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The Development of a Standardized Neighborhood Deprivation Index

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ABSTRACT *Census data are widely used for assessing neighborhood socioeconomic context. Research using census data has been inconsistent in variable choice and usually limited to single geographic areas. This paper seeks to a) outline a process for developing a neighborhood deprivation index using principal components analysis and b) demonstrate an example of its utility for identifying contextual variables that are associated with perinatal health outcomes across diverse geographic areas. Year 2000 U.S. Census and vital records birth data (1998–2001) were merged at the census tract level for 19 cities (located in three states) and five suburban counties (located in three states), which were used to create eight study areas within four states. Census variables representing five socio-demographic domains previously associated with health outcomes, including income/poverty, education, employment, housing, and occupation, were empirically summarized using principal components analysis. The resulting first principal component, hereafter referred to as neighborhood deprivation, accounted for 51 to 73% of the total variability across eight study areas. Component loadings were consistent both within and across study areas (0.2–0.4), suggesting that each variable contributes approximately equally to "deprivation" across diverse geographies. The deprivation index was associated with the unadjusted prevalence of preterm birth and low birth weight for white non-Hispanic and to a lesser extent for black non-Hispanic women across the eight sites. The high correlations between census variables, the inherent multidimensionality of constructs like neighborhood deprivation, and the observed associations with birth outcomes suggest the utility of using a deprivation, index for research into neighborhood effects on adverse birth outcomes.*

KEYWORDS *Low birth weight, Premature birth, Residence characteristics, Social class.*

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INTRODUCTION

Neighborhood level effects on health have increasingly become recognized as potentially important determinants of health disparities. Empirical research has established that a number of social indicators tend to cluster at the neighborhood level,[1] including the concentration of multiple markers of economic disadvantage.[2] Living in a disadvantaged neighborhood, defined using census indicators of deprivation, has been associated with a variety of health behaviors such as gambling[3] and perinatal substance use[4] as well as health intermediates, including late stage cancer diagnoses,[5,6] pediatric injury,[7] partner violence,[8] and violent injuries to women.[9] Living in deprived neighborhood environments has further been associated with health outcomes such as cardiovascular disease,[10–13] acquired immune deficiency syndrome (AIDS) incidence,[14] breast cancer incidence,[15] homicide risk,[16] and excess mortality.[17]

Research in perinatal health demonstrates modest but consistent effects of neighborhood-level socioeconomic disparities in key pregnancy outcomes.[18–21] Low birth weights (LBW) have been associated with a variety of neighborhood level socioeconomic variables including poverty,[22–24] unemployment,[24] education, income,[22,24,25] and median rent.[22] In addition to single variable associations, neighborhood indices representing aspects of economic disadvantage have also been associated with LBW. For example, Buka et al.[65] created an index measure of neighborhood economic disadvantage, utilizing, among other variables, 1990 census neighborhood percents living below the poverty level, with public assistance, and unemployed, and found the index to be significantly associated with birth weight. Krieger et al.[42] have used multiple indices to assess area level effects on LBW and child lead poisoning, observing the strongest effects on LBW (odds ratios >2.0) for tract and block group measures of economic deprivation. While research results have consistently confirmed effects of neighborhood deprivation on adverse birth outcomes, these findings can be difficult to interpret and compare because of the variety of indicators used to measure neighborhood-level deprivation.

The research addressing area-level effects on birth outcomes demonstrates variability in assessing area-level socioeconomic deprivation.[26] In studies that consider area-deprivation, little rationale is provided for the domains selected to represent socio-demographic status or for the variables used to characterize each domain. Furthermore, the high correlations between census variables make finding an effect of one census variable difficult to interpret.

A literature review in PubMed and Social Sciences Citation Index (SSCI) databases using the terms “neighborhood level,” “socio-demographic domains,” “health,” “neighborhood,” “area level constructs,” “area level domains,” and “contextual” as well as “housing,” “poverty,” “occupation,” “employment,” “education,” “stability,” or “residential stability” (year of publication unlimited) produced 966 articles; 227 were identified as relevant to area-level deprivation assessment. Of these 227 articles, the 15 studies from 2000–2006 that focused on neighborhood socio-economic status (SES) and racial disparities in birth outcomes are included in Table 1. Seven domains are regularly represented in the epidemiologic and social science literature: Poverty/income, racial/ethnic composition, education, employment, and occupation appeared consistently while housing/crowding and residential stability appear in a handful of studies. Economic inequality, affluence, and racial residential segregation were less commonly utilized. Across studies there is a lack of consistency in the use of domain-specific variables. For example, poverty is the socioeconomic construct used most frequently in research but is variable in its definition, including proportion of individuals or households below the federal poverty level, percentage on public assistance, and percentage of female-headed households with dependent children. Most studies include multiple domains to approximate the neighborhood-level socioeconomic status. Since each study has used different variables and a different approach to estimate neighborhood socioeconomic conditions, the accumulated evidence is difficult to assess systematically.

