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Article

Racial and ethnic disparities in adverse birth outcomes: Differences by racial residential segregation

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ABSTRACT

Racial and ethnic disparities in adverse birth outcomes have persistently been wide and may be explained by individual and area-level factors. Our primary objective was to determine if county-level black-white segregation modified the association between maternal race/ethnicity and adverse birth outcomes using birth records from the National Center for Health Statistics (2012). Based on maternal residence at birth, county-level black-white racial residential segregation was calculated along five dimensions of segregation: evenness, exposure, concentration, centralization, and clustering. We conducted a two-stage analysis: (1) county-specific logistic regression to determine whether maternal race and ethnicity were associated with preterm birth and term low birth weight; and (2) Bayesian meta-analyses to determine if segregation moderated these associations. We found greater black-white and Hispanic-white disparities in preterm birth in racially isolated counties (exposure) relative to non-isolated counties. We found reduced Hispanic-white disparities in term low birth weight in racially concentrated and centralized counties relative to non-segregated counties. Area-level poverty explained most of the moderating effect of segregation on disparities in adverse birth outcomes, suggesting that area-level poverty is a mediator of these associations. Segregation appears to modify racial/ethnic disparities in adverse birth outcomes. Therefore, policy interventions that reduce black-white racial isolation, or buffer the poor social and economic correlates of segregation, may help to reduce disparities in preterm birth and term low birth weight.

Introduction

Adverse birth outcomes, such as preterm birth (less than 37 completed weeks of gestation) and low birth weight (< 2500 g) are associated with increased morbidity and mortality throughout the life course. Poor health and developmental consequences of preterm birth arise from immature organ systems (Institute of Medicine, 2007), while for low birth weight they arise from inadequate fetal growth, which is determined by length of gestation, poor fetal weight gain for a given length of gestation, or both (Institute of Medicine, 1985). In the United States (US) in 2015, 9.6% of births were preterm and 2.8% were low birth weight at term (at least 37 completed weeks of gestation) (Martin, Hamilton, Osterman, Driscoll, & Mathews, 2017). Following declining preterm birth and term low birth weight rates since the mid to late 2000s, recent increases in both rates are of concern (Hamilton, Martin, Osterman, Curtin, & Matthews, 2015; Martin, Hamilton, Osterman, et al., 2013; Martin, Hamilton, Ventura, et al., 2013; Martin et al., 2010a,b; Martin, Hamilton, Osterman, Curtin, & Matthews, 2015; Martin et al., 2017; Martin et al., 2011; Martin et al., 2012).

These worrying trends are compounded by recent increases in racial and ethnic disparities in preterm birth in particular. Preterm birth and term low birth weight rates are higher for Hispanic births compared to non-Hispanic white (hereafter white) births. For non-Hispanic black (hereafter black) births compared to white births, the disparity is even more profound: 1.5 times that for preterm birth and more than two times that for term low birth weight (Martin et al., 2017).

In 2003, Misra and colleagues proposed a multilevel, life course framework for perinatal health (Misra, Guyer, & Allston, 2003). However, the majority of studies on racial and ethnic disparities in adverse birth outcomes have focused on individual maternal factors (Braveman

Abbreviations: CrI, credible interval; OR, odds ratio; SD, standard deviation

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et al., 2017; Braveman et al., 2015; Dunlop, Kramer, Hogue, Menon, & Ramakrishan, 2011; Harville, Knoepp, Wallace, & Miller, 2018; Hogue, Menon, Dunlop, & Kramer, 2011; Hong et al., 2017; Kramer, Hogue, Dunlop, & Menon, 2011; Menon, Dunlop, Kramer, Fortunato, & Hogue, 2011; Mohlman & Levy, 2016; Straughen, Sipahi, Uddin, Misra, & Misra, 2015; Strutz et al., 2014; Zhao et al., 2015), which only accounted for one-third of black-white differences (Goldenberg et al., 1996). Area-level factors such as racial residential segregation may further explain these disparities.

Racial residential segregation is a form of structural racism that refers to the physical separation of the races, typically imposed through enforced residence in specific urban areas (Williams & Collins, 2001). In the US, segregation between white and non-white populations has been enacted through institutional policies in the form of federal housing programs, urban renewal legislation, and zoning restrictions, as well as discriminatory housing lending and real estate practices, racially restrictive covenants of neighborhood associations, and racial violence (Massey & Denton, 1993). All non-white populations have experienced segregation, although the black population has experienced uniquely high levels of segregation that were evident as early as the 1880s and gave rise to persistent discriminatory social structures that exist today (Logan, Zhang, Turner, & Shertzer, 2015; Massey & Denton, 1993).

Segregation is posited as a fundamental cause of racial disparities in health as it is a driver of racial differences in socioeconomic status that are determined by differential access to opportunities (Williams & Collins, 2001). Kramer and Hogue outline four hypothesized mechanistic pathways between segregation and health: individual socioeconomic status; unhealthy neighborhood environments (i.e., fewer healthy food options and increased violence and crime); social capital (i.e., social support); and individual health behaviors and exposure to stress (Kramer & Hogue, 2009a).

Massey and Denton identified five distinct dimensions of segregation: evenness, exposure, concentration, centralization, and clustering (Table A1 in supplemental materials) (Massey & Denton, 1988). High levels of segregation on four or more dimensions is considered hypersegregation (Massey & Denton, 1989). The most salient dimension of segregation may vary by health outcome (Kramer & Hogue, 2009a). Furthermore, dimensions of segregation may be differentially associated with adverse birth outcomes through the aforementioned pathways due to deleterious effects of poorer socioeconomic and built environments and discrimination, or protective effects of cohesive social environments (Bell, Zimmerman, Almgren, Mayer, & Huebner, 2006). Moreover, segregation may be more harmful to non-white pregnancies as segregation is associated with lower socioeconomic status and poorer self-rated health among blacks but not whites (Cutler & Glaeser, 1997; Subramanian, Acevedo-Garcia, & Osypuk, 2005).

