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## Article

## Stressor landscapes, birth weight, and prematurity at the intersection of race and income: Elucidating birth contexts through patterned life events

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## ABSTRACT

Women of color and women in poverty experience disproportionately high rates of adverse birth outcomes in the United States (US). We use an intersectionality-based approach to examine how maternal life events (LE's) preceding childbirth are patterned and shape birth outcomes at the intersection of race and income. Using population data from the Pregnancy Risk Assessment Monitoring System we uncover common maternal LE clusters preceding births in 2011–2015, offering a description and measurement of what we call “stressor landscapes” that go beyond standard measures by frequency or type alone. Three landscapes emerge: (1) Protected, characterized by very few LE's; (2) Illness/Isolated, with very few LE's and most commonly involving an illness or death of someone close; and (3) Toxic/Cumulative, comprising more frequent and acute LE's. Mothers in the toxic landscape experience on average 107-g lighter birth weights and a 27%, 49%, and 57% greater risk of PTB, LBW, and VLBW, respectively, compared to in the protected landscape. Low-income and non-Hispanic black (NHB), Hispanic, American Indian (AI), and Alaska Native (AN) mothers are among the groups disproportionately exposed to toxic stressor landscapes. The association between landscape and birth outcomes additionally varies by race and income. Among non-Hispanic white mothers, toxic landscapes are linked to poor birth outcomes at lower incomes. Among NHB mothers, illness-related stressors are additionally linked to worse outcomes and stressor landscapes disproportionately harm middle-income mothers. Toxic stressors may contribute to worse outcomes among middle- and high-income Hispanic and AI/AN mothers, but these patterns are less clear. Our study offers a new approach to measuring LE's that match common conceptions of exposure clustering and applies it to US population data to reveal LE patterns underlying persistent social disparities in maternal and child health.

## 1. Introduction

Racial and socioeconomic disparities in perinatal health outcomes in the United States (US)—notably low birthweight (LBW) and preterm birth (PTB)—constitute an ongoing public health crisis. In 2016, non-Hispanic black (NHB) births in the US were 50% more likely to be premature than non-Hispanic white (NHW) births (Martin & Osterman, 2018). Among US singleton births in 2016, NHB infants were 2.2 times more likely to be low birth weight (LBW) than NHW infants (Womack, Rossen, & Martin, 2018). Although studied extensively, these inequalities are still not well understood. Across health indicators, overwhelming evidence demonstrates that differences in outcomes by socioeconomic position (SEP) account for a substantial proportion of racial inequalities (Blumenshine, Egarter, Barclay, Cubbin, &

Braveman, 2010; Nuru-Jeter et al., 2018). But race still has residual effects on birth outcomes beyond what is explicable by SEP indicators, risky health behaviors (e.g., smoking or drinking), and healthcare access (Almeida, Becares, Erbetta, Bettegowda, & Ahluwalia, 2018; Lorch & Enlow, 2016; Lu & Chen, 2004). Furthermore, the improvements in birth outcomes with higher SEP among African Americans are not as pronounced as among whites (Braveman et al., 2015). Residual race effects found in population studies are still often attributed to unmeasured aspects of the social environment and related stressors.

Current efforts to directly measure the health impacts of social stressors beyond individual SEP render inconsistent results and continue to face significant measurement challenges, including how to capture different types and scales of racism, stressors, and lived contexts that are ultimately embodied (Bailey et al., 2017; Krieger, 2005,

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2014). Many population studies and analytical models also fail to account for how SEP acts as a mediator in the embodiment of adversity and racism. For instance, poverty can result from both structural and interpersonal racism, as evident in labor market discrimination (Bertrand & Mullainathan, 2004) and systematic segregation (Massey, 1990; Massey & Denton, 1993; Rugh, Albright, & Massey, 2015). Poverty can furthermore contribute to chronic psychosocial stress, which impedes self-regulatory capacity, cognitive performance, coping, and overall health (G. W. Evans & Kim, 2013; G. W. Evans & Schamberg, 2009; C. A. McEwen & McEwen, 2017); thereby mediating and exacerbating many health consequences of racism and other stressors in early development and throughout the life-course. A closer examination of health at the *intersection* of race and SEP in the US is warranted and the use of life events (LE's) holds the potential to elucidate stressor-related health pathways at different positions at this intersection.

In this paper, we draw from intersectionality theory to unpack patterns and processes underlying US disparities in birth outcomes, focusing on maternal stressors and specifically LE's, that emerge at different social positions defined by race and SEP jointly. We focus on maternal LE's during pregnancy and in the months prior to conception as sensitive periods for maternal health, fetal development, and public health interventions (Lu & Halfon, 2003; Witt et al., 2014a, b). We use a novel approach to measuring and analyzing LE's, one that uncovers LE clusters within and across women. We call these clusters "stressor landscapes." Empirically, we take a descriptive epidemiological approach to identify dominant maternal stressor landscapes and examine whether and how stressor landscapes during pregnancy influence adverse birth outcomes at the race-income intersection.

### 1.1. Stress and perinatal health

Stress is generally conceptualized as a state of arousal resulting from either an adverse stimulus or an inability to attain sought-after ends that consequently taxes one's adaptive capacity (Lazarus, Tomita, Opton, & Kodama, 1966; Menaghan, 1983; Pearlin, 1989; Pearlin, Menaghan, Lieberman, & Mullan, 1981). The external socio-environmental events and circumstances that contribute to the internal arousal are *stressors*. The internal arousal process, or biological stress response, is marked by complex pathways regulated through the HPA axis and involving the autonomic nervous system, metabolic hormones, inflammatory immune responses, and neurotransmitters in the brain (C. A. McEwen & McEwen, 2017). Allostasis refers to the internal regulation of these pathways, which can become adversely affected by overstimulation or off-regulation inhibition, resulting in excessive "wear and tear," or allostatic load (B. S. McEwen, 1998).

