Title

How Place Matters: An Examination of Relationships Between Neighborhood Quality and Risk of Preterm Birth Among Black Women in Oakland, California

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By

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Professor Amani Allen, Chair
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Professor Carolina Reid

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Abstract

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The purpose of this dissertation is to explore the relationship between neighborhood quality and preterm birth (birth before 37-weeks' gestation, PTB) among Non-Hispanic Black and African American women (hereafter, Black women). Three interrelated studies assess different dimensions of this relationship within the population of Black women who lived in Oakland, California, at the time of giving birth (2007-2011). The risk of PTB among Black women in the United States remains 1.5 times that of Non-Hispanic White women (hereafter, White women), a gap which has persisted without much improvement for decades. Because this inequity remains largely unexplained by differences in individual-level risk factors, researchers have begun to look farther upstream. The physical and social environments in which Black women live are one source of risk which is being increasingly examined.

Study 1 examines the overall relationship between neighborhood quality and PTB among Black women in Oakland (N=5549). First, the study maps neighborhood quality as defined by the California Healthy Places Index (HPI) and its eight component domains across 107 Oakland census tracts. Next, the study assesses the relationship between neighborhood quality and PTB using log-linear generalized estimating equation (GEE) models with exchangeable correlation structures. Fully adjusted models control for maternal confounding factors: parity, nativity, age, educational attainment for age, and low-income status. The study finds that living in a higher quality neighborhood is significantly associated with reduced risk of PTB among Black women across Oakland neighborhoods.

Study 2 examines the effect modification of relationship between neighborhood quality and preterm birth among Black women in Oakland (N=5549), by maternal characteristic. This study assesses each maternal characteristic as a potential multiplicative effect modifier through a series of log-linear GEE models with exchangeable correlation structures. The study finds significant effect modification by maternal participation the Special Supplemental Nutrition Program for Women, Infants and Children (WIC). The relationship between neighborhood quality and PTB is only significant among women who did not use WIC.

Study 3 examines potential mediation of the relationships identified in Studies 1 and 2 among Black women in Oakland (N=5343) by the number of prenatal care (PNC) visits, adequacy of PNC initiation, adequacy of PNC received services, and adequacy of PNC use (APNCU). The Baron and

Kenny method is used to guide a series of models to identify the presence of mediation, and significance of mediation is tested through the calculation of a mediation percentage with non-parametric bootstrap-based 95% confidence intervals. The study finds that while adequacy of PNC initiation, adequacy of PNC received services, and APNCU are significant risk factors for PTB in this population, independent of neighborhood quality, there is no evidence of significant mediation of the relationship between neighborhood quality and PTB.

The findings of Studies 1, 2, and 3 can inform efforts in Oakland to improve neighborhood quality in order to have a long-term impact on risk of PTB among Black women. Building on these findings, future quantitative and qualitative research is warranted to understand in greater detail the specific pathways through which neighborhood quality influences Black women's risk of PTB in Oakland. Additional research in other urban environments would enhance a broader understanding of the diverse relationships between place and PTB among Black women in the United States. Our studies contribute to the growing body of literature investigating how place may matter and exploring intervention opportunities to reduce Black women's risk of PTB.

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Background and Significance

The rate of preterm births (PTB) – birth before 37-weeks gestation – in the United States has been on the rise since 2014, accounting for 9.93% of all births in 2017.[1] PTB is a leading cause of infant mortality in the United States and a risk factor for adverse health outcomes in infancy, childhood, and adulthood.[2–5] Compared to infants born at greater than or equal to 37 weeks, infants born preterm are at higher risk for infant complications like respiratory distress,[5] disabilities such as cerebral palsy, schizophrenia, and developmental disabilities,[3] and chronic health challenges such as depression in adulthood.[6] Being born preterm may also increase women's risk of having a preterm delivery.[7]

The risk of preterm birth among Non-Hispanic Black and African American women (hereafter, Black women) in the United States remains 1.5 times that of Non-Hispanic White women (hereafter, White women) (13.93% versus 9.05% of births in 2017, respectively); this gap has persisted with little improvement for decades.[1,8,9] This racial inequity is largely unexplained by differences in individual-level risk factors such as maternal age, socioeconomic status, parity, interpregnancy interval, or health.[1,10,11] The introduction of the life-course perspective in the field of maternal and child health has motivated scholars to consider how disparities in exposure to social determinants of health over time may explain the Black-White gap and provide opportunities for early intervention to reduce Black women's risk of PTB.[12,13]The neighborhoods where people live are increasingly studied as a social determinant of racial disparities in PTB.