A recent systematic review and meta-analysis of race-stratified studies found the dimension of exposure was associated with increased risk of preterm birth and low birth weight among black and white women (Mehra, Boyd, & Ickovics, 2017). Among black women, findings for evenness and clustering were mixed. Few studies examined dimensions of concentration and centralization, none found associations. Hypersegregation was associated with increased risk of various adverse birth outcomes. Among Hispanic women, only exposure was associated with low birth weight (McFarland & Smith, 2011; Walton, 2009). Rarely have studies examined associations between segregation and term low birth weight (Austin, Harper, & Strumpf, 2016).

Hypersegregation (Osypuk & Acevedo-Garcia, 2008), and clustering but not exposure (Grady, 2010) have been shown to moderate racial disparities in preterm birth. We aimed to extend the current literature by examining whether multiple dimensions of segregation modified black-white and Hispanic-white disparities in preterm birth and term low birth weight. Conceptually, segregation may be directly or indirectly associated with health (Acevedo-Garcia, 2000). Using a social inequality perspective, whereby segregation influences health through differential proximity to economic and social resources (Reardon, 2006), we test the hypotheses that racial/ethnic disparities in adverse birth outcomes are greater in segregated relative to non-segregated counties, particularly for dimensions of segregation that are associated with area-level economic and social measures, and segregation is indirectly associated with these disparities through area-level poverty.

Table 1
Distribution of counties by census division, United States, 2012.

Census division	Counties in preterm birth analyses % (n = 376)	Counties in term birth analyses % (n = 294)
New England	2.4	2.7
Middle Atlantic	11.7	10.2
East North Central	18.4	16.7
West North Central	6.7	5.8
South Atlantic	32.7	33.7
East South Central	4.3	3.1
West South Central	12.8	14.6
Mountain	2.7	3.1
Pacific	8.5	10.2

Material and methods

Study population

The study population included singleton live births in the US in 2012 obtained from the National Center for Health Statistics (National Center for Health Statistics). In an effort to include viable births and reduce measurement error, only births with gestation length between 20 and 44 weeks and birth weight of at least 500 g were included (American College of Obstetricians and Gynecologists, 2017; Bell et al., 2006; Boulet, Alexander, & Salihu, 2005; World Health Organization, 2011). Births were included if maternal race/ethnicity was either white, black, or Hispanic. Births using the 2003 revision of the birth certificate were included since this version collects information on important confounding variables (i.e., principal source of payment), and information collected between this and previous versions are not compatible (Centers for Disease Control and Prevention, 2012).

Exposure classification

Counties were used as the geographic spatial unit because there is significant between-county variation in both preterm birth and low birth weight rates and segregation (Nyarko & Wehby, 2012), this unit of analysis has been used in previous research on adverse birth outcomes (Brown, Hogue, & Kramer, 2012; Nyarko & Wehby, 2012), and counties are political and administrative units at which public and health policy interventions can be implemented (Shaw, Pickett, & Wilkinson, 2010).

County-level black-white segregation was calculated across five dimensions of segregation—evenness, exposure, concentration, centralization, and clustering—as identified by Massey and Denton (Massey & Denton, 1988). Using methodology of the US Census Bureau (Iceland, Weinberg, & Steinmetz, 2002), we calculated indices for each dimension of segregation (see Table A1). We also calculated hypersegregation, defined as segregation on at least four dimensions (Massey & Denton, 1989).

Data to calculate segregation indices were obtained from 2012, 5-year estimates from the American Community Survey (United States Census Bureau, 2012). Each dimension was calculated across micro-level spatial units (census tracts) within macro-level spatial units (counties). Typically, indices range from 0 to 1, although the relative concentration index ranges from −1 to 1. Higher values indicate higher levels of segregation. Based on cut-off values of Massey and Denton (Massey & Denton, 1989), counties was considered segregated if evenness or clustering were > 0.6, exposure or concentration were > 0.7, and centralization was > 0.8. Sensitivity analyses used the cut-off value of 0.6 for all dimensions of segregation, as has been done in previous research (Hearst, Oakes, & Johnson, 2008; Osypuk & Acevedo-Garcia, 2008). Maps were created using ArcGIS (version 10.4.1, Environmental Systems Research Institute (ESRI), Redlands, CA, 2015) using 2012 TIGER/Line Shapefiles prepared by the US Census Bureau.

To ensure reliable measures of segregation, particularly in areas with small minority populations (Iceland et al., 2002), counties with an overall population of at least 100,000 and a population of black individuals of at least 5000 were included, similar to previous studies (Britton & Shin, 2013; Ellen, 2000; Walton, 2009). Additionally, counties were included if the first stage statistical models converged and county-level parameter estimates were valid. Counties that were included in analyses were in each of the nine US Census Bureau divisions, groupings of three to eight adjacent states (Bureau of the Census, 1994) (Table 1). The majority of counties were in the South Atlantic, East North Central, and West South Central divisions.