Recent and compelling studies, both clinical and quasi-experimental, show a significant association between external maternal stressors near or during the time of pregnancy and adverse birth outcomes, notably PTB and LBW (Borders, Grobman, Amsden, & Holl, 2007; Novak, Geronimus, & Martinez-Cardoso, 2017; Rini, Dunkel-Schetter, Wadhwa, & Sandman, 1999; Wadhwa et al., 2001; Wadhwa, Sandman, Porto, Dunkel-Schetter, & Garite, 1993). Elevated perinatal risks are outcome- and pathway-specific. For instance, higher amounts of corticotropin releasing hormone (CRH) in the placenta during pregnancy—a product of the cortisol-mediated maternal stress response initiated by the hypothalamus—is associated with fetal growth restriction and LBW (Thomson, 2013). Exaggerated stress reactivity also increases susceptibility to infection (Culhane et al., 2001) and primes the inflammatory response in utero, which contributes to PTB risk (Christian, 2012), and ultimately LBW.

Despite evidence for the causal link between maternal stressors and birth outcomes in biomedical studies (e.g., Christian, 2012; Culhane et al., 2001; Thomson, 2013) and natural experiment settings (e.g., Torche, 2011; Xiong et al., 2008), it remains unclear how the distribution of stressors embedded in social environments and circumstances in the US population contribute to race- and SEP-based

disparities in birth outcomes. Efforts to do this require population data, adequate measurement of stressors, and a close examination of race and SEP jointly. Current population studies have inconsistently addressed these issues and provide inconsistent results. For instance, studies focusing on prenatal stressors can overcontrol for important mediators (e.g., unhealthy coping strategies like substance use) or overlook racial and ethnic differences in how SEP and psychosocial stressors affect health outcomes (Almeida et al., 2018; Grobman et al., 2018; Lu & Chen, 2004). Meanwhile, studies looking at broader contexts have found that neighborhoods and local income disparities significantly affect birth risks, but how these translate to personal experiences that get under the skin is still understudied (Culhane & Goldenberg, 2011; Ncube, Enquobahrie, Albert, Herrick, & Burke, 2016; Seabrook et al., 2018; Wallace, Mendola, Chen, Hwang, & Grantz, 2016).

### 1.2. Life events

Life events reveal how personal experiences are embedded in greater social structures. When measured in population-based data, they can link generalized statistics to more qualitative information to reveal the nature of inequalities. They elucidate social environments and have long been used by social scientists to understand how stress is socially patterned (Aneshensel, 1992; Kessler, 1979a, b; Sternthal, Slopen, & Williams, 2011). An ongoing debate in the LE literature involves the relative influence of differential stressor exposure and vulnerability.

Smith (1987) uses an engineering physics analogy that illustrates exposure and vulnerability, in which the impact of a stressor on a subject is represented by a quantifiable load, or stressor exposure, dropped on a surface with a given capacity to withstand it or not, *i.e.*, vulnerability. To elaborate, LE's are like weights loaded onto a net and the net's capacity before breaking depends on its ability to absorb, bounce back from, or readjust to the weight. This capacity to flex, resist, or adapt can be reinforced by advantageous social positioning, resources, and social support—like extra webbing. Acute and recurrent LE's ultimately contribute to the stressor weight, deterioration of the net, or both.

Differential vulnerability to stressful LE's has long been considered an important driver of racial and socioeconomic disparities in health (Dohrenwend, 1973; Dohrenwend & Martin, 1979; Rosenberg & Dohrenwend, 1975; Thoits, 1987), but there is also empirical evidence supporting the differential LE exposure hypothesis, such as in Canada (Turner & Avison, 2003; Turner & Lloyd, 1995). Life events tend to cluster within disadvantaged groups and individuals, reinforcing patterns of cumulative disadvantage and adverse health over the life-course (Galobardes, Lynch, & Smith, 2004; Lloyd & Turner, 2003; Seabrook & Avison, 2012). However, this finding is population- and outcome-dependent and evidence supporting the differential exposure hypothesis in a US-representative sample remains limited (Hatch & Dohrenwend, 2007). Existing studies focused specifically on the impact of the unequal distribution of maternal LE's on birth outcome inequalities (*i.e.*, differential exposure) have rendered inconsistent results, even within US-based studies using the same survey instrument (Almeida et al., 2018; Lu & Chen, 2004).

Beyond instrument and study sample differences, how LE's are conceptualized and parameterized could be contributing to study discrepancies and weak findings. Life events are most commonly analyzed as additive scales based on frequency of events, as is the default measurement provided by Center for Disease Control and Prevention (CDC) in the Pregnancy Risk Assessment Monitoring System (PRAMS) data. Some studies use more sophisticated models to account for latent dimensions driving different LE types, conceptualized *a priori*. Despite being optimized for hypothesis-testing and scale-building, such approaches carry weaknesses in their application when latent variables are conceptualized in overly simplistic ways. Life events are commonly theorized as fitting into rigid types that are actually deeply and

complexly interrelated at any cross-sectional timepoint, *e.g.*, partner- and finance-related stressors.

A new approach to analyzing and interpreting LE's is warranted, one that does not treat them as simply additive, interchangeable, or rigidly categorized, but that considers how they are experienced in cascades and interactive clusters. The quantity *and* the co-occurrence of LE's in any personal configuration likely has important health impacts. In other words, how stressful one LE is can depend on whether or not another LE does or does not occur; meanwhile, there are other LE's that can produce shock waves regardless of what else occurs. Consider moving, a common item in LE instruments. It is a common stressor but its ultimate impact depends on other household circumstances or changes, like family separations or even upward mobility (Desmond & Perkins, 2016). For these reasons, a close examination of LE configurations—what we call stressor landscapes—across race and SEP is both a valuable exercise in further contextualizing common LE scales and potentially revealing underlying heterogeneity and divergent effects of common LE's in a socially stratified population.