In their review of neighborhood context and reproductive health, Culhane and Elo highlight direct and indirect pathways through which a neighborhood's physical, service, and social environments may impact PTB.[14] The *physical environment* includes the natural environment, the built environment, available economic and educational opportunities within an area, housing quality. Studies have found evidence for relationships between risk of PTB and increased exposure to air pollution,[15–18] proximity to waste facilities,[19] and community green space.[19] Relatedly, the *service environment* describes the presence of goods, services, and resources within a neighborhood. For example, relationships with risk of PTB have been identified with availability of different types of food outlets.[20] Finally, the *social environment* captures how neighbors interact with each other, safety, feelings of being supported or connected, civic engagement, and socioeconomic composition. For example, studies have identified associations between neighborhood socioeconomic deprivation and PTB[21–29] as well as community violence and PTB.[30–34]

That neighborhoods matter for birth outcomes is generally accepted within public health, but answering the question of *how* neighborhoods matters remains a challenge.[35,36] Across studies, there is variation in the magnitude, direction, and significance of the associations between the quality of a neighborhood's physical, service, and social environments and PTB.[18,19,25,26] This, it has been suggested, may be due to the fact that relationships between neighborhood characteristics and individual health outcomes differ by the context of a particular place, the history and experiences of an individual, and the opportunities that individuals are able to access within and around their neighborhoods.[36–39]

Studies of neighborhood quality and PTB usually focus on a single dimension of the neighborhood environment, meaning that they tend to characterize only one dimension of the neighborhood environment (physical, social, or service) [40] or include multiple dimensions as independent variables in a single model, an approach which does not capture the potential cumulative effects of different

domains.[41] To date, few studies consider the cumulative effect of the intersecting dimensions of neighborhood environments and PTB.[42] Research which considers how domains work in concert to make a healthy community is needed to inform local place-based community development interventions which seek to assess and intervene on multiple dimensions of neighborhood quality to have a long-term impact on birth outcome inequities (Gap 1).[36,43–45].

Place may also matter differently for Black women and White women. Studies that stratify results between Black and White women have found different relationships in the same geographic areas between the two groups.[46,47] Black individuals are more likely than White individuals to live in disadvantaged and impoverished neighborhoods in the United States, regardless of individual socioeconomic status.[14,31,48,49] Even within the same neighborhood, Black women's experiences of neighborhood quality may differ from those of White women.[36,38,50] This may be due in part to the history and contemporary realities of structural racism – intersecting and reinforcing societal systems and institutions which foster and perpetuate racial discrimination – in the United States.[51–53] Neighborhood quality may be a particularly important source of Black women's stressors, both directly (through racialized neighborhood deprivation resulting in diminished opportunities and resource availability) and indirectly (as the space in which interpersonal stressors are experienced), affecting birth outcome racial inequities.[54] More research focusing explicitly on understanding how Black women experience place as it relates to PTB is needed and can support the identification of opportunities for tailored intervention to reduce their risk and ultimately reduce the persistent racial inequity (Gap 2).[55]

Among those studies that focus on the relationship between neighborhood quality and PTB specifically for Black women, few have assessed whether there are differences in the relationship between neighborhood quality and PTB across different demographic and socioeconomic groups of Black women (Gap 3).[27,56,57] Assessing whether the relationship between neighborhood quality and risk of PTB varies among groups of Black women would generate a more nuanced understanding of the potential pathways through which neighborhood context may affect Black women's PTB risk. Such research would inform developers of neighborhood change interventions to reduce Black women's risk of PTB, identifying for which groups such interventions might have the most impact and signaling when other complementary interventions might be necessary in order to support all Black women in a neighborhood.

In addition, though it is often hypothesized that factors such as health behaviors mediate the relationship between neighborhood quality, potential mediation is less often investigated directly (Gap 4).[21,58] Inadequate or late initiation of prenatal care (PNC)[10,59,60] is one health behavior often studied in relation to PTB, though the evidence on the impact of PNC on PTB is mixed. PNC utilization and timing of initiation may be influenced by neighborhood characteristics that affect the availability and accessibility of PNC.[61,62] Specific investigation of PNC initiation and use as potential mediators would further enrich the understanding of relationships between neighborhood quality and preterm birth. Behaviors that mediate the relationship between neighborhood quality and PTB also represent intermediate outcomes which could be tracked as part of the long-term evaluation of neighborhood transformation interventions seeking to reduce Black women's risk of PTB.

This dissertation contributes to addressing the three identified gaps in the literature through three interrelated studies examining relationships between neighborhood quality and PTB among Black women in Oakland, California, who gave birth between 2007 and 2011. The first study described in this dissertation asks the following question: what is the relationship between neighborhood quality

and preterm birth among Black women in Oakland, California? Building on this, the second study assesses whether maternal characteristics – age, parity, nativity, educational attainment for age, and low-income status – modify the relationship described in the first study. The third study explores whether two behavioral risk factors for PTB – smoking and accessing PNC – mediate the relationship between neighborhood quality and PTB, in the total population and in sub-populations identified through the second study.

We focus on the city of Oakland for three reasons. First, like many urban environments in the United States, Oakland is home to racial inequities in preterm birth – 11.1% for Black women as compared with 6.3% for White women.[63] There have also been significant investments in recent years into understanding and addressing racial inequities in preterm birth within Oakland specifically, with an emphasis on neighborhood transformation as an opportunity for intervention.[45,64] In addition, ongoing place-based community development in Oakland could provide opportunities for evaluating the impact of transforming neighborhoods on racial inequities in preterm birth.[65,66] By focusing in Oakland, our research can complement existing efforts and provide information to inform community development moving forward.