Birth outcomes

Data on birth outcomes were obtained from the birth certificate. Preterm birth was defined as birth before 37 completed weeks of gestation. Gestational age was measured as a continuous variable in weeks as either the date from last menstrual period to date of birth (when available), or based on the obstetric estimate of gestation (Centers for Disease Control and Prevention, 2012). In 2012, 5.4% of official gestational ages were based on the obstetric estimate of gestation. Low birth weight was defined as < 2500 g. Birth weight was measured as a continuous variable in grams. Low birth weight was determined for term births (births of at least 37 weeks gestation).

Covariates

Individual-level covariates (obtained from the birth certificate) and county-level covariates (obtained from 2012, 5-year estimates from the American Community Survey) used in previous studies that are known or suspected confounders of segregation and adverse birth outcomes were considered for inclusion in the analyses. Relevant individual-level covariates were included in analyses to reduce cross level confounding by individual-level covariates (Blakely & Woodward, 2000). Individual-level covariates considered to be mediators of the association between maternal factors and adverse birth outcomes (e.g., education, marital status, hypertension, diabetes, cigarette use) (Kramer, Cooper, Drews-Botsch, Waller, & Hogue, 2010) were not included in analyses.

Statistical analysis

We used a two-stage statistical modeling approach (DuMouchel & Harris, 1983; Gelman, Carlin, Stern, & Rubin, 2003; Lindley & Smith, 1972) to properly link individual-level covariate and area-level segregation regression models within a computationally tractable framework. The method allowed us to correctly quantify the uncertainty in each stage of the model, leading to an accurate assessment of whether county-level black-white segregation modified the association between maternal race/ethnicity and adverse birth outcomes.

In the first-stage analysis, for each county, logistic regression models were run separately for each adverse birth outcome. Each of the fitted models included the individual-level covariates: maternal race/ethnicity, nativity, age, Medicaid insurance status, prenatal care initiation during the first trimester, parity, method of delivery, and sex of the infant. Additionally, previous preterm birth was used in models for preterm birth, and gestational age was used in models for term low birth weight. From these models, for each county and adverse birth outcome, estimates and standard errors for regression parameters associated with maternal race/ethnicity were obtained. These estimates describe the association between maternal race/ethnicity and adverse birth outcome specific to an individual county. The estimates and standard errors were then used as input to the second stage model. All first stage models were fit using SAS software (version 9.4, The SAS Institute Inc., Cary, NC, 2013), using Proc LOGISTIC.

In the second-stage analysis, separate maternal race/ethnicity and adverse birth outcome-specific Bayesian meta-analyses were conducted to determine if each dimension of segregation moderated the association between individual-level maternal race/ethnicity and preterm birth and term low birth weight. The second-stage model attempts to explain variability in the associations estimated in the first stage using county-level factors, including the dimensions of segregation. By introducing a regression model for the first-stage parameters, the second-stage analysis is investigating the interaction between the individual-level factor of interest from stage one and the included county-level factors. An estimated regression parameter from stage two that is not statistically significantly different from zero indicates that the interaction is unimportant.

For a specific maternal race/ethnicity and adverse birth outcome of interest, the estimated regression parameter for a particular county (obtained in first stage analyses) was assumed to follow a normal distribution with a mean value equal to the true, but unknown, regression parameter value for that county, and standard deviation equal to the county-specific standard error obtained from stage one. Unobserved true regression parameter values, which describe the association between maternal race/ethnicity and risk of adverse birth outcome, were then modeled using a multiple linear regression framework as a function of county-specific dimensions of segregation, and county-level covariates including standardized values for log of population size and percent black, and census region (Northeast, Midwest, South, and West) (Bureau of the Census, 1994). Percent black was not included in analyses with the dimension of exposure as we observed high biserial correlation values ($r_{\text{bis}} > 0.95$) (Sheskin, 2011). Additional models included standardized values of percent poverty. These county-level covariates help to explain the variability in the first-stage parameter estimates and to identify significant interactions with maternal race/ethnicity with respect to the impact on adverse birth outcomes. For example, if we found a significant segregation association in stage two, this would suggest that the impact of race/ethnicity on the risk of an adverse birth outcome differs by segregation level. Full details on the statistical modeling framework are provided in supplemental materials.

Second-stage analyses were fitted in the Bayesian setting using Markov chain Monte Carlo sampling techniques using Proc MCMC within SAS software. Standard weakly informative prior distributions were selected for parameters involved in multiple linear regression models. Regression parameters were assigned independent normal prior distributions with a mean equal to zero and standard deviation equal to 100, while the regression variance parameter was assigned an inverse gamma (0.01, 0.01) prior distribution. Convergence was investigated through visually inspecting individual parameter trace plots and calculating the Geweke diagnostic (Geweke, 1992) for each parameter, with no obvious signs of non-convergence across each of the fitted models. The number of posterior samples needed to make an accurate inference was determined by analyzing the effective sample size for each parameter. Full details on the number of posterior samples obtained and burn-in amounts for each model are given in supplemental materials.

Results

In 2012, there were 3,960,796 live births. For preterm birth analyses, 2,036,564 singleton live births (between 20 and 44 weeks of gestation with a birth weight of at least 500 g) across 376 counties met the selection criteria and were included. For term birth weight analyses, 1,701,777 singleton live births (between 37 and 44 weeks of gestation with a birth weight of at least 500 g) across 294 counties were included (number and distribution of counties by census division shown in Table 1). The difference in the number of counties for preterm birth and

Table 2
Maternal characteristics of singleton live births by preterm birth and term low birth weight status, United States, 2012.