Research addressing social class in the United Kingdom (U.K.) represents an alternative approach to assessing neighborhood deprivation.[27,28] Established area-level indices such as the Townsend Material Deprivation Score and the Carstairs Deprivation Index have been widely utilized in the U.K., which allows for the comparison of deprivation effects across a variety of geographic regions. The Townsend Material Deprivation Score,[29] an area-level index comprising unemployment, overcrowding, and not owning a car or a home, is the most widely used deprivation index, and it tends to be favored by health authorities and has been used to assess the effect of area deprivation on height, weight, and body mass index in two birth cohorts.[30] The Carstairs Deprivation Index, developed to study health outcomes in Scotland, is similar to the Townsend Index but substitutes low social class for non-home ownership.[31,32] Living in the most deprived wards, based on the Carstairs Index, has been inversely associated with birth weight,[33] as well as a variety of other health outcomes. Because these indices are used regularly in the U.K., their interpretation and utility are widely understood. Some research has attempted to recreate these indices in the U.S.,[27] which is difficult given the different census variables used. Using U.S. census data, however, U.S. researchers can approach assessing area deprivation in a similarly systematic and replicable manner.

This manuscript outlines a reproducible approach to the development of a neighborhood deprivation index that capitalizes on readily available U.S. census data and employs a principal components analysis approach. Using data from four socio-demographically diverse regions, this paper will a) outline the neighborhood deprivation index development process and b) demonstrate the index's utility in differentiating between areas with more and less numerous adverse birth events.

MATERIALS AND METHODS

The Multilevel Modeling of Disparities to Explain Preterm Delivery (MODE-PTD) project is a collaborative partnership of four universities and their government health department partners. The project was established to identify policy-relevant contextual factors associated with infant and child health disparities to inform state and city Maternal and Child Health officials of potentially modifiable environmental risk factors relevant for policy and program planning.

Project Study Areas

Four university-health department partnerships were selected to participate in the project based on state partner interest, ongoing research activities in maternal and infant health, and representation of a variety of demographic and geographic contexts. Eight study areas were represented including three urban centers (Philadelphia, Pennsylvania [PA], Baltimore City, Maryland [MD], and 16 pooled

TABLE 1. The use of deprivation indices in perinatal epidemiology; 2000–2006 literature review

Domain	Variable used	Author, year (and rationale for chosen variables)
Education	% adults with < HS	Ahern et al., 2003[77] (variable choice based on racial segregation, to approximate individual SES); Krieger et al., 2003[42] (variable choice based on theory, prior empirical research); Pearl et al., 2001[24] (no rational given for chosen variables); Pickett et al., 2002[78] (variables chosen to estimate neighborhood SES, prior associations)
	% with high school or college graduate	English et al., 2003[79] (variable choice based on study hypotheses)
	% college graduate adults	English et al., 2003
	% adults > college	Krieger et al., 2003
Employment	% unemployed males	Ahern et al., 2003; Pearl et al., 2003; Pickett et al., 2002
	% unemployed	Krieger et al., 2003
	>10% unemployment	Ponce et al., 2005[80] (variables chosen based on prior associations)
	<10% unemployment	Ponce et al., 2005
Housing	% owner-occupied units	Kaufman et al., 2003[81] (no rationale offered for variables chosen)
	Median house/unit value	Kaufman et al., 2003
	% owner occupied homes > $300,000	Krieger et al., 2003
	% homes with > 1 person/room	Krieger et al., 2003
	% vacant homes	Reagan and Salsberry, 2005[40] (rationale offered for ‘poverty’ variable only)
Occupation	% persons in ‘working class’ occupation[82]	Ahern et al., 2003; Krieger et al., 2003; Pickett et al., 2002
	% white collar occupation	English et al., 2003
	% blue collar occupation	English et al., 2003
	% professional occupations	Reagan and Salsberry, 2005
Poverty	% individuals at/below poverty line	Ahern et al., 2003; Krieger et al., 2003; Pickett et al., 2002; Rauh et al., 2001[23] (variable chosen to represent community poverty)
	% families at/below poverty line	Morenoff, 2003[83] (variable choice based on theoretical framework guiding larger study); Pearl, 2001

TABLE 1. ***Continued***

Domain	Variable used	Author, year (and rationale for chosen variables)
	% HH below at/poverty line	Ahern et al., 2003; Rich-Edwards et al., 2003[84] (variable chosen as proxy for individual-level poverty)
	>40% HH at/below poverty line	Jaffe and Perloff, 2003[85] (variable choice based on theory, racial minority status)
	<20% families at/below poverty line	Ponce et al., 2005
	Tract poverty rate	Reagan and Salsberry, 2005 (chose poverty rate because most widely used variable)
	>15% families on public assistance	Ponce et al., 2005
	<15% families on public assistance	Ponce et al., 2005
	% female headed HH w/ dependents	Kaufman et al., 2003; Reagan and Salsberry, 2005
	Median income	Ahern et al., 2003
	Median HH income	Kaufman et al., 2003; Krieger et al., 2003; Pickett et al., 2002
	<$8,000 annual HH income	Jaffe and Perloff, 2003
	$8,000–$11,000 annual HH income	Jaffe and Perloff, 2003
	% HH income < $15,000/year	Krieger et al., 2003
	% HH income > $150,000/year	Krieger et al., 2003
Racial composition	% black males	Ahern et al., 2003
	% black	Pickett et al., 2002
	% Hispanic	English et al., 2003; Morenoff, 2003
	% NH black	English et al., 2003; Morenoff, 2003
	% NH white	English et al., 2003
	>60% NH black	Jaffe and Perloff, 2003
	>60% Hispanic	Jaffe and Perloff, 2003
Residential stability	Consistently measured with % living in same house since 1995 and one other variable, but other variable varies	English et al., 2003
	Residential stability (two variables)	Morenoff, 2003
Other variables	Growth: total population	English et al., 2003
	Marital status (% married)	English et al., 2003
	Marital status (% single)	English et al., 2003
	Gini coefficient	Krieger et al., 2003; Reagan and Salsberry, 2005
Other indices	Neighborhood disadvantage (three variables)	Buka et al., 2003[65] (variables based on prior associations, social capital, birth weight)
	Worth (three variables)	English et al., 2003
	Affluence (three variables)	English et al., 2003
	Education index (two variables)	Kirby et al., 2001[86] (variable choice based on literature review and available census data)