### 1.3. Intersectionality

We draw from intersectionality theory (Crenshaw, 1991), a conceptual framework that highlights how multiple social identities are interdependent and together shape lived experiences and health. This framework informs how we analyze the joint role of race and SEP in shaping maternal stressors and perinatal health. In doing so, we overcome shortcomings of the majority of existing population studies that misrepresent minority health by ignoring, incorrectly specifying, or misinterpreting race-SEP interactions (Bauer, 2014; Viruell-Fuentes, Miranda, & Abdulrahim, 2012). Our contributions include: (i) contextualizing the race-SEP intersection by characterizing corresponding LE patterns at different positions at this intersection; (ii) analyzing health across the SEP continuum instead of singularly considering health effects of SEP disadvantage; and (iii) testing for multiplicative effects, or interactions, on the additive scale, which better matches the intersectional hypothesis that race- and SEP-related health effects are not simply the sum of their parts (Bauer, 2014). This last point contrasts with simply testing for statistically significant interaction terms on the multiplicative scale (*e.g.*, logistic regression coefficients).

### 1.4. Uncovering life event patterns

Machine learning techniques, particularly cluster analysis, is uniquely well-suited for characterizing population heterogeneity in a manner paralleling social stress theory. It uncovers underlying LE patterns that reflect different social landscapes. The grouping of individuals into different landscapes furthermore allows LE's to be considered holistically as contexts that jointly influence birth outcomes. The presence or absence of one LE can shape the meaning of another, for instance. Clustering thereby serves as an alternative to common frequency-based stress categorizations. The latter are limited by their inability to differentiate between stressor type or severity, including low specificity for rare and acute stressors. Clustering even has the potential to overcome limitations of weighted scales as well, such as those based on factor analysis, through its ability to flexibly handle complex interactions between events or circumstances.

The use of machine learning to uncover the underlying structure of population characteristics is a relatively new approach in social research, but it aligns with long established interests of sociologists to better understand the constellation of events and circumstances that constitute personal social contexts (Abbott, 1995; Molina & Garip, 2019). Clustering techniques have been used to characterize patterns in American mothers' employment (Killewald & Zhou, 2019), cohorts of first-time Mexican migrants to the US (Garip, 2012, 2016), and personal events leading to sex initiation among Malawi women (Frye & Trinitapoli, 2015). In such analyses, the meaningfulness of the patterns

that emerge can be validated substantively—that is, based on alignment with existing typologies or human judgement—and through confirmatory or predictive validation techniques that are highly transparent but not necessarily conforming to more traditional parametric approaches (Bail, 2008; Bonikowski & DiMaggio, 2016; Frye & Trinitapoli, 2015; Garip, 2016; Grimmer & Stewart, 2013; Molina & Garip, 2019).

### 1.5. The current study

In the present study we take a novel approach to measuring prenatal stress and focus on more descriptive epidemiological aims to uncover an in depth and expansive depiction of the social contexts into which recent U.S. birth cohorts are being born at the race-SEP intersection. Our approach involves multiple stages. First, we determine the underlying structure and typical LE patterns during pregnancy and in the months preceding childbirth. Second, we consider women's likelihood of finding themselves in different stressful LE clusters, depending on their position at the race-SEP intersection. Lastly, we evaluate the degree to which these patterns account for racial disparities in birth outcomes at different levels of SEP.

## 2. Methods

### 2.1. Study design and sample

We use exceptionally rich population-based data from the CDC PRAMS, a postpartum survey of US resident live births during 2011 through 2015 from 32 participating states and New York City using stratified random sampling, with oversampling of racial and ethnic minorities (Shulman, D'Angelo, Harrison, Smith, & Warner, 2018). The multi-mode survey entails an initial mail phase using standardized self-administered questionnaires. A telephone-based, interviewer-administered version is deployed to recruit and complete surveys for non-respondents from the first phase. PRAMS data include questions covering a broad range of topics related to women's experiences, risk factors, and health care before, during, and after the index pregnancy. Survey data are linked to the child's birth record and made available to out-of-state investigators for all participating states achieving minimum response rates (65% in 2011, 60% in 2012–2014, and 55% in 2015). For all data description and analyses, we use CDC's constructed weights to account for the survey design. All respondents with non-missing plausible responses for birthweight total 131,418 (included in Table 1), and 111,330 respondents comprise our analytical sample when we limit to NHW, NHB, Hispanic, and American Indian or Alaska Native (AI/AN) mothers (Fig. 3).

### 2.2. Variables

We use birth weight (grams) and gestational age (completed weeks) from birth records. We analyze birth weight as continuous and as binary-coded, where values lower than 2,500 g constitute LBW. We use gestational age to determine prematurity, a binary indicator variable with less than 37 weeks as the cut-off. We code respondents' races based on the categories listed in their birth records (Table 1), and in our analyses focused on the race-SEP intersection we limit our analytical sample to NHW mothers and the larger, more commonly disadvantaged minority groups in the US: Hispanic, NHB, and AI/AN subgroups. If respondents are not identified as Hispanic on their birth record, but reported being Hispanic in the survey, we code them as Hispanic. Household income level is measured in quartiles from self-reported income categories, with values based on the midpoints of the ranges provided in the questionnaire response categories and weighted to account for the survey design.

We construct eleven binary LE indicators based on responses to the LE survey instrument and an additional LE indicator for intimate

**Table 1**

Characteristics of study sample from CDC Pregnancy Risk Assessment Monitoring System, overall and by cluster. Cluster values are in bold when statistically significantly different from total sample. Numbers represent US resident live births during 2011 through 2015 from 32 participating states and New York City, calculated using CDC survey weights.