Maternal characteristic	All births		Term births	
	Preterm birth % (n = 197,748)	Term birth % (n = 1,838,816)	Low birth weight % (n = 43,903)	Normal weight % (n = 1,657,874)
Demographics				
Race/ethnicity				
White	41.5	52.3	38.2	50.3
Black	27.4	18.1	33.1	18.0
Hispanic	31.2	29.7	28.6	31.7
Nativity				
US-born	77.7	77.5	80.3	76.3
Age at delivery (years)				
18 or younger	3.3	2.2	3.7	2.2
18–34	79.3	82.5	82.4	82.4
35 and older	17.4	15.2	13.8	15.4
Prior obstetric history				
Prior preterm birth	6.0	1.8	–	–
Health care access and use				
Medicaid insurance	52.4	43.6	57.2	44.2
First trimester prenatal care initiation	72.8	74.7	65.6	74.6
Pregnancy-related				
Multiparous	60.8	59.2	50.9	59.5
Cesarean section	40.5	30.7	36.5	30.6
Male infant	53.7	50.9	41.2	51.1
Gestational age in weeks (mean, SD)	–	–	38.4 (1.5)	39.3 (1.3)

Abbreviation: SD, standard deviation.

term low birth weight analyses was due to fewer first stage analysis models that converged with valid county-level parameter estimates for term low birth weight analyses.

In the study population, 9.7% of births were preterm and 2.6% of term births were low birth weight. Distributions of maternal characteristics by preterm birth and term low birth weight status are shown in Table 2. For first-stage analyses, approximately 50% of women were white, 30% were Hispanic, and 20% were black. Among all live births in 2012, the distribution of these races/ethnicities were 59% white, 25% Hispanic, and 16% black.

Dimensions of segregation were calculated for all counties (N = 3221). Distribution of dimensions of segregation are shown in Table 3. Due to the low number of counties that were clustered, results are included in supplemental materials (Table A3). To aid in the visualization of each dimension of segregation, examples that best illustrate the spatial distribution of black individuals for highly segregated and non-segregated counties are shown in Fig. 1.

Evenness is the degree to which each neighborhood has the same proportion of minority members as the urban area as a whole (Massey & Denton, 1988). For evenness, darker shades of blues and reds indicate greater differences between the proportion of population that is black in census tracts compared to the county. For other dimensions of segregation, darker shades of red indicate a higher proportion of the census tract population that is black. Exposure is typically measured as the degree to which minority members are exposed to other minority members (i.e., isolation) (Massey & Denton, 1988). Separation of census tracts with high and low proportions of the population that is black, indicate the black population is only being exposed to itself. Concentration, centralization, and clustering are spatial dimensions of segregation that take into account the spatial relationships of census tracts and are more intuitive to understand. Concentration is the degree to which minority members occupy a small proportion of the total area of an urban area; centralization is the degree to which the minority group is centrally located within an urban area; and clustering is the degree to which minority neighborhoods are contiguous and tightly clustered within an urban area (Massey & Denton, 1988).

Preterm birth

County-specific posterior mean odds ratios and highest posterior density 95% credible intervals (CrI) derived from second-stage analyses for preterm birth for black compared to white women, by level of segregation, are shown in Fig. 2. Compared to white women, black women had higher odds of preterm birth in all counties for each dimension of segregation (i.e., lower 95% CrI was above 1). The mean black-white disparity in preterm birth for segregated relative to non-

Table 3
Distribution of county-level black-white segregation, United States, 2012.

Dimension (and measure) of segregation	All counties[a] (N = 3221)		Counties included in the preterm birth analysis (n = 376)		Counties included in the term low birth weight analysis (n = 294)	
	Segregated No. (%)	Not segregated No. (%)	Segregated No. (%)	Not segregated No. (%)	Segregated No. (%)	Not segregated No. (%)
Evenness (Index of dissimilarity)	466 (15.1)	2622 (84.9)	78 (20.7)	298 (79.3)	68 (23.1)	226 (76.9)
Exposure (Isolation index)	91 (2.9)	2999 (97.1)	26 (6.9)	350 (93.1)	25 (8.5)	269 (91.5)
Concentration (Relative concentration index)	515 (17.7)	2391 (82.3)	86 (22.9)	290 (77.1)	61 (20.8)	233 (79.3)
Centralization (Absolute centralization index)	473 (16.1)	2459 (83.9)	69 (18.4)	307 (81.7)	55 (18.7)	239 (81.3)
Clustering (Index of spatial proximity)	3 (0.1)	2924 (99.9)	3 (0.8)	373 (99.2)	2 (0.7)	292 (99.3)
Hypersegregation	16 (0.6)	2890 (99.5)	6 (1.6)	370 (98.4)	5 (1.7)	289 (98.3)

[a] Some counties have missing values for different dimensions of segregation.