TABLE 1. ***Continued***

Domain	Variable used	Author, year (and rationale for chosen variables)
	Employment index (five variables)	Kirby et al., 2001
	Housing index (two variables)	Kirby et al., 2001
	Income/poverty index (four variables)	Kirby et al., 2001
	Female marital status (three variables)	Kirby et al., 2001
	Townsend (U.K.; four variables)	Krieger et al., 2003
	Carstairs (U.K.; four variables)	Krieger et al., 2003
	Local economic resources (three variables)	Krieger et al., 2003
	Socioeconomic position 1 (three variables)	Krieger et al., 2003
	Socioeconomic position 2 (three variables)	Krieger et al., 2003
	Factor 1 (three variables)	Krieger et al., 2003
	Factor 2 (three variables)	Krieger et al., 2003
	SEP index (six variables)	Krieger et al., 2003
	Socioeconomic factor index (Canadian)	Martens et al., 2004[87]

cities in Michigan [MI]) and five racially heterogeneous counties (three Maryland [MD] counties near Washington, DC, and Baltimore, MD, and two in North Carolina [NC]). Michigan's 16 cities were combined after exploratory work revealed the cities shared similar relationships between census-tract level poverty indices and prevalence of adverse birth outcomes.

Data Sources

Birth outcome and maternal characteristics were obtained from birth certificates for selected years between 1995 and 2001 (Table 2). Because of minimal short-term secular trends in adverse birth outcomes, the slight differences in dates across study areas are inconsequential.[34] Tract level year 2000 Census of Population and Housing Data from the U.S. Census Bureau[35] were used to develop a deprivation index.

Unit of Analysis

Neighborhood is a term used to refer to a person's immediate residential environment, hypothesized to contain both material and social characteristics relevant for health.[36] The census tract level of aggregation was chosen to maximize the precision and stability of area-level rates of adverse birth outcomes and to ensure a rough approximation of each woman's immediate physical neighborhood. According to the U.S. Census Bureau, tracts are small, relatively permanent statistical subdivisions of counties, designed to be fairly homogenous units with respect to socio-demographic characteristics and living conditions, containing on average 4000 residents.[37] Previous research has employed census tracts to characterize neighborhood influences[38–41] and has confirmed their utility in birth outcomes research.[42]

TABLE 2. Maternal characteristics in the Non-Hispanic white and non-Hispanic black cohort by study area

Maternal attributes	Baltimore City, MD	Baltimore County, MD	Montgomery County, MD	P. G. County*, MD	MI-16 cities	Durham County, NC	Wake County, NC	Philadelphia, PA
N (%)	1999–2001	1999–2001	1999–2001	1999–2001	1995, 1998–1999	1999–2001	1999–2001	1999–2000
Births	23,745	17,221	19,156	20,792	86,592	8,210	24,287	31,909
PTB	3,401 (14.3)	1,490 (8.7)	1,334 (7.0)	2,160 (10.4)	7,743 (11.1)	961 (11.7)	2,022 (8.3)	3,499 (11.0)
LBW	2,816 (11.9)	1,096 (6.4)	928 (4.8)	1,799 (8.7)	6,848 (9.8)	737 (9.0)	1,448 (5.7)	3,077 (9.6)
NH black	18,038 (76.0)	4,599 (26.7)	4,934 (25.8)	16,568 (79.7)	42,210 (60.4)	4,382 (53.4)	6,304 (26.0)	19,845 (62.2)
Age								
<20	5,450 (23.0)	1,424 (8.3)	624 (3.3)	2,243 (10.8)	16,668 (19.2)	861 (10.5)	1,377 (5.7)	5,343 (16.7)
20–24	7,075 (29.8)	3,242 (18.8)	1,663 (8.7)	4,577 (22.0)	26,365 (30.4)	1,754 (21.4)	3,742 (15.4)	8,839 (27.7)
25–29	4,995 (21.0)	4,516 (26.2)	3,788 (19.8)	5,224 (25.1)	22,522 (26.0)	2,219 (27.0)	6,566 (27.0)	7,844 (24.6)
30–34	3,788 (16.0)	4,967 (28.8)	7,084 (37.0)	5,182 (24.9)	13,878 (16.0)	2,183 (26.6)	8,002 (33.0)	6,125 (19.2)
35+	2,437 (10.3)	3,072 (17.8)	5,997 (31.1)	3,566 (17.2)	7,159 (8.3)	1,193 (14.5)	4,600 (18.9)	3,758 (11.8)
Education								
<12 years	7,522 (31.7)	1,617 (9.4)	792 (4.1)	1,956 (9.4)	26,347 (30.4)	812 (10.2)	1,950 (8.0)	7,007 (31.6)
12 years	9,028 (38.0)	5,364 (31.2)	3,014 (15.7)	7,449 (35.8)	31,149 (36.0)	1,829 (23.1)	4,462 (18.4)	13,184 (41.3)
>12 years	7,195 (30.3)	10,240 (59.5)	15,350 (80.1)	11,387 (54.8)	29,096 (33.6)	5,292 (66.7)	17,826 (73.5)	11,718 (36.7)