	Total	C1: Protected (PL)	C2: Illness/ Isolated (ISL)	C3: Toxic/ Cumulative (TSL)
Total (percent of total)	131,310	(62.8%)	(24.5%)	(12.8%)
Birthweight (g)	3310	<b>3355</b>	<b>3360</b>	<b>3248</b>
Low birthweight	6.2%	<b>5.8%</b>	6.2%	<b>8.7%</b>
Very low birthweight	1.0%	0.9%	0.9%	<b>1.5%</b>
Preterm	7.8%	7.5%	7.8%	<b>9.6%</b>
Non-Hispanic white	70.3%	70.0%	<b>74.4%</b>	<b>60.3%</b>
Non-Hispanic black	8.3%	<b>7.1%</b>	8.0%	<b>17.7%</b>
Hispanic	11.6%	11.9%	<b>1.0%</b>	<b>14.4%</b>
Chinese	1.4%	<b>1.8%</b>	<b>0.8%</b>	<b>0.4%</b>
Filipino	0.7%	0.8%	0.8%	<b>0.4%</b>
Japanese	0.3%	0.3%	0.2%	0.4%
Other Asian	4.1%	<b>4.9%</b>	<b>2.6%</b>	<b>1.9%</b>
American Indian	0.5%	<b>0.4%</b>	0.7%	1.1%
Hawaiian	0.1%	0.1%	0.1%	0.1%
Alaska Native	0.1%	0.1%	0.1%	<b>0.3%</b>
Other non-white	0.6%	0.7%	<b>0.4%</b>	0.4%
Mixed	1.9%	1.8%	2.0%	<b>2.9%</b>
Income quartile				
1	16.2%	<b>13.0%</b>	<b>13.7%</b>	<b>45.9%</b>
2	23.3%	<b>22.2%</b>	<b>22.6%</b>	<b>32.8%</b>
3	29.1%	<b>30.4%</b>	<b>30.9%</b>	<b>14.2%</b>
4	31.5%	<b>34.3%</b>	32.8%	<b>7.0%</b>
Marital status in birth year				
Married	83.6%	<b>87.3%</b>	<b>85.1%</b>	<b>53.1%</b>
Single	15.3%	<b>11.9%</b>	<b>14.0%</b>	<b>43.1%</b>
Divorced	1.1%	<b>0.8%</b>	0.9%	<b>3.8%</b>
Maternal age				
≤ 17	0.1%	0.5%	0.8%	<b>1.7%</b>
18-19	2.3%	<b>1.7%</b>	2.6%	<b>5.9%</b>
20-24	16.2%	<b>14.1%</b>	15.9%	<b>31.5%</b>
25-29	31.1%	31.1%	31.6%	30.4%
30-34	32.1%	<b>33.8%</b>	32.2%	<b>20.1%</b>
35-39	14.2%	<b>15.3%</b>	13.6%	<b>8.3%</b>
40+	3.4%	3.4%	3.3%	<b>2.0%</b>
Previous live births				
0	38.8%	38.7%	39.5%	37.0%
1	34.3%	34.9%	34.3%	<b>29.8%</b>
2+	26.9%	26.3%	26.2%	<b>33.2%</b>
Maternal educational attainment				
Less than high school	9.1%	8.6%	<b>7.9%</b>	<b>16.1%</b>
High school	19.2%	<b>17.6%</b>	18.6%	<b>32.0%</b>
Above high school	90.9%	91.4%	<b>92.1%</b>	<b>83.9%</b>

partner violence (IPV), specifically physical abuse by a partner. These are summarized in Fig. 1 and original survey questions are listed in the appendix. All LE items are based on questions referencing a full year prior to childbirth, and the IPV reference period additionally encompasses a full year prior to conception. Our adjusted models include state and self-reported maternal marital status (single, married, or divorced), age (years) at delivery (categorized: < = 17, 18–19, 20–24, 25–29, 30–34, 35–39, 40+), first births (binary), education (categorized by years of schooling: 0–8, 9–11, 12, 13–15, ≥ 16), height (centimeters), and body mass index (based on self-reported pre-pregnancy weight and height and categorized by kg/m<sup>2</sup>: < 19.8, 19.8–26, 26–29, > 29).

### 2.3. Statistical analysis

In order to characterize stressor landscapes within the sample, we perform hierarchical clustering on principal components (HCPC) for our entire analytical sample based on LE's alone. We identify principal components underlying the maternal LE's in our sample in a preliminary step, multiple correspondence analysis (MCA)—a graphical technique based on the chi square statistic and optimized for uncovering the latent structure behind the joint responses to multiple categorical variables (Greenacre, 2017; Greenacre & Blasius, 1994; Sourial et al., 2010). This step is an eigenvalue-based approach that accounts for variation in LE's, both within and across respondents, to extract and feed the most informative information into the second step: clustering. The clustering uncovers prominent configurations of responses (columns) and respondents (rows) along the MCA dimensions uncovered. We use the FactoMineR package in R for the HCPC and multiple imputation for missing values (Husson et al., 2010, 2017; Husson & Josse, 2014, pp. 165–184; Josse & Husson, 2016; Lê, Josse, & Husson, 2008). The clustering is non-parametric. To enhance robustness, we replicate the HCPC on 100 random (without replacement) subsamples to ensure comparable clusters are consistently found. We compare our resulting clusters to groups defined by the frequency-based categories more commonly used with PRAMS by cross-tabulating weighted counts.

We assess risk of landing in the most severe stressor cluster based on race and income using a single multiple logistic regression performed in Stata 15 with survey weights and interaction terms between each income quartile and race category (each category is coded as a dummy variable to allow for non-linearity; Model 1). To confirm that our measurement of stressor landscapes is consistent across race and income subgroups we compare the relative frequencies of individual LE items within each cluster across these subgroups.

To assess the degree to which maternal stressor landscape (cluster membership) is linked with differences in birth outcomes by race, we estimate birth weights associated with each stressor landscape across race and income categories based on a single ordinary least squares regression on birthweight (grams), allowing for all interactions between race, income, and stressor landscape categories and adjusting for all covariates (all categorical covariates are included as dummy variables; Model 2a). This approach is repeated with logistic regressions for each binary outcome: PTB (Model 2b), LBW (Model 2c), and VLBW (Model 2d). We present regression results as margins, based on marginal standardization using Stata 15.