We characterize neighborhood quality using the California Healthy Places Index (HPI), a publicly available characterization of neighborhoods in California developed in 2017 by the Public Health Alliance of Southern California, the Virginia Commonwealth University Center of Society and Health, and a steering committee of subject matter experts and health department representatives.[67] The HPI quantifies a California neighborhood's potential to support residents' health and wellbeing and was created to inform the efforts of policy makers and public health practitioners working in communities.[67] The HPI includes 25 indicators grouped into one of eight policy action domains – economics, education, healthcare access, housing, neighborhood conditions, clean environment, social environment, and transportation. These are in turn combined through weighted quantile sum regression on census tract life expectancy at birth (LEB), an accepted measure of the status of the general population's health,[68] to form the HPI.

Through HPI's online portal, practitioners and researchers can identify the overall score and domain-specific scores for their census tract and use this information to guide local community transformation efforts. This study adapts the HPI to characterize neighborhood quality in Oakland for four reasons: (1) the HPI's domains capture neighborhood characteristics of the physical, social, and service environments of a place which are thought to impact reproductive outcomes; (2) the HPI is publicly available and accessible to practitioners and community members through the online portal, ensuring more individuals can use the index in their community-based work; (3) the domains and score were derived from both literature and the experiences of ~ 20 practitioners and researchers from health departments around the state, supporting the ability of findings using these measures to be translatable to testable intervention and policy development; and (4) the HPI score captures the cumulative, interconnected effects of multiple neighborhood characteristics (the unidimensional domains which make up the HPI), a more holistic picture of place than could be captured by a single domain.[36]

Through their focus on relationship between neighborhood quality and PTB specifically among Black women, the studies in this dissertation contribute to research and programmatic efforts considering how upstream interventions on place may reduce Black women's risk of experiencing PTB. Study results have direct implication for the ongoing research and work happening in Oakland, and the methods used in these studies are replicable in other urban areas around the country.

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Study 1 – Protective places: the relationship between neighborhood quality and preterm births to Black women in Oakland, California (2007-2011)

Introduction

Preterm birth (PTB) – birth before 37-weeks gestation – is a leading cause of infant mortality and a risk factor for adverse health outcomes in infancy, childhood, and adulthood (Heron, 2019; Moster et al., 2008; Purisch and Gyamfi-Bannerman, 2017; Saigal and Doyle, 2008). In the United States, Non-Hispanic Black and African American women (hereafter, Black women) experience 1.5 times the incidence of PTB compared with Non-Hispanic White women (hereafter, White women), a disparity that has persisted for decades and is largely unexplained by individual risk factors such as maternal age, health status, and parity (DeSisto et al., 2018; Martin et al., 2018, 2017). The introduction of the life-course perspective has motivated scholars to consider how disparities in exposure to social determinants of health over time may explain the Black-White gap and provide opportunities for early intervention to reduce Black women's risk of PTB (Lu and Halfon, 2003; Lu et al., 2010).

The neighborhoods where people live are increasingly studied as a social determinant of racial disparities in PTB. In their review of neighborhood context and reproductive health, Culhane and Elo highlight direct and indirect pathways through which a neighborhood's physical, service, and social environments may impact PTB (Culhane and Elo, 2005). The *physical environment* includes the natural and environment, available economic and educational opportunities within an area, and housing quality. Studies have found evidence for relationships between risk of PTB and the physical environment, for example in relation to increased exposure to air pollution (Basu et al., 2017; Hao et al., 2016; Laurent et al., 2016; Li et al., 2017), proximity to waste facilities (Woods et al., 2017), and community green space (Woods et al., 2017). Relatedly, the *service environment* describes the presence of goods, services, and resources within a neighborhood. For example, relationships with risk of PTB have been assessed for presence of and proximity to convenience stores, supermarkets, and grocery stores (Ma et al., 2016). Finally, the *social environment* captures, among other things, how neighbors interact with each other, perceived safety, feelings of being supported or connected, civic engagement, and socioeconomic composition. Studies have identified associations of neighborhood socioeconomic deprivation and PTB (Kane et al., 2017; Kramer et al., 2014; Ma et al., 2015; Messer et al., 2006b; Mutambudzi et al., 2017; Ncube et al., 2016; Pearl et al., 2018; Phillips et al., 2013; Sealy-Jefferson et al., 2016) and community violence with risk of PTB (Bloch, 2011; Giurgescu et al., 2012; Mayne et al., 2018; Messer et al., 2006a; Okah et al., 2014).

That neighborhoods matter for health is widely accepted within public health, but answering the question of *how* neighborhoods matters remains a challenge (Diez Roux and Mair, 2010; Macintyre et al., 2002). For example, across studies, there is variation in the magnitude, direction, and significance of the associations between the quality of a neighborhood's physical, service, and social environments and PTB (Li et al., 2017; Mutambudzi et al., 2017; Ncube et al., 2016; Woods et al., 2017). This, it has been suggested, may be due to the fact that relationships between neighborhood characteristics and individual health outcomes differ by the context of a particular place, the history and experiences of an individual, and the opportunities that individuals are able to access within and around their neighborhoods (Diez Roux, 2016; Diez Roux and Mair, 2010; Sharkey and Faber, 2014; Williams and Cooper, 2019).