N Number, *PTB* Preterm birth, *LBW* Low birth weight, *NH* non-Hispanic.
*Prince George's County

Data Reduction and Exposure Definition

Variable selection Socioeconomic variables at the neighborhood level represent aspects of community stratification, opportunity structures, and social conditions.[43–46] The investigators identified seven broad socioeconomic and demographic domains associated with health outcomes in previous studies, including poverty, housing, occupation, employment, education, residential stability, and racial composition.[26] These domains have been previously characterized using multiple related characteristics derived from census data. Based on a review of literature, we identified 20 census variables that have been used consistently to approximate neighborhood-level environments for possible inclusion in the deprivation index. These measures included the following*: one education variable,[47,48] two employment,[49,50] five housing,[51–53] four variables representing occupation,[10,54] five poverty,[55–58] one racial composition,[51,59] and two residential stability.[22,53]

Data reduction Principal components analysis (PCA) and factor analysis (FA) are data reduction techniques frequently used in neighborhood-level research to create socio-demographic scales or indices for inclusion in statistical models.[43,60–69] PCA analyzes total variance while FA analyzes shared variance,[70,71] but in both cases, the loading represents the correlation between the variable and the factor or component.[†72] Similar to the methods employed in other research,[15,63–69] PCA was chosen for census data reduction in this study because the investigators sought an empirical summary of total area-level variance explained by the census variables, rather than a confirmation of any underlying factor structure comprised of the previously identified domains.[73] Further, no independent factors emerged following exploratory FA with these data.

Component extraction and index construction Although it is possible to form as many independent linear combinations as there are variables, we retained only the first principal component: The unique linear combination that accounted for the largest possible proportion of the total variability in the component measures.[71] The census tract data from the eight study units were merged prior to performing the PCA. Across the study areas, the variable loadings on the first principal component ranged from −0.041 to 0.295, with a mean loading of 0.211 on the all-site index. Since the goal of the index was to facilitate comparison of neighborhood deprivation and health across study areas, we compared each site-specific and all-

*Education included percent males and females with less than a high school education. Employment variables include percent males and females unemployed and percent males no longer in work force. Housing variables include percent rented, percent vacant, percent crowded, percent renter or owner costs in excess of 50% of income, and median household value. Occupation variables include percent males in management, percent males in professional occupations, percent females in management, and percent females in professional occupations. Poverty variables include percent households in poverty, percent female headed households with dependent children, percent households earning under $30,000/year, percent households on public assistance, and percent households with no car. Racial composition was estimated using percent residents who were non-Hispanic blacks. Residential stability variables include percent in same residence since 1995 and percent residents 65 years and above.

†For FA, a moderate correlation (0.50) represents the minimum loading thought to denote one factor. For PCA, no minimum-loading recommendations are established because the amount of variance explained and subsequent component loading will differ based on the number of variables included in the PCA and the magnitude of error variance.

site loadings on the aforementioned 20 census variables that contributed most to the first component across geographies. Variables were assessed for inclusion based on two a priori criteria: First, variables that loaded above 0.25 in any site (a loading in the upper 20% of any loading) were then assessed for consistency of loadings across sites. While variable loadings were generally consistent across sites, variables with high loadings at any single site were included in the index because the team sought to produce an index that captured both the unique and the shared expressions of deprivation across the eight locations. Second, we considered the lower 95% confidence limit of each loading. This second criteria was established to guard against high loadings that may have resulted from sampling variability, especially because some sites have fewer tracts and, therefore, have more associated sampling variability. After identifying variables with high loadings, we then stipulated that the lower 95% confidence limit of the variable loading could not be below 0.16, which was chosen because it is the lower 95% confidence limit for the median factor loading.* Of the 20 variables included in the PCA, eight variables (percent of males in management and professional occupations, percent of crowded housing, percent of households in poverty, percent of female headed households with dependents, percent of households on public assistance and households earning <$30,000 per year estimating poverty, percent earning less than a high school education, and the percent unemployed) were retained for the index. The PCA was then re-run including only these census variables to obtain the final item loadings, which were used to weight each variable's contribution to the neighborhood deprivation summary score for each census tract of the eight study areas. The deprivation index was then standardized to have a mean of 0 and standard deviation (SD) of 1 by dividing the index by the square of the eigenvalue.[73] Quartiles (Q) of continuous neighborhood deprivation were created.

Variable and Study Population Definitions

Low birth weight (LBW) was defined as birth at <2,500 g and preterm birth (PTB) was defined as birth at gestational age <37 weeks and weighing <3,888 g.[74] Less than 1% of records were missing gestational age or birth weight data. Data analyses were restricted to singleton births because multiple gestations often result in LBW or PTB even in otherwise normally progressing pregnancies.

Statistical Analysis

Data reduction and PCA were performed using Stata 9.0 (College Station, TX). Analyses were race-stratified and limited to black non-Hispanic (black) and white non-Hispanic (white) race due to the small numbers of women of other races and ethnicities represented in the eight-area birth records. Unadjusted proportion of LBW and PTB deliveries were estimated for each quartile of the deprivation score using tabular analyses (adjustment for the two domains not included in the index, residential stability and racial heterogeneity, did not substantially alter the LBW/PTB proportions). The authors employed deprivation quartiles (the highest quartile corresponding to the most deprived areas and the lowest quartile serving as the referent category) to allow for potential dose response relations and to avoid linearity assumptions in the association of deprivation and birth outcomes. Risk

*Three of the 64 (0.05) possible lower 95% confidence limits failed to meet this 0.16 criteria for inclusion.

differences (RD), 95% Confidence Intervals (95% CI), and *P* for trend statistics were estimated.