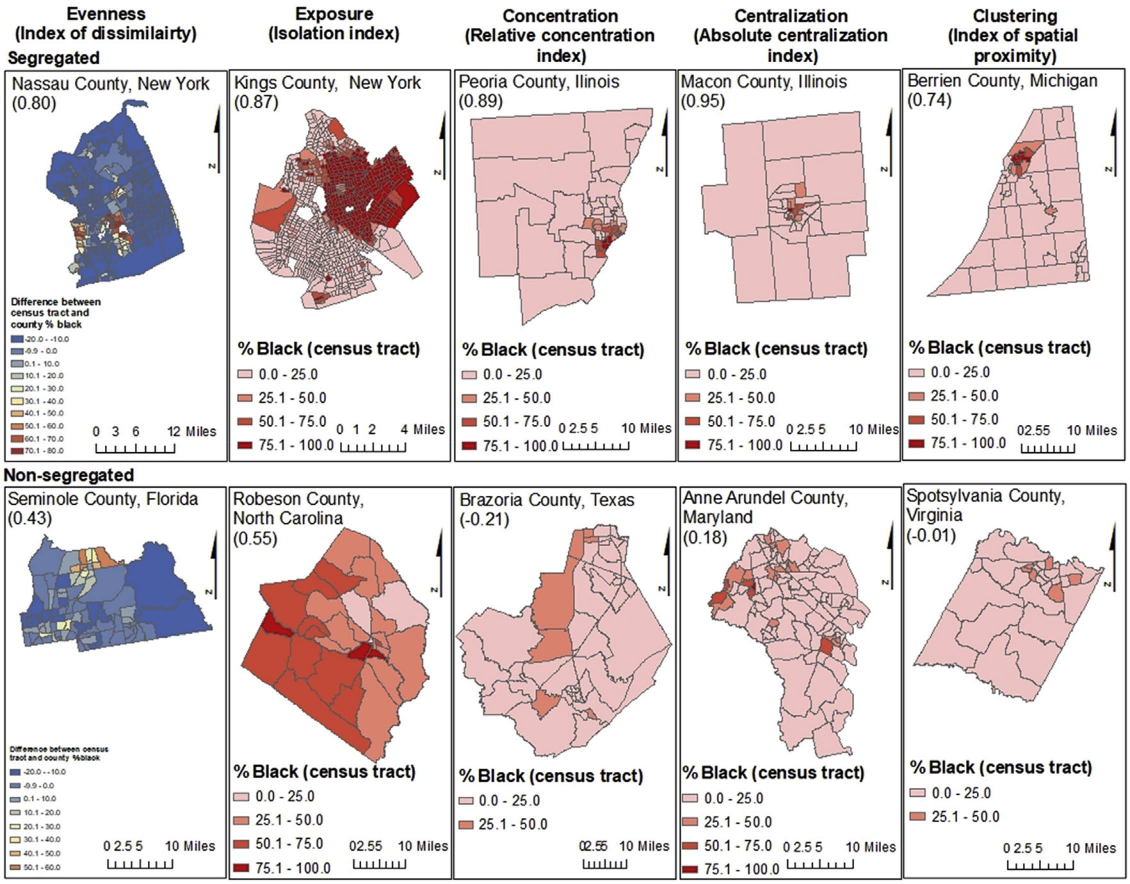

Fig. 1. Distribution of the proportion of black individuals for segregated and non-segregated counties for each dimension of segregation, United States, 2012. For evenness, the difference between the percent of the population that is black at the census tract and county level is shown. Values above zero indicate the percent of the population that is black at the census tract level is greater than the percent of the population that is black at the county level. For the other dimensions of segregation, the distribution of the percent of the population that is black at the census tract level is shown. The level of segregation for each county appears in parentheses. Data were obtained from 2012, 5-year estimates from the American Community Survey.

segregated counties was greater for evenness and exposure, and reduced for concentration and centralization. Plots for other maternal race/ethnicity and adverse birth outcome associations appear in supplemental materials (Figure A1, these data are also summarized in Table A2). Compared to white women, Hispanic women had higher odds of preterm birth in 72%–77% of counties across dimensions of segregation.

Table 4 shows the multiplier of the odds ratios (and 95% CrI) from Bayesian meta-analyses in the second-stage analyses for maternal race/ethnicity for women residing in segregated relative to non-segregated counties (i.e., the interaction results). For example, if the regression parameter comparing segregated and non-segregated counties was equal to 0, indicating no moderation by segregation, then the exponentiated value would be 1 and the odds of preterm birth would be the same in segregated relative to non-segregated counties (i.e., no significant interaction). However, in the case of the black-white disparity in preterm birth for exposure, the parameter estimate was 0.067 and the exponentiated value was 1.069, indicating there was a 6.9 increase in the odds of preterm birth in black compared to white women residing in isolated relative to non-isolated counties (i.e., a significant interaction effect).

On average, black-white and Hispanic-white disparities in preterm birth were greater in isolated counties (exposure) relative to non-isolated counties. The Hispanic-white disparity in preterm birth had the greatest magnitude. After controlling for area-level poverty, exposure only moderated the Hispanic-white disparity in preterm birth (Table 4). There were no differences in disparities between segregated and non-segregated counties for evenness, concentration, centralization, and clustering (results for clustering are presented in Table A3 in supplemental materials).

Term low birth weight

Compared to white women, black women had higher odds of term low birth weight in all counties for each dimension of segregation (i.e., lower 95% CrI was above 1, see Figure A1 in supplemental materials). Hispanic and white women had similar odds of term low birth weight in 82%–93% of counties across dimensions of segregation. On average there were reduced Hispanic-white disparities in term low birth weight in more racially concentrated and centralized counties, relative to non-segregated counties. After controlling for area-level poverty, these disparities were no longer significant (Table 4). There were no differences in disparities between segregated and non-segregated counties for evenness, exposure, and clustering.

Sensitivity analyses

Using the cut-off point of 0.6 resulted in similar findings for 10 of 12 maternal race/ethnicity and adverse birth outcome associations (Table A4 in supplemental materials).