In addition, place may matter differently for Black women and White women. While studies examining the relationship between neighborhood quality and preterm birth compare outcomes of

Black and White women, fewer studies explore relationship between neighborhood quality and preterm birth specifically among Black women (Blumenshine et al., 2010; Mutambudzi et al., 2017; Ncube et al., 2016). Studies that stratify results between Black and White women have found different relationships between the two groups, even when women are living in the same neighborhoods or cities (Messer et al., 2008; Ncube et al., 2016; O'Campo et al., 2007). Overall, Black individuals are more likely than White individuals to live in disadvantaged and impoverished neighborhoods in the United States, regardless of individual socioeconomic status (Culhane and Elo, 2005; Culhane and Goldenberg, 2011; Giurgescu et al., 2012; Krieger et al., 2005). In addition, Black women's experiences of neighborhood quality may differ from those of White women because of the history and contemporary realities of structural racism – intersecting and reinforcing societal systems and institutions which foster and perpetuate racial discrimination – in the United States (Bailey et al., 2017; Jones, 2000; Williams and Collins, 2001). Thus, neighborhood quality may be a particularly important source of Black women's stressors, both directly (through racialized neighborhood deprivation resulting in diminished opportunities and resource availability) and indirectly (as the space in which interpersonal stressors are experienced), affecting racial inequities in birth outcomes (Giurgescu et al., 2013b).

In order to address racial inequities in PTB and reduce PTB risk among Black women, it is important to move beyond studying "race" as a "risk factor" (Nuru-Jeter et al., 2018). Studies which examine the association between being a Black woman (using White women as the reference group) and PTB are often using the variable of "race" as a proxy for examining how the effects of racism as experienced by Black women may affect their likelihood of PTB when compared with White women (Nuru-Jeter et al., 2018). While such studies identify the existence of the racial disparity in risk of PTB, they do not help scholars understand why Black women may experience such disproportionately high rates of PTB. More research focusing explicitly on understanding how Black women experience place as it relates to PTB can support the identification of opportunities for tailored intervention to reduce their risk and ultimately reduce the persistent racial inequity (Suplee et al., 2018).

This study seeks to fill some of these fundamental gaps by examining the relationship between neighborhood quality and risk of preterm birth among Black women in the city Oakland, California. We focus on the city of Oakland for three reasons. First, like many urban environments in the United States, Oakland is home to racial inequities in preterm birth – 11.1% for Black women as compared with 6.3% for White women (March of Dimes, 2019). There have also been significant investments in recent years in understanding and addressing racial inequities in preterm birth within Oakland specifically, with an emphasis on neighborhood transformation as an opportunity for intervention (Pies et al., 2016; University of California San Francisco, 2019). In addition, ongoing place-based community development in Oakland could provide opportunities for evaluating the impact of transforming neighborhoods on racial inequities in preterm birth (East Bay Asian Local Development Corporation, 2019; The California Endowment, 2019). By focusing in Oakland, our research hopes to complement existing efforts and provide information to inform community development moving forward.

We hypothesize that living in a higher quality neighborhood will have a protective effect against preterm birth risk for Black women in Oakland. This study defines neighborhood quality based on the California Healthy Places Index (HPI), a publicly available characterization of neighborhoods in California developed in 2017 by the Public Health Alliance of Southern California, the Virginia Commonwealth University Center of Society and Health, and a steering committee of subject matter

experts and health department representatives (Delaney et al., 2018). The HPI includes 25 indicators grouped into one of eight policy action domains – economics, education, healthcare access, housing, neighborhood conditions, clean environment, social environment, and transportation – which are in turn combined through weighted quantile sum regression on census tract life expectancy at birth (LEB), an accepted measure of the status of the general population's health (Bollyky et al., 2019), to form the HPI. We assess both domain-based and HPI-based neighborhood quality as it relates to risk of preterm birth among Black women in Oakland.

Methods

The study population drew from all singleton births between 2007 and 2011 to Black women residing in Oakland, California. Births were identified from the California Biobank Program Linked Dataset for statewide births, maintained by the California Department of Public Health. The dataset includes data from California certificates of live birth linked to information from California's statewide Prenatal Screening Program (Cunningham and Tompkinson, 1999), where available. A birth was eligible for inclusion in the study if gestational age (between 20-44 weeks) was available from the birth certificate or prenatal screening data; the birth certificate did not indicate congenital abnormalities; and the birth certificate address was located in an included Oakland census tract (see Appendix 1.A). Among women who had more than one birth between 2007-2011, one birth was randomly selected for inclusion. The final study population included 5549 mothers and births. Our cross-sectional analysis did not examine differences across years within the 2007-2011 time period but included multiple years in order to ensure sufficient sample size for stable effect estimates.

Outcome: Preterm Birth

Preterm birth is a dichotomous variable (1=PTB, 0=Term birth) based on the infant's gestational age (< 37 weeks' gestation). Gestational age was defined using data from birth and prenatal screening records following a hierarchy of available data sources (Pearl et al., 2018), with highest priority given to prenatal screening estimates where available, largely derived from ultrasound (Dietz et al., 2007) or high-quality last menstrual period dates (Pearl et al., 2007). The remainder derived from obstetric estimate at time of delivery from birth records (Barradas et al., 2014) followed by reported last menstrual period from birth records.