RESULTS

A substantial number of births occurred during the study years at the eight study areas (Table 2). The percent of preterm births ranged from 7.0 to 14.3%, and the low birth weight percentage ranged from 4.8 to 11.9%. Baltimore City had the highest while Montgomery County had the lowest outcome proportions of adverse birth outcomes. The proportion of black women delivering singleton births varied across the study areas, from 79.7% in Prince George's County to 26.0% in Wake County. Michigan had the fewest births to women ≥35 years of age (8.3%) while Montgomery County had the most (31.1%). Maternal education varied by site. Uniformly, the fewest singleton mothers obtained <12 years, and the most obtained >12 years, but the relative percentages differed geographically. Baltimore City had the highest percent who received <12 years (31.7%) compared with 4.1% in Montgomery County. In Wake County 73.5% of women had >12 years of school compared with 33.6% in Michigan.

Tracts had varying population counts, ranging from a mean of 3,009 for Michigan-16 cities to 5,979 in Wake County, NC (Table 3). Significant variability was also observed for the census socio-demographic descriptors. On average, Montgomery County, MD, had the wealthiest tracts according to the census characteristics (i.e., 14.6% of the population had income less than $30,000 compared with 51.3% of Baltimore city residents). The three urban study areas—Baltimore City, Philadelphia, and MI-16 cities—were characterized as the "most deprived," based on these socio-demographic indicators. The Michigan 16-city site appeared to be the poorest according to poverty-related indicators such that, on average, 24.9% lived below the poverty level, and 25.2% were female-headed households with dependent children. Philadelphia had the largest percent of households with no vehicle (34.8%). Prince George's County, MD, had the lowest percentage of white population (24.4%) compared to Baltimore City, MD, with the highest proportion (75.6%) in these data. Thus, these eight urban and suburban regions demonstrated considerable socio-demographic variability.

The index resulting from the principal components analysis accounted for 51 to 73% of the total variance in the variables that were included in the eight study areas and 67% of the total variance for the combined all-site neighborhood deprivation index. The second component added 7 to 10% to the explained variance and so was not retained. The higher the score on the standardized deprivation index, the more area-level deprivation associated with the census tract.

Three important patterns emerged from the site specific and all-site first principal component score loadings (Table 4). The first was the consistency *within each site* of variable loadings that comprised the first principal component, which were used to produce the deprivation score with loadings ranging, for example, from 0.22 to 0.40 in Philadelphia. These results suggested that each component contributed almost equally to the neighborhood deprivation index. Second, the component loadings were quite consistent *across the study areas*; for example, poverty loadings ranged from 0.35 to 0.41, despite significant geographic and socio-demographic variability. The consistency of the loadings across units suggested these variables function similarly across geography, despite meaningful heterogeneity in demographics and economic status. Unemployment, for instance,

TABLE 3. Mean (standard deviation) of sociodemographic data of each MODE-PTD study area, Year 2000 U.S. census data

Site variables	Baltimore City, MD	Baltimore Co.**, MD	Montgomery Co., MD	P. G. Co., MD	MI-16 cities	Durham Co., NC	Wake Co., NC	Philadelphia, PA
Mean (sd)	200 tracts	204 tracts	177 tracts	183 tracts	607 tracts	53 tracts	105 tracts	381 tracts
Tract pop	3,256 (1,434)	3,698 (1,771)	4,934 (1,906)	4,380 (1,699)	3,009 (1,546)	4,213 (2,175)	5,979 (3,375)	3,854 (2,416)
% Mgmt (m)	5.8 (4.9)	10.4 (6.1)	15.0 (6.2)	8.1 (4.4)	7.1 (5.8)	11.9 (7.1)	18.6 (8.9)	9.7 (8.5)
% crowd	4.9 (3.3)	1.9 (2.3)	5.2 (5.8)	7.4 (7.2)	6.6 (4.8)	6.0 (5.3)	3.6 (3.4)	5.0 (4.5)
% poverty	24.5 (13.7)	7.1 (8.9)	5.4 (3.8)	7.9 (6.0)	24.9 (13.8)	17.4 (16.6)	9.8 (9.6)	22.1 (15.5)
% FHHH	14.5 (8.85)	6.3 (4.8)	5.4 (3.4)	11.1 (6.5)	25.2 (13.2)	17.4 (15.0)	11.0 (8.6)	19.0 (13.1)
% < $30K	51.3 (15.9)	27.1 (13.9)	14.6 (9.2)	21.8 (11.7)	50.5 (16.5)	40.4 (23.1)	26.2 (15.0)	47.0 (19.4)
% pub asst	8.2 (6.0)	1.7 (1.9)	1.3 (1.2)	2.0 (1.8)	10.2 (6.9)	3.6 (5.1)	1.9 (2.6)	8.8 (8.6)
% unemp	12.4 (8.0)	4.5 (4.0)	3.2 (2.0)	5.8 (3.6)	12.5 (8.1)	7.2 (8.9)	4.5 (5.4)	11.1 (7.8)
% no HS	33.8 (13.3)	17.1 (11.4)	9.9 (8.3)	16.2 (9.9)	28.2 (13.7)	20.1 (14.4)	12.0 (9.8)	28.1 (15.0)
HH value	70.4 (44.9)	137.2 (65.8)	250.5 (127.0)	140.9 (34.2)	66.9 (45.4)	109.9 (51.8)	167.3 (65.7)	72.5 (70.2)
% white NH	31.9 (33.3)	75.6 (25.9)	61.0 (20.2)	24.4 (22.7)	32.6 (32.8)	44.3 (30.2)	67.1 (23.8)	42.6 (36.6)