### 3. Results

Our clustering results uncover three different groups, reflecting three types of stressor landscapes in which mothers have lived during the year before childbirth and into which their infants have been born. Below, we summarize stressor landscape characteristics, how they correspond to social causes of adverse birth outcomes, and how they compare to previously used LE categorizations. We then review regression results that uncover how more adverse stressor landscapes are distributed at the race-SEP intersection and how stressor landscapes account for US birth outcome disparities.

Fig. 1 depicts the percent of the sample reporting each LE, overall and within the three stressor landscapes. The first cluster, characterized by relatively low LE frequencies, we label the Protected Landscape (PL). The second is distinguishable by the predominance of illness-related LE's and a relatively low frequency of more acutely stressful LE's. Thus, we refer to it as the Illness/Isolated Stressor Landscape (ISL). Of all the mothers in this group, 81% report a close relative being very sick or hospitalized, 25% report a single LE, and 33% report two LE's. Finally, we call the third cluster the Toxic Stressor Landscape (TSL). These stressors overrepresented in this group are toxic by being more traumatic in nature, commonly triggering additional stressors and

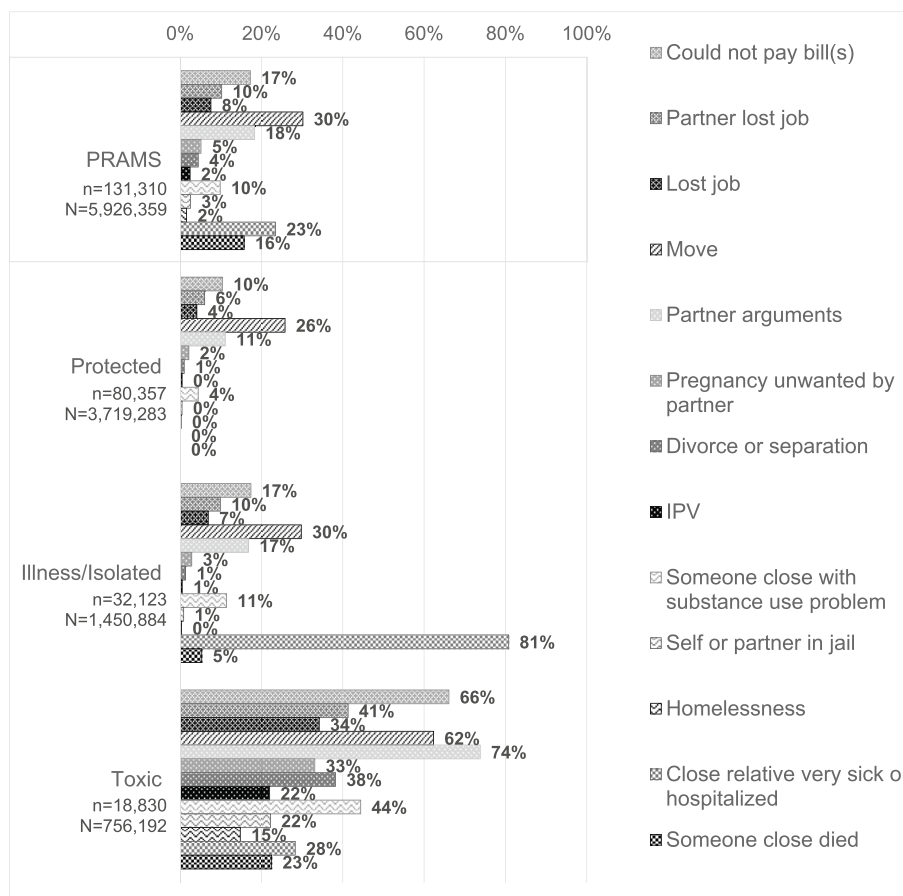


Fig. 1. Percentages of mothers experiencing individual LE's overall and within each stressor landscape (unweighted [n] and weighted [N] counts listed). Percentages are weighted based on the PRAMS design to represent US resident live births during 2011 through 2015 from 32 participating states and New York City.

Table 2

Cross-tabulation comparing membership to stressor landscapes and to the CDC-prescribed categorization by number of stressors. Numbers represent US resident live births during 2011 through 2015 from 32 participating states and New York City, calculated using CDC survey weights.

Total stressors	C1: Protected/Buffered	C2: Illness/Isolated	C3: Toxic/Cumulative	Total
0	1,841,948	0	0	1,841,948
1	1,073,385	357,254	1,994	1,432,633
2	489,194	468,739	22,831	980,765
3+	170,268	589,109	687,925	1,447,302
Total	3,574,795	1,415,102	712,750	5,702,648

adversity, or both. Experiencing either homelessness, IPV, incarceration of self or a partner, or divorce alone nearly perfectly predicts being in the TSL group. In this group, 15% report homelessness, 22% report being in jail or having their partner in jail, 22% report IPV, 23% report the death of someone close to them, and 33% report being separated or divorced in the year prior to childbirth.

Also as expected under the differential exposure hypothesis, low-income and disadvantaged minority groups are disproportionately represented in the TSL group, including NHB, Hispanic, and AI/AN women. Higher income and NHW mothers meanwhile are over-represented in the PSL group. Single and divorced mothers are more concentrated in the TSL group, and married mothers in the PSL and ISL groups. Within the TSL group, there is additionally differential exposure to more LE's and acute LE's among low-income and minority mothers compared to NHW and high-income mothers (results not shown).