Exposure: Neighborhood Quality

The HPI quantifies a California neighborhood's potential to support residents' health and wellbeing and was created to inform the efforts of policy makers and public health practitioners working in communities (Delaney et al., 2018). Through HPI's online portal, practitioners and researchers can identify the overall score and domain-specific scores for their census tract and use this information to guide local community transformation efforts. The HPI was created for the state of California. This study adapts the HPI to characterize neighborhood quality in Oakland for four reasons: (1) the HPI's domains capture neighborhood characteristics of the physical, social, and service environments of a place which are thought to impact reproductive outcomes; (2) the HPI is publicly available and accessible to practitioners and community members through the online portal, ensuring more individuals can use the index in their community-based work; (3) the domains and score were derived from both literature and the experiences of practitioners and researchers from health departments around the state, suggesting that findings using these measures may be more directly translatable to local intervention and policy development; and (4) the HPI score captures the cumulative, interconnected effects of multiple neighborhood characteristics (the unidimensional domains which make up the HPI), a more holistic picture of place than could be captured by a single domain (Diez Roux and Mair, 2010).

Because the current HPI uses indicator data from 2010-2015, this study recreated the HPI for the 2007-2011 time period for eligible Oakland neighborhoods following established methods for index construction (Delaney et al., 2018). Eligible census tracts were those with 2010 population estimates of >1500, a requirement for the original HPI construction. This resulted in the exclusion of five of the 113 Oakland census tracts (4%) and the 64 women and births residing within those census tracts (1% of births, see Appendix 1.A) from the analysis.

When indicator data for the 2007-2011 time period were unavailable, we included data of the next-closest time period. Appendix 1.B includes the list of HPI indicators by domain, their data sources, the time periods of data used in this study, and explanations for use of data outside of the 2007-2011 time period. Five indicators use data outside of the 2007-2011 time period. Due to insufficient data, the 2007-2011 American Community Survey did not include estimates of % of 15-17-year-olds enrolled in school for five Oakland census tracts, estimates of % of 3- and 4-year-olds enrolled in preschool for one Oakland census tract, and estimates of either indicator for one Oakland census tract. Values of these indicators for these census tracts were imputed using a weighted average of its 10 nearest neighborhoods in the DMwR package in R (Torgo, 2010). The ozone indicator was excluded from the calculation of the Clean Environment domain because there was no variation across Oakland census tracts.

To construct the domains and the HPI, indicators were standardized (mean=0, standard deviation=1) and reverse scored where appropriate such that values greater than 0 represented higher neighborhood quality. The standardized values of all indicators within a given domain were averaged to create a domain score for each census tract. The miWQS package in R (Hargarten and Wheeler, 2018) was used to calculate domain weights using weighted quantile sum regression relating all domains to LEB across 108 Oakland census tracts. A minimum domain weight was set to 0.05 in recognition of the practitioner-identified importance of each domain (Appendix 1.C). To assess the potential impact of calculating domain weights within Oakland instead of across the state of California, we created an Oakland-weighted HPI using the current HPI 2010-2015 data for Oakland census tracts and assessed its correlation with the state-weighted HPI of the same time period. Due to the high correlation (Pearson correlation coefficient: 0.994, $p<0.0001$), we felt confident in our ability to proceed with the 2007-2011 Oakland-weighted HPI.

The HPI-based overall neighborhood quality was the primary exposure of interest in this analysis. The individual domains were secondary exposures as unidimensional characterizations of neighborhood quality. One census tract which contained no study births was removed, resulting in 107 Oakland census tracts being included in the study.

Confounders – maternal characteristics

The following *a-priori* confounders, which could influence both where a woman lived at the time of giving birth and her likelihood of experiencing a preterm birth, were included (Basu et al., 2017; DeFranco et al., 2008; Laurent et al., 2016; Ma et al., 2015; Mason et al., 2011; Messer et al., 2006a): age (continuous), parity (1=first live birth, 0=not first live birth), educational attainment-for-age (0=low [older than 13 with 8th grade or less, older than 19 with 9-11 years of education], 1=appropriate [19 or younger with 9-11 years, any age with high school graduation or some college], 2=high [any age with college graduation or beyond] (Fraser, 1995)), nativity (1=foreign-born, 0=U.S. born), and low income status proxy (1=used WIC and/or Medi-Cal during pregnancy, 0=did not use WIC or Medi-Cal during pregnancy). All confounders were included in fully adjusted models. We conducted a sensitivity analysis in which use of WIC (yes, no, or unknown) and use of Medi-Cal

(yes, no) replaced low income status to see if the potential for WIC being protective in the relationship between neighborhood quality and PTB (Ma et al., 2015) altered the observed relationships in this study. There was minimal difference between models using low income status and models using WIC and public insurance; models controlling for WIC and public insurance are presented as the primary results.

Statistical analysis

Descriptive

To characterize the Oakland census tracts included in the study (N=107), we assessed the 2007-2011 census tract population estimates, the number of study births per tract, and the number of study preterm births per tract (mean, standard deviation, median, minimum, and maximum values). To explore relationships between domains across included Oakland census tracts, we calculated the Pearson correlation coefficients and p-values comparing the eight domains. Using ArcMap™ 10.6 (Esri, 2019), we created maps for the 107 included census tracts to visually explore the distributions of domain and HPI-based neighborhood quality values, divided into quartiles. The distribution of maternal characteristics across the study sample and by preterm birth status was described. Crude log-linear generalized estimating equations (GEE) models with exchangeable correlation structures assessing the relationship between preterm birth and each maternal characteristic were run to examine the statistical significance of differences in maternal characteristics by preterm birth status, independent of clustering by neighborhood.