Tract pop Tract population; *% Mgmt (m)* % males in management; *% Crowd* % households with > 1 person per room; *% Poverty* % individuals with 1,999 income below federal poverty level; *% FHHH* % families with female headed household with dependent children; *% < $30K* % households with income less than *$30,000; *% Pub Asst* % households with public assistance income; *% No Car* % households with no vehicle; *% No Phone* % households with no telephone; *Costs > 50%* households with rent; selected owner costs > 50% of income; *HH value* median value of owner occupied unit (×1,000); *% Unemp* % males and females unemployed; *% No HS* % and females with no high school education; *% White NH* % White non-Hispanic; ****Co.** county.

TABLE 4. Site specific and all-site first principal component deprivation score loadings for each study area

Domains and variable loadings	Baltimore City, MD	Baltimore Co., MD	Montgomery Co., MD	P. G. Co., MD	MI-16 cities	Durham Co., NC	Wake Co., NC	Philadelphia PA	All-site index
Poverty domain									
% poverty	0.389	0.346	0.394	0.384	0.408	0.345	0.374	0.396	0.397
% FHHH	0.359	0.264	0.287	0.304	0.347	0.381	0.359	0.356	0.357
% < $30K	0.394	0.422	0.378	0.405	0.370	0.350	0.373	0.380	0.386
% pub asst	0.392	0.357	0.297	0.302	0.382	0.355	0.345	0.385	0.382
Occupation domain									
% Mgmt (m)	−0.244	−0.380	−0.371	−0.349	−0.304	−0.374	−0.338	−0.219	−0.285
Housing domain									
% crowd	0.302	0.356	0.387	0.360	0.286	0.390	0.331	0.329	0.261
Employment domain									
% unemp	0.371	0.355	0.320	0.360	0.346	0.226	0.331	0.372	0.366
Education domain									
% no HS ed	0.349	0.328	0.377	0.352	0.370	0.382	0.374	0.359	0.369
% variance	65.8	51.0	63.7	58.9	62.0	63.7	73.2	68.2	66.9

made as important a contribution to this deprivation index in Philadelphia as it did in Durham County. The third important pattern emerging from these analyses was the consistency of the factor loadings on the all-site deprivation score. The all-site weights were of similar magnitude to each other and to each site's loadings. The all-site deprivation index represented a weighted average of the component variables from diverse geographic and socioeconomic units, the loadings for which could be reasonably applied to census variables from virtually any area to produce a comparable deprivation index.

Figure 1 graphically demonstrates the significant socioeconomic heterogeneity in the distribution of the all-site deprivation scores across the eight study areas. Philadelphia had the largest range in deprivation score, ranging from −1.8 to 3.7, followed by Michigan-16 cities. Particularly noteworthy is Montgomery County, with deprivation index values ranging from −1.7 to 0.7, suggesting that this area is relatively not deprived. Along with Montgomery County, most tracts in Maryland (Baltimore and Prince George's County) and North Carolina (Wake and Durham Counties) were at the affluent end of the all-site deprivation continuum, compared to the three most urban study areas (Michigan-16 cities, Baltimore City, and Philadelphia), which were clearly at the more deprived end of the range.

Among white women, there was a gradient in the relationship between deprivation and adverse birth outcomes in at least two-thirds of the sites: Larger percentages of LBW (Table 5) and PTB (data not shown) occurred at higher levels of deprivation. For instance, Baltimore County, one of the more affluent study areas, had LBW percentages that ranged from 4.0 to 7.6% and PTB percentages that ranged from 6.0 to 9.2%, respectively, in the first to third quartiles of deprivation (no Baltimore County tracts fell into the fourth quartile of all-site deprivation). In a more deprived area these rates were similar; the LBW percentages in the Michigan-16 cities site increased from 3.8 to 7.6% while the PTB percentages increased from 6.1 to 8.8%, respectively. Risk differences indicated the contrast of adverse birth proportions for women living in quartiles four or three compared with those living in the lowest quartile of deprivation. Across the socio-demographically diverse study areas, the relationship between adverse birth

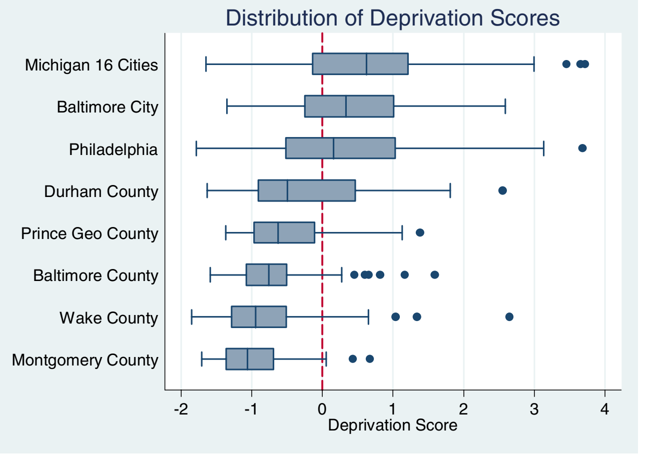

FIGURE 1. Box plot of all-site deprivation index by MODE-PTD study area.