Table 1 summarizes analytical sample characteristics overall and by

stressor landscape. Birth outcomes and socio-demographic characteristics differ systematically across stressor landscapes, with the most dramatic differences evident between mothers in the TSL group as compared to the more similar PL and ISL groups. The TSL group has a disproportionately skewed distribution of income and education levels represented, with 46% of the group being in the lowest income quartile and 16% having not completed high school. In contrast, the income and education distributions in the PL and ISL groups are more skewed toward higher values. Mothers in the TSL group face the worst birth outcomes. When compared to PL mothers, infants of mothers in the TSL group were 107-g lighter on average, 1.3 times greater risk of PTB, 1.5 times greater risk of LBW, and 1.6 times greater risk of VLBW on average. This is despite women of advanced maternal age who are at elevated risk of adverse birth outcomes (Weng, Yang, & Chiu, 2014) being overrepresented in on the PSL group.

Table 2 is a cross-tabulation of weighted counts comparing our stressor measurements to the standard frequency-based categories. Within our TSL categorization, 96.5% report 3 or more events (3+). The remaining 3.5% is a non-trivial proportion of mothers experiencing acutely stressful events but that are not captured in the 3+ category. For instance, of the women that report a single LE but still land in our TSL group, 51.4% report partner abuse, 39.5% report a divorce, 7.5% report homelessness, and 1.5% report incarceration of self or partner. In contrast, the frequency category captures a diluted top stressor category (3+) with 52% of women in this group not being included in our TSL categorization. These findings indicate that our categorization has both greater sensitivity for identifying mothers with acute but isolated stressors that are more likely to be toxic (e.g., partner abuse and homelessness) and greater specificity against misclassifying mothers with multiple common and non-acute stressors as equivalent to mothers

with more rare and acute stressors. Beyond qualitative comparisons, the standard frequency-based categorization is less predictive of adverse birth outcomes than our categorization as well. Using the LE frequency-based categorization (0, 1, 2, 3+), percent LBW by ascending order is 5.5%, 5.9%, 6.0%, and 7.8%, with only values from the highest and lowest frequency groups significantly different from each other ( $p < 0.05$ ). In contrast, using our categorization percent LBW is statistically significant between each group, with 5.8%, 6.2%, and 8.3% LBW in the PL, ISL, and TSL groups respectively ( $p < 0.05$ ).

Fig. 2 presents mothers' estimated probabilities of landing in the TSL cluster by income quartile and racial/ethnic subgroup (Model 1). Mothers' predicted risks of being in the TSL decline with higher income quartiles, but not to the same degree across race/ethnic subgroup. Hispanic and NHB mothers do not experience as dramatic a decline in TSL risk with higher income as NHW mothers, *i.e.* higher income correlates with protection against toxic stressors landscapes less among Hispanic and NHB women than among NHW women.

Fig. 3<sup>1</sup> illustrates how stressor landscapes shape birth outcomes and inequalities by race and income (results from Model Set 2). Infants of NHB mothers have, on average, a lower birth weight and higher rate of adverse birth outcomes compared to infants of NHW mothers across all stressor landscapes ( $p < 0.05$ ). In contrast, Hispanic mothers experience similar birth weights to NHW mothers and AI/AN mothers experience the highest birth weights, on average. However, race and income differences are minimized under stressor-protected landscapes, which is most dramatically influenced by the advantages to birth outcomes realized by NHB mothers in the PSL group.

All race subgroups exhibit different relationships between stressor landscape and birth outcome, depending on income.<sup>2</sup> For NHW mothers, toxic landscapes are associated with lower birth weights in the lower income quartiles ( $p < 0.05$  in models with and without adjustment for weeks gestation). This suggests that for NHW mothers TSL's are most influential, if at all, in low-income settings. Among NHB and Hispanic mothers, the opposite is apparent. Differences between stressor landscapes are widest in the upper-middle income group ( $p < 0.05$  in models with and without adjustment for weeks gestation). Among AI/AN mothers, wider differences also emerge in higher income groups. Birth weight is highest among high-income mothers in stressful landscapes. When maternal diabetes and weight gain during pregnancy are added to the model, birth weights for AI/AN mothers in the highest income quartile remain significantly higher for TSL mothers and also become higher for ISL mothers, relative to PL mothers ( $p < 0.05$ ).

In addition to the birth weight findings, similar patterns emerge for PTB, LBW, and VLBW outcomes. However, their respective models render few statistically significant findings, possibly due to their rarity and small subgroup sizes—particularly for high-income minority mothers.<sup>3</sup> We still consider patterns in each outcome, however, due to the clinical significance of each outcome, the relative consistency of patterns across outcomes, and the data being population-based and therefore depicting what we deem meaningful estimates regardless of statistical significance.

#### 4. Discussion

Our study provides rich, contextual description and measurement of racial disparities in perinatal health in the US beyond most previous

<sup>1</sup> Confidence intervals are not depicted for clarity, but statistical significance of subgroup differences is noted in the text and based on Stata margins using unconditional variance-covariance matrices of the estimators (VCE) and an alpha level of 0.05.

<sup>2</sup> The corresponding three-way interaction is statistically significant for continuous birth weight (Adjusted Wald F Test:  $p = 0.002$ ), not significant for VLBW ( $p = 0.095$ ), PTB ( $p = 0.118$ ) or LBW ( $p = 0.103$ ).

<sup>3</sup> Margins for high-income AI/AN mothers in the TSL group were not estimable for LBW or VLBW.