Models

We examined the relationship between HPI-based neighborhood quality and PTB, first unadjusted (Model 1) and then adjusted for all covariates (Model 2A with low income status, Model 2B with WIC and public insurance), using log-linear GEE models with exchangeable correlation structure. We also examined the relationship between each domain-based neighborhood quality variable and PTB, first unadjusted (Model 1) and then adjusted for all covariates (Models 2A and 2B). Statistical analysis was conducted in SAS 9.4 ("SAS(R) 9.4 -- Today and Tomorrow," n.d.). This study was approved by the Committee for the Protection of Human Subjects of the California Health and Human Services Agency (Project 14-01-1466).

Results

The average population size across study census tracts was 3,596 (Standard Deviation (SD): 1216.67; Minimum (Min): 1,420; Maximum (Max): 6,449). The average number of study births per census tract was 51.86 (SD: 38.31; Min: 3; Max: 183), and the average number of preterm births per census tract was 6.19 (SD: 4.85; Min: 1; Max: 23).

Most domains are significantly correlated with one and other; the clean environment domain, however, is only significantly correlated with the education domain (Appendix 1.C). For the HPI score, the social domain has the largest weight (0.12), followed by the economic domain (0.06) (Appendix 1.D). Oakland neighborhoods closest to the Bay (the western side of the city) tended to have lower HPI scores, while those farthest from the Bay (the eastern side of the city) tended to have higher HPI scores (Figure 1). A similar pattern is apparent for five domains – economic, education, healthcare access, housing, and social (Appendix 1.E) – while the patterns for neighborhood conditions, clean environment, and transportation domains are more spatially varied.

Figure 1: Map of HPI-based neighborhood quality across 107 Oakland census tracts

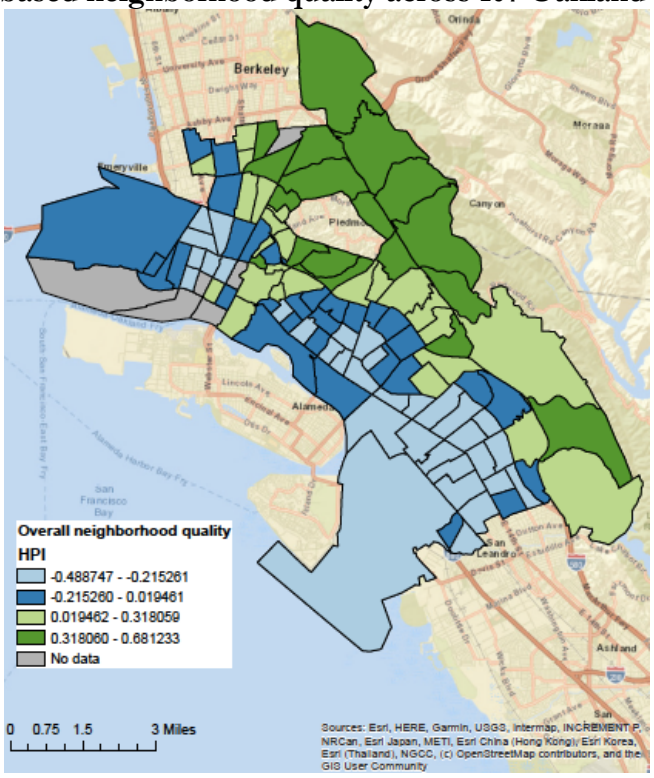

Table 1 presents descriptive statistics for the study population of Black women residing in Oakland neighborhoods at the time of giving birth between 2007-2011, overall and by preterm birth status (N=5549). The average age of the study population was 26.67 years, and the majority of women in the study population were US-born, had appropriate educational attainment for their age, and were characterized as low income (most used WIC and/or public insurance). For the majority of women, this birth was not their first live birth. In comparison with women who experienced a term birth, women who experienced a preterm birth were less likely to be experiencing their first live birth and were more likely to be US-born, older on average, and have low educational attainment for their age.

Table 1: Description of Maternal Characteristics for the Study Population and by Preterm Birth Status (N=5549)

	Total N(%)	Preterm Birth N(%)	Term Birth N(%)	Significance[1]
Total population	5549 (100)	576 (10.38)	4973 (89.62)	
Parity				
First live birth	2660 (47.94)	255 (44.27)	2405 (48.36)	p=0.048
Not first live birth	2889 (52.06)	321 (55.73)	2568 (51.64)	Reference
Nativity				
Foreign-born	460 (8.29)	32 (5.56)	428 (8.61)	p=0.0169
US-born	5089 (91.71)	544 (94.44)	4545 (91.39)	Reference
Age at time of giving birth				
Continuous	26.67 (6.54)	27.44 (6.94)	26.58 (6.49)	p=0.0001
Level of education for age				
High	750 (13.52)	56 (9.72)	694 (13.96)	p=0.0115
Appropriate	4126 (74.36)	430 (74.65)	3696 (74.32)	Reference
Low	673 (12.13)	90 (15.63)	583 (11.72)	p=0.0050
Low income status				
Yes	4256 (76.7)	459 (79.69)	3797 (76.35)	p=0.0676
No	1293 (23.3)	117 (20.31)	1176 (23.65)	Reference
WIC				
Yes	3512 (63.29)	349 (60.59)	3163 (63.60)	p=0.4097
No	1913 (34.47)	203 (35.24)	1710 (34.39)	Reference
Unknown	124 (2.23)	24 (4.17)	100 (2.01)	p=0.0027
Public Insurance				
Yes	3612 (65.09)	388 (67.36)	3224 (64.83)	p=0.2982
No	1937 (34.91)	188 (32.64)	1749 (35.17)	Reference