TABLE 5. Percentage of white non-Hispanic low birth weight [LBW] (total number of births) and Q4–Q1, Q3–Q1 risk differences [RD] (95% confidence intervals [CI]) in each quartile [Q] of deprivation by MODE-PTD study area

Prince George's All-site deprivation index quartiles	Baltimore City, MD 1999–2001	Baltimore County, MD 1999–2001	Montgomery County, MD 1999–2001	Prince George's County, MD 1999–2001	MI-16 cities 1995, 1998–1999	Durham County, NC 1999–2001	Wake County, NC 1999–2001	Philadelphia, PA 1999–2000
Q1: [-1.85]–[-0.81]	3.4 (827)	4.0 (6,413)	3.2 (10,875)	4.1 (2,610)	3.8 (5,090)	4.2 (2,407)	3.8 (14,248)	3.1 (1,608)
Q2: [-0.80]–[-0.173]	5.3 (2,237)	5.6 (5,067)	4.2 (2,939)	5.3 (1,134)	5.3 (6,864)	3.9 (982)	5.2 (3,342)	4.5 (5,870)
Q3: [-0.17]–0.76	7.8 (1,917)	7.6 (1,137)	5.4 (408)	4.8 (478)	6.2 (13,068)	5.9 (340)	7.4 (299)	5.4 (3,049)
Q4: 0.77–3.72	10.6 (726)	*	**	*	7.6 (6,708)	*	*	7.6 (1,537)
P for trend	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P = 0.20$	$P < 0.001$	$P = 0.38$	$P < 0.001$	$P < 0.001$
Q3–Q1 RD (95% CI)	4.4 (2.7, 6.1)	3.6 (2.0, 5.2)	2.2 (-0.02, 4.4)	0.7 (-1.4, 2.8)	2.4 (1.7, 3.1)	1.7 (-0.9, 4.3)	3.6 (0.6, 6.6)	2.3 (1.1, 3.5)
Q4–Q1 RD (95% CI)	7.2 (4.6, 9.8)	*	**	*	3.8 (3.0, 4.6)	*	*	4.5 (2.9, 6.1)
Percent LBW (# LBW/total)	6.5 (373/5,707)	5.0 (625/12,622)	3.5 (493/14,222)	4.5 (190/4,224)	5.9 (1,882/31,730)	4.3 (165/3,824)	4.1 (741/17,983)	4.9 (595/12,064)

*Data not shown; fewer than 100 births in deprivation quartile.
**No tracts fell into this deprivation quartile.

TABLE 6. Percentage of black non-Hispanic low birth weight [LBW] (total number of births) and Q4–Q1, Q3–Q1 risk differences [RD] (95% confidence intervals [CI]) in each quartile [Q] of deprivation by MODE-PTD study area

Prince George's All-site deprivation index quartiles	Baltimore City, MD 1999–2001	Baltimore County, MD 1999–2001	Montgomery County, MD 1999–2001	Prince George's County, MD 1999–2001	MI-16 cities 1995, 1998–1999	Durham County, NC 1999–2001	Wake County, NC 1999–2001	Philadelphia, PA 1999–2000
Q1: [-1.85]–[-0.81]	*	9.9 (910)	8.7 (2,429)	8.5 (4,378)	10.2 (919)	10.5 (628)	9.8 (2,390)	9.0 (267)
Q2: [-0.80]–[-0.173]	12.0 (2,468)	10.5 (2,942)	9.1 (1,809)	10.1 (5,711)	11.2 (4,097)	11.9 (1,137)	11.0 (2,106)	9.4 (2,287)
Q3: [-0.17]–0.76	12.9 (6,786)	9.5 (745)	8.3 (696)	10.2 (6,325)	11.9 (17,339)	13.7 (1,307)	12.8 (1,246)	11.6 (6,240)
Q4: 0.77–3.72	14.4 (8,706)	*	**	9.7 (154)	13.3 (32,507)	14.8 (1,301)	14.4 (561)	13.8 (11,051)
P for trend	$P < 0.001$	$P = 0.87$	$P = 0.93$	$P = 0.01$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.001$
Q3–Q1 RD (95% CI)	*	-0.4 (-2.3, 1.5)	-0.4 (-1.5, 0.7)	1.7 (0.9, 2.5)	1.7 (0.3, 3.7)	3.2 (0.2, 6.2)	3.0 (0.8, 5.2)	2.6 (-0.9, 6.1)
Q4–Q1 RD (95% CI)	*	*	**	1.2 (-3.5, 5.9)	3.1 (1.1, 5.1)	4.3 (1.2, 7.4)	4.6 (1.5, 7.7)	4.8 (1.3, 8.3)
Percent LBW (# LBW/Total)	13.5 (2,443/ 18,038)	10.2 (471/ 4,599)	8.8 (435/4,934)	9.7 (1,609/ 16,568)	12.7 (6,949/ 54,862)	13.1 (572/4,373)	11.2 (707/ 6,303)	12.5 (2,482/ 19,845)

*Data not shown; fewer than 100 births in deprivation quartile.