Discussion

In this study on a national sample of births, we examined the moderating effect of various dimensions on segregation on disparities in adverse birth outcomes by maternal race/ethnicity. We found county-

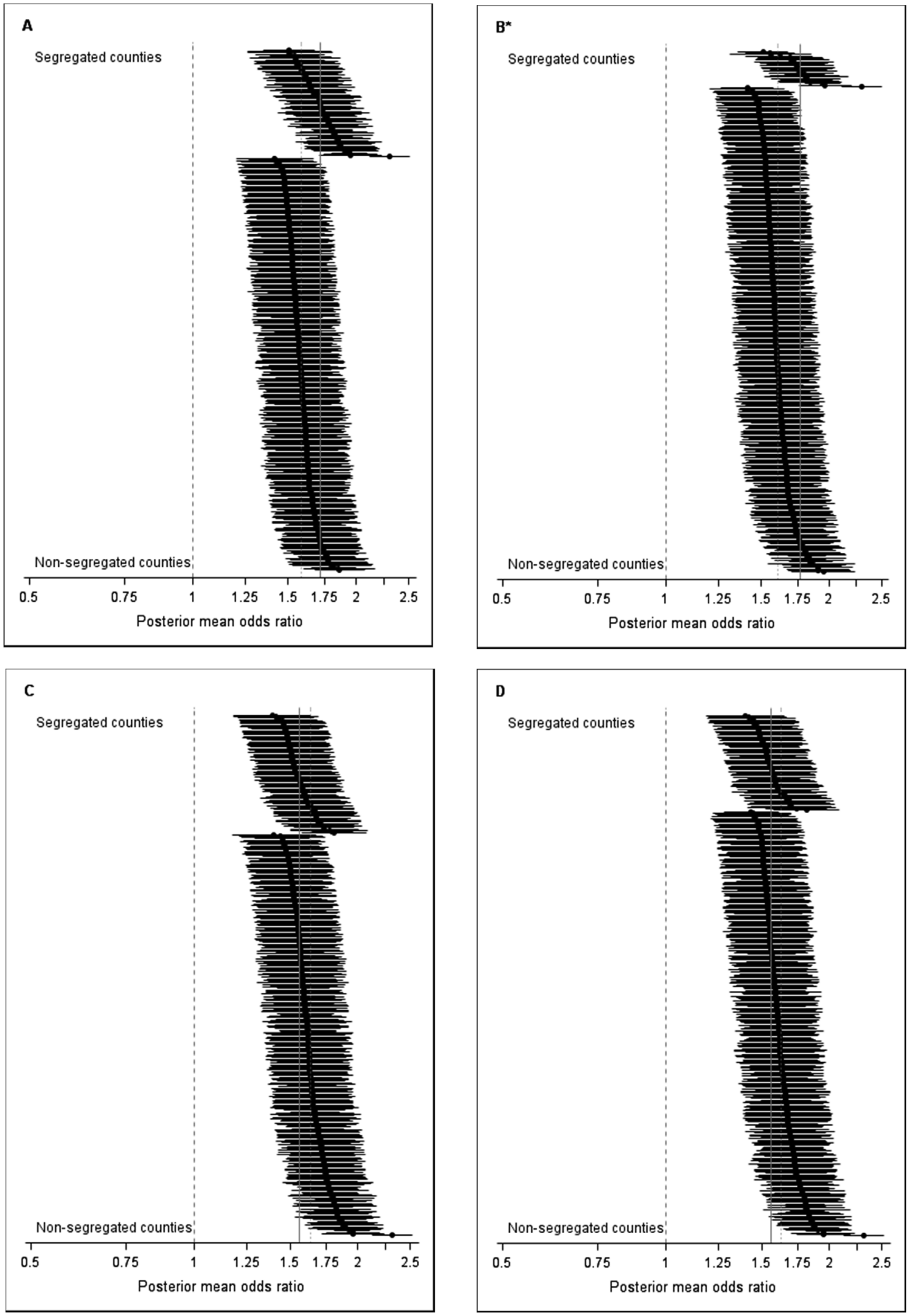

Fig. 2. County-specific posterior mean odds ratios and highest posterior density 95% credible intervals for black compared to white women for preterm birth by level of segregation, United States, 2012
Panel A is evenness, panel B is exposure, panel C is concentration, and panel D is centralization. An asterisk indicates that the 95% credible interval for the posterior mean odds ratio multiplier for segregated relative to non-segregated counties excludes 1. Dots represent county-specific posterior mean odds ratios and horizontal lines represent highest posterior density 95% credible intervals. Vertical lines indicate mean odds ratios for segregated counties (solid line), mean odds ratios for non-segregated counties (dotted line), and odds ratio of 1 (dashed line).

Table 4
Posterior mean odds ratio multiplier and highest posterior density 95% credible interval for maternal race/ethnicity and adverse birth outcome associations comparing segregated and non-segregated counties with or without controlling for area-level poverty, United States, 2012.

Maternal race/ethnicity	Evenness		Exposure		Concentration		Centralization	
	Posterior mean OR multiplier	95% CrI	Posterior mean OR multiplier	95% CrI	Posterior mean OR multiplier	95% CrI	Posterior mean OR multiplier	95% CrI
Not controlling for area-level poverty								
Preterm birth								
Black (vs. white)	1.042	0.990, 1.101	**1.069**	**1.004, 1.135**	0.966	0.912, 1.019	0.976	0.920, 1.034
Hispanic (vs. white)	1.029	0.963, 1.101	**1.120**	**1.033, 1.214**	0.943	0.877, 1.004	0.995	0.937, 1.059
Term low birth weight								
Black (vs. white)	0.963	0.882, 1.052	1.001	0.909, 1.102	0.932	0.849, 1.030	0.949	0.860, 1.048
Hispanic (vs. white)	0.995	0.896, 1.108	1.035	0.911, 1.177	**0.900**	**0.810, 0.993**	**0.876**	**0.789, 0.973**
Controlling for area-level poverty								
Preterm birth								
Black (vs. white)	1.035	0.980, 1.091	1.041	0.975, 1.115	0.963	0.912, 1.016	0.969	0.915, 1.025
Hispanic (vs. white)	1.041	0.978, 1.111	**1.148**	**1.049, 1.257**	0.950	0.894, 1.012	1.004	0.944, 1.070
Term low birth weight								
Black (vs. white)	0.972	0.890, 1.065	1.027	0.926, 1.136	0.934	0.845, 1.028	0.957	0.855, 1.073
Hispanic (vs. white)	1.017	0.919, 1.114	1.102	0.955, 1.252	0.908	0.813, 1.020	0.904	0.812, 1.004