1. P-value of the beta in univariate GEE model of characteristic and preterm birth outcome

Across Oakland neighborhoods, a one-unit increase in HPI score was significantly associated with 44% lower magnitude risk of preterm birth when controlling for all covariates, WIC, and public insurance (Table 2). When examining individual domains, we observed significant relationships with lower risk of preterm birth based on living in a neighborhood with greater educational attainment (RR: 0.87, 95% CI: 0.76, 1.00), greater healthcare access (RR: 0.84; 95% CI: 0.76, 0.93), or greater housing quality (RR: 0.82; 95% CI: 0.68, 0.99). Results when controlling for all covariates and low-income status were similar in magnitude, and results for education and housing domains were nearly statistically significant (p=0.0596 and p=0.0508, respectively) (Appendix 1.F).

Table 2: Relationships between neighborhood quality and preterm birth: Risk Ratio (RR), 95% Confidence Intervals (CI) [Models 1 and 2B]

	Model 1			Model 2B		
	RR	95% CI		RR	95% CI	
HPI	**0.52**	**0.35**	**0.78**	**0.56**	**0.38**	**0.84**
Economic	**0.86**	**0.76**	**0.98**	0.89	0.78	1.01
Education	**0.84**	**0.74**	**0.96**	**0.87**	**0.76**	**1.00**
Healthcare Access	**0.83**	**0.75**	**0.91**	**0.84**	**0.76**	**0.93**
Housing	**0.79**	**0.66**	**0.95**	**0.82**	**0.68**	**0.99**
Neighborhood	0.92	0.72	1.17	0.92	0.73	1.17
Clean Environment	0.84	0.59	1.19	0.83	0.60	1.15
Social	**0.87**	**0.76**	**0.99**	0.89	0.78	1.02
Transportation	**0.82**	**0.68**	**1.00**	0.84	0.70	1.01

-Model 1: Crude GEE model for each individual domain
-Model 2B: Model 1 for each individual domain adjusted for parity, nativity, age, educational attainment for age, WIC use, and public insurance use
-Bolded values are statistically significant at p<0.05

Conclusion

Our findings support the hypothesis that living in a higher quality neighborhood is associated with reduced risk of preterm birth among Black women in Oakland. Maps reveal a visual relationship between neighborhood quality scores and neighborhoods subject to historical disinvestment. Significant domain-specific findings highlight dimensions across Oakland neighborhoods which are associated with Black women's risk of preterm birth. However, the relationship between overall neighborhood quality and risk of preterm birth was greater in magnitude than any individual domain-based relationship, demonstrating the importance of considering the cumulative impact of neighborhood characteristics.

Maps

The overarching pattern of neighborhood quality across Oakland – with lower quality neighborhoods closer to the West and higher quality neighborhoods to the East – mirrors that of the 1930s Oakland redlining map (Green, 2016). Redlining was the Home Owners' Loan Corporation's practice of categorizing neighborhoods it deemed safe and desirable for mortgage lending. Neighborhoods colored "red" – areas where investment was discouraged – were also those in which Black families were likely to reside, contributing to residential segregation and the concentration of fewer resources and opportunities in Black communities (Williams and Collins, 2001). Today, the Eastern higher quality neighborhoods encompass the Oakland Hills, areas which are generally wealthier, safer, and with greater opportunity than the Oakland Flatlands of North, West, and East Oakland (Haley et al., 2012; McClintock et al., 2013). While we did not assess the statistical relationship between historical redlining and contemporary neighborhood quality, visually it appears that many redlined neighborhoods would be characterized as lower quality today, suggesting the continued impact of these discriminatory policies. Future research assessing neighborhood quality as a potential mediator between historical redlining and risk of preterm birth would contribute to new research assessing the long term effect of these racist policies (Anthopolos et al., 2014; Klivans and Green, 2019).

Domain-based neighborhood quality

Identifying the neighborhood quality domains that are most meaningful for Black women's preterm birth risk across Oakland can illuminate potential opportunities for city-wide policy intervention

focus (Messer et al., 2008). The significant relationships we found between living in a higher quality neighborhood defined by education, housing, or healthcare access are novel. Few studies appear to examine the relationships between preterm birth and neighborhood quality defined solely by education or housing variables among Black women (Giurgescu et al., 2012; Messer et al., 2008; Reagan and Salsberry, 2005), and to our knowledge no studies have explored the relationship between neighborhood percentage of adults with health insurance and preterm birth among Black women.

Messer et al (2008) used principal component analysis to construct their own neighborhood quality domains: low education, unemployment, poor housing, low occupation, poverty, and residential instability. In their examination of each domain's relationship with preterm birth for Black women across eight geographically separate county and city sites, women who lived in neighborhoods in the third or fourth quartile of the low education index (% of adults without a high school degree and the inversed standardized version of % of adults with college degree or higher) had significantly increased odds of experiencing preterm birth. This finding is similar to our own, though from a deficit-based perspective.