**No tracts fell into this deprivation quartile.

outcomes and neighborhood deprivation appeared fairly consistent among white women.

The relationship between deprivation and adverse birth outcomes for black women was slightly less clear (Table 6). While the PTB and LBW percentages in the highest quartile of deprivation were consistently large, we found high levels of adverse outcomes throughout the continuum. Among black women delivering singleton infants, we found increasing percentages of LBW associated with increasing deprivation in five of the study areas, even if some of the increases were modest (e.g., Baltimore City's LBW percentages increased from 12.0 to 14.0% from the second to fourth quartile). In Philadelphia, for instance, the percent LBW ranged from 9.0 to 13.8% in the first compared with fourth quartile. The pattern of association was similar for PTB where, in Durham County, for instance, the percent PTB increased from 11.6 to 17.7% (data not shown). The pattern of increasing proportion PTB with increasing deprivation was observed in six of the study areas. The relationship between deprivation and adverse birth outcomes among black women in these data was not quite as consistent with the hypothesized pattern of monotonically increasing risk.

DISCUSSION

Literature posits that class, status, and party (or power), contemporarily operationalized as occupation, education, and income, are differentially distributed and may influence opportunities for health and well-being.[28] In the absence of direct measures of "status" and related concepts, research in epidemiology has struggled with how best to approximate these constructs at individual and area levels. This paper outlined a standardized and reproducible approach for developing a neighborhood index summarizing various domains of socioeconomic deprivation for use in research. In contrast to other work, this research sought not to reproduce distinct socioeconomic domains through factor analysis but rather sought to create a composite index that would empirically summarize "neighborhood deprivation". By finding consistent loadings on the first principal component both within and across each of the eight study areas, this work provides insight into the relative importance of each of the components to the concept of "deprivation". The index was further able to differentiate between areas of higher and lower adverse birth outcome proportions for white and, to a lesser extent, black women, confirming previous findings on the association of deprivation and adverse birth outcomes.[18–25,65] The relationship between neighborhood deprivation and adverse birth outcomes is further explored in forthcoming work by the MODE-PTD group.

Indicators of deprivation are strongly associated in a given area because dimensions of disadvantage are inherently intertwined. While single administrative indicators have been shown to be effective at approximating socioeconomic disadvantage, their highly correlated nature recommends the use of an index including multiple domains of disadvantage, similar to those developed for the U.K. By including variables representing numerous domains, a deprivation index is robust to problems with single variables. Single variables may be subject to secular or geographic trends (for instance, the value of a high school education), which prevents comparison over time and place. A composite index is less likely to be significantly influenced by changes in a single variable. Lastly, making inferences based on the inclusion of one deprivation-related variable, i.e., finding an 'employment effect', while not simultaneously considering the remaining constellation of factors that contribute to the deprivation environment, risks producing incomplete or inappropriate conclusions. The deprivation index described here represents an attempt to more accurately reflect the multidimensional character of community socioeconomic position.[43,68,75]

This study was limited by several factors. While heterogeneous, study areas were neither a randomly selected nor nationally representative sample; the study does not adequately capture the rural or Western deprivation experience, which is likely to differ from urban and Eastern disadvantage. Additionally, some of the study areas were characterized by the intersection of hyper racial and socioeconomic segregation, which resulted in few black births in the least deprived areas, minimal white births at the upper ends of deprivation and limited direct comparisons across all eight study areas. This study is further limited by its reliance on administratively defined boundaries to approximate the 'neighborhood', which may bear little resemblance to the salient neighborhood-level exposure. Despite the potential misattribution of "neighborhood" influence to an administrative unit, other authors have found using the census tract as the unit of analysis useful in studies of birth outcomes.[42] Further, research using census data to approximate deprivation is inherently limited in its ability to address causality or mechanisms.[76] Using LBW as a health outcome is often considered problematic, since LBW can result from preterm delivery, impaired fetal growth, or both. We consider it a relevant study outcome in this example, however, because if neighborhood deprivation is associated with birth outcomes, it is likely to affect both pregnancy duration and fetal growth. Lastly, this index has been neither validated nor tested with additional populations.

Despite its limitations, this study has several strengths. The numerous contexts (tracts) and outcome events (births) improved our ability to observe modest effects of deprivation in relatively non-deprived areas and to develop race-specific models, which was important given the segregated contexts that we observed for these women. This index demonstrated utility across diverse geographic and sociodemographic features, suggesting it has broad geographic generalizability. Finding uniform multidimensionality of neighborhood deprivation, for instance—employment and education appear to contribute equally to deprivation—is relevant to policy. By using this index, researchers can identify the most deprived areas and work within those neighborhoods to address neighborhood deficiencies. Good community interventions have broad multifaceted effects. For example, interventions are unlikely to be targeted at a single neighborhood component, such as households lacking telephones. Rather, neighborhood development impacts multiple conditions, so a combined deprivation score may be more policy relevant than a single measure, which can suggest that these neighborhood factors operate in isolation, which is clearly not the case.

The neighborhoods in which women live and work are a probable source of both support and stress. These neighborhood influences, which arise from political, economic and racial structures, may reasonably affect birth outcomes. Work in this area has been hindered by non-comparable measures used in studies conducted in isolation. This research represents an important step toward developing a reproducible method for measuring deprivation across space and time to improve our understanding of the role neighborhood environments may play in adverse birth outcomes.

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