Abbreviations: CrI, credible interval; OR, odds ratio.
Note: Bolded entries represent 95% credible intervals that exclude 1.

specific odds of both preterm birth and term low birth weight were consistently higher among black compared to white women, however only exposure moderated the black-white disparity in preterm birth. County-specific odds of preterm birth, but not term low birth weight, were generally higher among Hispanic compared to white women. The Hispanic-white disparity in preterm birth was greater in isolated counties (exposure), and the Hispanic-white disparity in term low birth weight was reduced in concentrated and centralized counties, relative to non-segregated counties. After controlling for area-level poverty, only the moderating effect of exposure on the Hispanic-white disparity in preterm birth remained statistically significant.

We found significant black-white disparities in preterm birth and term low birth weight in all counties. The majority of counties also had significant Hispanic-white disparities in preterm birth. Our findings highlight the need for each county to address racial disparities in adverse birth outcomes.

Studies assessing the moderating effect of segregation on racial disparities in adverse birth outcomes have found black-white disparities in preterm birth were greater in hypersegregated relative to non-hypersegregated metropolitan areas (typically one or more counties that contain a city of 50,000 or more inhabitants (Bureau of the Census, 1994) (Osypuk & Acevedo-Garcia, 2008). Using local spatial indices of exposure and clustering, black-non-black disparities in preterm birth were reduced in high relative to low racially clustered areas, but not high relative to low racially isolated areas (exposure) (Grady, 2010). We found black-white and Hispanic-white disparities in preterm birth were greater in isolated relative to non-isolated counties (exposure). Due to the small number of hypersegregated and clustered counties in our study, we did not detect significant moderation by these dimensions of segregation (data for hypersegregation not shown). However, our study extends the literature by examining the moderating effects of multiple dimensions of segregation on both preterm birth and term low birth weight. The different conceptual relevance of each dimension of segregation to health and different theoretical perspectives may explain our findings.

Evenness is the most widely used dimension but may have the least clear conceptual relevance for health (Acevedo-Garcia, Lochner, Osypuk, & Subramanian, 2003), as it is only associated with few area-level economic and social measures (Denton, 1994). Previous studies found mixed results for associations between evenness and adverse birth outcomes among black women, and no association among white and Hispanic women (McFarland & Smith, 2011; Mehra et al., 2017). We found evenness did not moderate disparities by race/ethnicity.

Exposure (blacks isolated from whites) is associated with numerous area-level measures including limited access to educational and economic opportunities and resources and social and health services, and neighborhood quality and violence (Acevedo-Garcia et al., 2003; Denton, 1994; Shihadeh & Flynn, 1996; Wilson, 1987). Given that exposure has generally been associated with higher risk of adverse birth outcomes (Grady & Ramirez, 2008; McFarland & Smith, 2011; Walton, 2009), we found exposure moderated disparities in preterm birth by race/ethnicity as expected, but it did not moderate disparities in term low birth weight.

Concentration is associated with lower area-level socioeconomic status and poorer housing (Denton, 1994). One study found no association between concentration and low birth weight among black women when all five dimensions of segregation were included in the model. Dimensions of segregation are related (Denton, 1994), thus inclusion of all dimensions in a model may attenuate associations. Contrary to our expectations, we found reduced Hispanic-white disparities in term low birth weight in concentrated relative to non-concentrated counties.

Racial and ethnic minorities typically reside in central city areas, characterized by poor neighborhood and housing quality (Denton, 1994; Massey, 1985), but not area-level income (Wilkes & Iceland, 2004). Two studies found no association between centralization and low birth weight among black or non-black women (Ellen, 2000; McFarland & Smith, 2011). Unexpectedly, we found reduced Hispanic-white disparities in term low birth weight in centralized relative to non-centralized counties.

The theoretical perspective of place stratification, where places are ordered hierarchically, and racial and ethnic groups are sorted by place resulting in unequal opportunities (Logan, 1978), may explain why exposure was associated with greater disparities in preterm birth. Exposure may reflect racial and ethnic minorities residing in disadvantaged neighborhoods and the diffusion of unhealthy behaviors (Bell et al., 2006), although the association between segregation and health behaviors is complex (Yang, Shoff, Noah, Black, & Sparks, 2014).

Ethnic enclaves which derive from the spatial assimilation perspective (Massey, 1985), may explain protective health effects of concentration, centralization, and clustering, especially among Hispanics. Whereas discrimination may have a larger role in the segregation of blacks, non-black minorities may be more likely to self-segregate into ethnic enclaves (Yang, Zhao, & Song, 2017). Such enclaves may be associated with increased social support, which may buffer the effects of residing in segregated areas. Alternatively, higher black-white than Hispanic-white dimensions of segregation for a given urban area (Iceland et al., 2002), may explain more similar birth outcomes between Hispanic and white women.