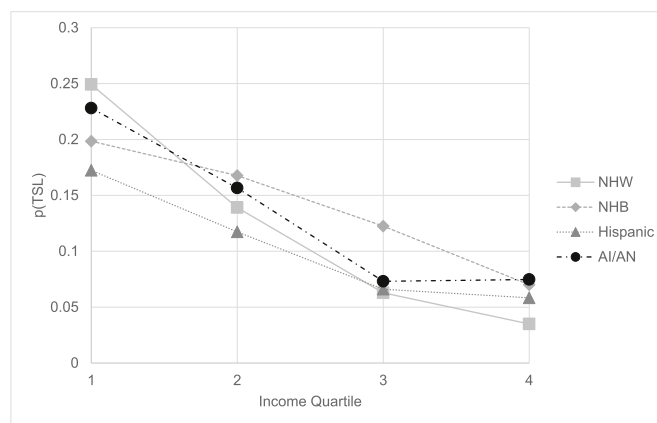


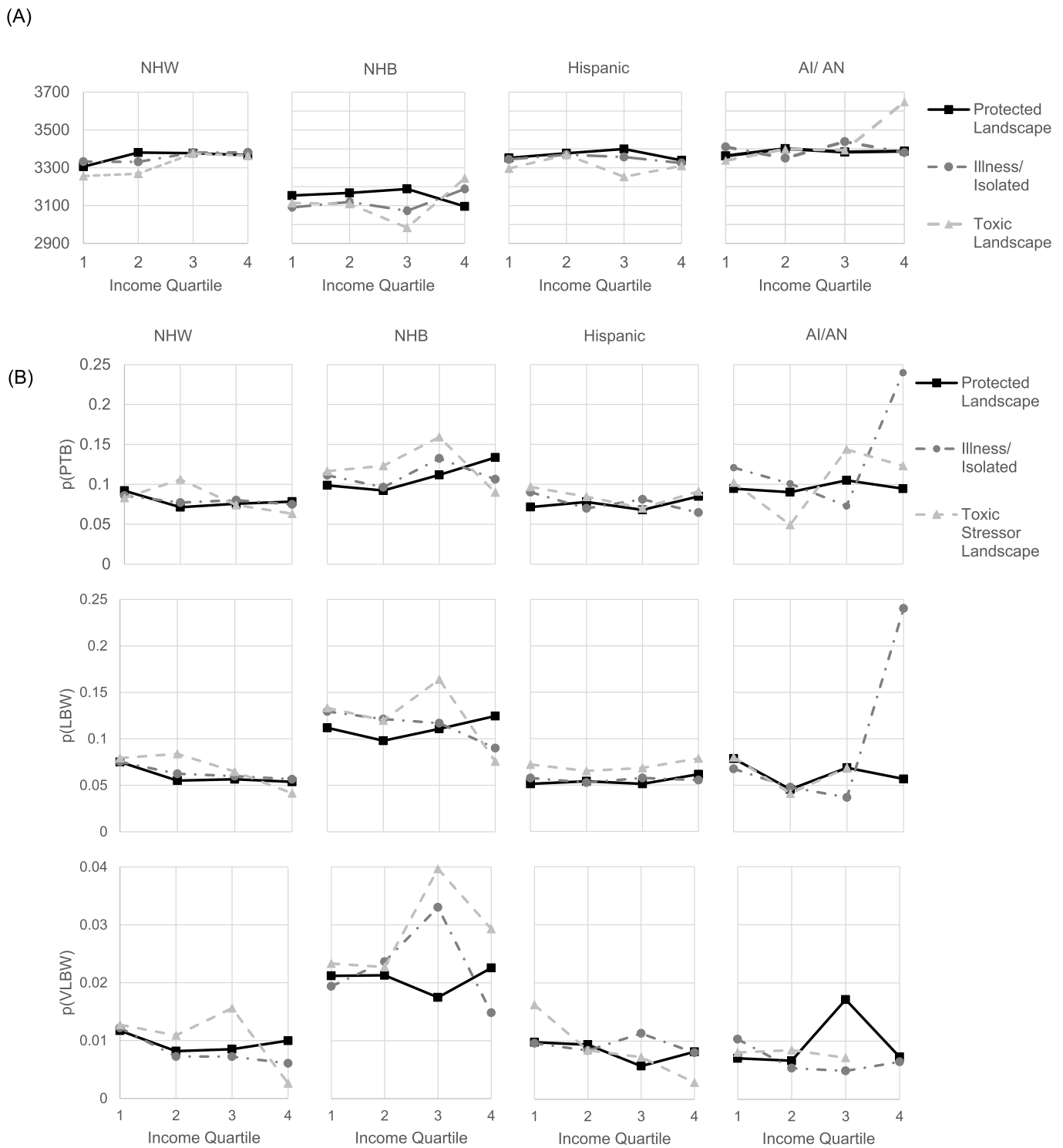
Fig. 2. Probability of being born in toxic stressor landscape (TSL) based on maternal race/ethnicity and income, adjusting for age, education, marital status, and state of residence. Estimations were derived using marginal standardization and based on US resident live births during 2011 through 2015 from 32 participating states and New York City, calculated using CDC survey weights.

population-based studies. First, our findings agree with other US-based studies finding wide disparities in birth outcomes by race and SEP (Almeida et al., 2018; Amjad et al., 2019; Blumenshine et al., 2010; Braveman et al., 2015; Culhane & Goldenberg, 2011; Grobman et al., 2018). Second, we uncover maternal LE patterns preceding US births that systematically disadvantage low-income and minority women, through differential clustering of toxic stressors. Our measurement of “stressor landscapes” highlights the role of LE's in shaping the personal and temporal contexts of pregnancies, births, and related social disparities. These stressor landscapes are related to, but still distinct from, important social and spatial contexts linked to race and SEP, such as environmental hazards, area racism, and other neighborhood characteristics (Chae et al., 2018; Neube et al., 2016; Seabrook, Smith, Clark, & Gilliland, 2019). Our measurement approach to LE's serves as an alternative to common frequency-based categorizations of LE's which are limited by their low sensitivity to isolated acute LE's, low specificity for toxic LE's, inability to differentiate between LE types or interactions, and lower predictive validity for birth outcomes.

