0.45	1.02 (0.87, 1.06)	0.45
Hispanic	0.86 (0.74, 1.00)	0.04	0.93 (0.83, 1.04)	0.21	–	–	–	–	0.91 (0.79, 1.04)	0.16	0.83 (0.81, 1.04)	0.19
Obese[c]												
Black	1.06 (0.90, 1.26)	0.48	0.99 (0.89, 1.11)	0.92	–	–	–	–	1.05 (0.93, 1.20)	0.42	0.92 (0.90, 1.16)	0.75
Hispanic	0.94 (0.76, 1.18)	0.61	1.02 (0.90, 1.17)	0.73	–	–	–	–	1.03 (0.86, 1.22)	0.75	1.05 (0.90, 1.23)	0.53

[a] Complete cases sample: 5,128 births to 3,190 mothers; multiple imputation sample: 6,182 births to 3,704 mothers

[b] Models adjusted for pre-pregnancy weight class, parity, participant's education, participant's mother's education, equivalized income, employment, marital status, smoking during pregnancy, child's birth year, and mother's age at birth

[c] Point estimates for racial/ethnic differences within strata of pre-pregnancy weight

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