Concentration of poverty in general and among blacks in particular is caused by segregation of blacks in urban housing markets (Massey, Gross, & Shibuya, 1994). Thus, we consider area-level poverty a mediator of the association between segregation and racial disparities in adverse birth outcomes. Consistent with the social inequality perspective, after controlling for area-level poverty, all but the moderating effect of exposure on the Hispanic-white disparity in preterm birth became non-significant. These findings suggest area-level poverty is a mediator for multiple dimensions of segregation (explaining greater black-white disparities with exposure (i.e., through unequal opportunities) and reduced Hispanic-white disparities with concentration and centralization (i.e., overcoming protective effects of ethnic enclaves)), and there remains a direct association or indirect association through other economic and social factors between exposure and Hispanic-white disparities in preterm birth.

Limitations of the study include restricting the study population to births using the 2003 revision of the birth certificate, which may reduce the generalizability of the results. However, the study population included births from each census division.

Potential measurement error in the level of segregation may have occurred through the use of county of residence at time of birth, rather than length of stay at maternal residence. One in five mothers move during pregnancy, however the majority continue to reside in the same county (Miller, Siffel, & Correa, 2010; Saadeh et al., 2013). While residential mobility during pregnancy is not related to birth defects (Miller et al., 2010), it is related to maternal covariates such as age, socioeconomic status, and smoking, which are associated with preterm birth and low birth weight. Thus, we cannot rule out differential mobility by adverse birth outcome. Additionally, we were unable to assess potential heterogeneity in risk by racial and ethnic subgroups (Acevedo-Garcia, Soobader, & Berkman, 2007; Elo & Culhane, 2010). Method of delivery was controlled for in the analysis, but data on type of cesarean section (i.e., medically-indicated or elective) was unavailable.

We used census tracts as micro units, consistent with other studies. However, we used counties as macro units, most importantly as they are an appropriate unit to target pubic and health policy interventions. Segregation is conceptualized as a metropolitan-area phenomenon because metropolitan areas approximate housing and labor markets (Acevedo-Garcia & Osypuk, 2008). Previous studies have used metropolitan statistical areas, consisting of one or more counties, and having a total population of at least 100,000, as macro units (Bureau of the Census, 1994). Despite this difference, our findings at the county level are robust for preterm birth, in particular the disparities across comparison groups are consistent for the dimension of exposure. Our study included births within counties with a population of at least 100,000 and a population of black individuals of at least 5,000, thus our results are valid for highly populated urban areas, but may not generalize to rural areas.

Alternative frameworks for the dimensions of segregation exist. Most notably, Reardon and O'Sullivan assert that there are only two dimensions of segregation: spatial exposure and spatial evenness or clustering, with centralization and concentration being subcategories of spatial evenness (Reardon & O'Sullivan, 2004). Common measures of exposure and evenness are aspatial as they account for compositional but not spatial relationships between micro-level spatial units. Furthermore, aspatial measures of evenness and exposure are susceptible to the checkerboard problem (different spatial arrangements of micro-level units not affecting the segregation level at the macro level (White, 1983)), and the modifiable areal unit problem (sensitivity of findings to the size of the spatial unit of analysis (Fotheringham & Wong, 1991)). However, spatial measures of exposure and evenness generally require census tract or point level data which are typically not available in vital statistics data. Few studies have used spatial measures of segregation and it is yet to be determined whether these measures improve our understanding of the association between segregation and health (Kramer & Hogue, 2009b).

Methodological heterogeneity in dimensions and measures of segregation, and size of spatial unit may result in different but important findings. Consistent findings within dimensions of segregation will allow researchers to focus on interventions to reduce the association between segregation and health disparities. Findings from aspatial and spatial measures of segregation may provide insights into different processes through which segregation influences health disparities. Findings for different spatial units may indicate at which level interventions may be most effectively implemented.

On a methodological note, researchers should provide a conceptual justification for the use of particular dimensions of segregation and a conceptual framework of the mediating pathways between segregation and health to identify causal pathways and confounders but not mediators to control for in analyses (Acevedo-Garcia et al., 2003; Acevedo-Garcia & Osypuk, 2008) The use of different cut-off values for dimensions of segregation across studies may lead to heterogeneous study findings. Sensitivity analyses are encouraged for future studies on segregation.

In conclusion, multiple dimensions of segregation moderated associations between maternal race/ethnicity and adverse birth outcomes such that there were greater disparities in adverse birth outcomes in isolated counties (exposure), and reduced disparities in concentrated and centralized counties relative to non-segregated counties, not only among black women, but also among Hispanic women, compared to white women. Area-level poverty explained most of the moderating effect of segregation on disparities in adverse birth outcomes. Few studies have examined how race and ethnicity-specific dimensions of segregation moderate associations between other racial and ethnic disparities (i.e., Hispanic-white and Asian-white disparities) and adverse birth outcomes, or the three-way moderating effect of segregation, race/ethnicity, and nativity, and are avenues for further research.

Differences in the moderating effect of segregation may be related to different processes for prematurity and birth size. Future research should be conducted to better understand under which conditions and through which mediating pathways the most relevant dimensions of segregation are associated with prematurity and birth size. In particular, use of outcomes that more accurately assess birth size, such as term low birth weight and biometric parameters (i.e. femur length), may provide a better understanding of which dimensions of segregation are associated with birth size. Interventions that directly address segregation, such as reducing racial isolation (exposure), or indirectly address segregation, such as reducing area-level poverty, and improving social support and cohesion that may buffer the effects of segregation (Yang et al., 2017), may reduce disparities in adverse birth outcomes by race and ethnicity.

ETHICS STATEMENT.

We obtained de-identified data from the National Center for Health Statistics, therefore this study was exempt from review by Institutional Review Boards.

Conflict of interest statement

The authors declare that they have no conflict of interest.

Financial disclosure statement

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2019.100417.

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