Toxic stressor landscapes significantly predict lower infant birth weight on average, and greater risk of LBW, VLBW, and PTB. These markers of health at birth ultimately influence adult health and therefore likely will have an intergenerational impact on health (Barker et al., 1993; Gluckman, Hanson, Cooper, & Thornburg, 2008; Pathik D; Wadhwa, Buss, Entringer, & Swanson, 2009). The toxic stressor landscapes we uncover are not rare—with 15% of the U.S. infants in our sample being born into such environments—and they are disproportionately distributed among disadvantaged minorities and low-income mothers.

How stressor landscapes affect mothers appears to depend on race and income jointly, as theorized using an intersectionality-based approach. Hence, in addition to the evidence we find of differential exposure by race and income in the US, we also find potential evidence of differential vulnerability or susceptibility to stressors. One of the starkest illustrations of this is the exceptionally lower birth weight and higher risk of LBW and VLBW among middle-income NHB mothers. This pattern suggests that women of color are more acutely vulnerable to social stressors relative to white women of similar income and relative to lower-income women of color, potentially due to greater social isolation or the accumulation of stress related to overcoming other obstacles coinciding with upward mobility (Brody et al., 2013; Cole & Omari, 2003; Colen, Geronimus, Bound, & James, 2006; Higginbotham & Weber, 1992).

Additional findings that warrant further study include the higher



**Fig. 3.** Birth outcome margins by race, income, and stressor landscape: (A) birth weight (continuous) and (B) risk of adverse birth outcomes (preterm birth, low birth weight, and very low birth weight). Each model controls for maternal age, parity, height, BMI, education, marital status at birth, and state of residence; and includes all interaction terms between race, income, and stressor landscapes.

birth weights of infants born to AI/AN mothers in high income and toxic stressor landscapes. Assuming this is not an artifact of small sample size ( $n = 994$ ), it could suggest that there is a closer link between maternal stressors and birth weight gain for higher income AI/AN mothers than for other subgroups—possibly via calorie-dense diets in stress environments. Other studies have documented heightened risks of macrosomia and child and adult obesity among AI/AN populations in

the U.S. (Boulet, Alexander, Salihu, & Pass, 2003; Sarche & Spicer, 2008), but we are not aware of any pathways linking maternal stress and upward mobility to exceptional high birth weights in this particular group.

Our study is constrained by its use of cross-sectional survey data that do not allow us to detail temporal sequences of events and circumstances that could better elucidate causal pathways. Explanations

for our results that possibly go beyond psychosocial stress pathways include other factors that relate to race, income, and buffers against stressful LE's, such as unequal distributions of wealth, social support, and aspects of the physical environment. Unequal access to wealth—such as personal property, debt and social safety nets—by race in the US is well-documented (Oliver & Shapiro, 2006; Rugh et al., 2015). Wealth is not included in PRAMS, nor most population-based studies of birth outcomes. Wealth could account for the observed health advantage that is realized for NHW mothers at relatively lower income levels than for NHB mothers and for the apparent differential impact of stressors on health along different positions at the race-income intersection. Social support, an important contributor to perinatal health, could buffer against exposure or vulnerability to toxic stressors by race and income as well (Collins, Dunkel-Schetter, Lobel, & Scrimshaw, 1993; Hoffman & Hatch, 1996; Rothberg & Lits, 1991). We encourage more states to include questions on wealth and social support in future waves in order to investigate related mechanisms further.

Overall, our study likely provides relatively conservative estimates of the actual effects of life stressors and related social environments on maternal and child health. First, there are still race- and income-based inequalities in the severity of LE's experienced within the TSL group, which dilutes our estimates of the actual inequities in exposure and vulnerability to toxic stressors. In addition, we only measure stressful life events within a relatively narrow period surrounding pregnancy, whereas increasing evidence suggests that pre-conception maternal stress can also shape pregnancy health and birth outcomes (Witt et al., 2014a, b). Furthermore, the stressor landscapes into which infants are born additionally have significant influence directly on child health, wellbeing, and development, which we do not capture in the scope of our study and data available. In fact, some of the stressors we measure as maternal LE's are the same stressors that would be used to measure adverse childhood experiences among their offspring, which predict health over the life-course (Felitti et al., 1998). Specifically, childhood experiences of household dysfunction, including parent separation, abuse, and substance use have lasting effects on biopsychosocial development and risk of age-related disease into adulthood (Danese et al., 2009; Danese & McEwen, 2012).

Through this study, we challenge future epidemiological work to approach disparities research with a more intersectionality-informed perspective and to balance current studies that narrowly focus on individual mechanisms, or simply adjust for race and SEP as covariates, with aims to understand the broader contexts of coinciding and cascading events and circumstances that jointly affect health. Stressor landscapes can be uncovered in population studies to help contextualize health disparities and provide key insights for hypothesis generation and future study design. For instance, we encourage future studies to more closely examine temporal orders of stressful life events and related biosocial mechanisms underlying perinatal health. Using our proposed measure is most relevant for population-based data and would render qualitatively different landscapes with different samples, which would limit direct comparability across studies but would provide richer description of context-specific stressors and patterns of stressors. Additional areas for future research include taking a closer look at US subpopulations facing high risks of adverse perinatal outcomes and significant race- and SEP-based disparities, such as adolescent pregnancies (Amjad et al., 2019), where specific stressor landscapes affecting such groups can be more closely examined.

As pointed out in recent reviews such as Bauer (2014), the concentration on social health inequalities alone is problematic, at best redundant and at worst re-enforcing differences as inevitably persistent. In this piece we hope to further nudge the discussion beyond this by refocusing on the lived events behind the statistics and general conversations of social stress. We have demonstrated that richer description of context is possible and informative with population-based data than what is typically presented and is critically important to social epidemiology as a compliment to other qualitative methods and

hypothesis-testing strategies. Future studies should focus further on how stressor landscapes and related health hazards emerge among neighborhoods and over the individual life-course in order to further inform appropriate social policy and public health improvements.

### Ethical approval

This study has been deemed exempt from human subjects review, because it entails secondary analysis of de-identified survey data from a federal agency.

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