Living in an environment in which more of your neighbors are educated and in which more children, particularly 3- and 4- year old children, are able to attend school, may suggest neighborhood social norms in support of educational attainment and/or the availability of resources for early childhood education, which in turn may facilitate a less stressful environment in relation to supporting the educational trajectory of oneself and one's family. Chronic stress in particular is known to result in physiological changes which may increase the risk of adverse birth outcomes (Giurgescu et al., 2013b; Wadhwa et al., 2011). Neighborhoods as a source of stress are noted as an potential pathway through which place may impact risk of preterm birth (Culhane and Elo, 2005). A reduction in neighborhood stress may be particularly important for Black women's risk of preterm birth because of the other unique sources of stress they experience over their life course and during pregnancy due to exposure to racism at individual, interpersonal, and institutional levels as well as within the healthcare system they navigate during pregnancy (Alio et al., 2010; Dominguez et al., 2008; Giurgescu et al., 2013b, 2013a, 2012; McLemore et al., 2018; Nuru-Jeter et al., 2009; Rosenthal and Lobel, 2011; Woods-Giscombe, 2010; Woods-Giscombé and Lobel, 2008). Additional research, in Oakland specifically and more broadly, is needed to better understand how neighborhood educational attainment may affect Black women's risk of preterm birth.

Results of studies examining the relationship between neighborhood housing quality and preterm birth among Black women are varied. Reagan and Salsberry (2005) found that living in a neighborhood with a higher percentage of vacant homes was associated with increased risk of very preterm birth among Black women. Similarly, Giurgescu et al (2012) found that neighborhood physical disorder, which included housing vacancy, predicted preterm birth among Black women. Messer et al (2008) found significant associations between poorer housing quality (including variables of percent of housing that is crowded, vacant, rented, and percent of people spending greater than 50% on housing) and Black women's increased risk of preterm birth for only two of the eight geographic areas they assessed. They attribute the heterogeneity of results to the different implications of these variables across regions (for example, in a wealthy area with lots of vacation properties, you may have a higher percentage of vacant homes). Our finding for the housing quality domain generally aligns with these studies' results and expand on the housing-related variables considered (% of occupied housing units occupied by property owners; % of households with complete kitchen facilities and plumbing).

The lack of available and affordable quality housing is an ongoing challenge in the city of Oakland (Rose and Lin, 2015). In addition, the time period of this study coincides with the 2007-2009 Great Recession (Belcher and Tice, 2018; Stock and Watson, 2012). The Recession in California continued into 2010, with median income falling over 10 percent between 2007-2010, increasing the need for affordable housing (Bohn and Schiff, 2011; Rose and Lin, 2015). It is possible that a neighborhood in which fewer households are paying over half their salary for housing costs may be a less stressful environment with respect to the affordability of housing for residents. As with the education domain, this may in turn reduce one source of chronic stress for Black women before and during pregnancy. Future research should consider understanding the pathways through which improving housing quality and affordability may impact preterm birth risk for Black women.

It is worth noting that neighborhood educational attainment and housing quality are often included along with variables characterizing neighborhood employment and poverty in composite measures to describe the socioeconomic characteristics of an area's social environment (Culhane and Elo, 2005; Messer et al., 2006b; Mutambudzi et al., 2017; Ncube et al., 2016). The strong correlations we observed across the economic, education, and housing domains suggest a relationship among these neighborhood characteristics (Appendix 1.C). However, unlike other studies, we did not find a significant relationship between the economic domain (which includes poverty and employment variables) and preterm birth among Black women (Kaufman et al., 2003; Masho et al., 2014). Given the interconnectedness of these domains, we see these results as demonstrating the particular importance of the education and housing domains for Black women across Oakland neighborhoods, rather than suggesting that poverty and employment characteristics are summarily unimportant. Additional research into the nature of these domains' interconnectedness in Oakland is necessary to fully understand how city-wide policy could be used to improve Black women's risk of preterm birth.

Our study findings also suggest that greater neighborhood health insurance coverage may be protective against preterm birth for Black women independent of individual health insurance coverage. The impact of living in a neighborhood with increased healthcare access (measured by a higher % of adults with health insurance) on preterm birth risk among Black women is understudied. It is possible that neighborhoods with a higher percentage of insured residents may also have a greater number of readily available healthcare resources, increasing the quality of the service environment in that area (Culhane and Elo, 2005). In addition, prior to the Affordable Care Act, Medicaid expansion, and the health insurance exchanges, the majority of adults with health insurance received that insurance through an employer for which they worked full time in the public sector, manufacturing jobs, or managerial and professional jobs (Fronstin, 2011; Serakos and Wolfe, 2016). It is possible that our findings also reflect the population's socioeconomic position with respect to type of employment; according to 2007-2011 American Community Survey estimates, the average percent of the employed Oakland population in a census tract that was employed by a private, non-profit, or government employer was 88% (U.S. Census Bureau, 2011). This is turn could suggest that more resources and services are made available in these places, possibly creating a less stressful neighborhood environment for Black women residing there. As with the education and housing quality, additional research is needed to understand the relationship between increased health insurance coverage and risk of preterm birth among Black women within Oakland and more broadly.

Overall neighborhood quality

The domains whose maps most closely resemble that of HPI – economic, education, healthcare access, housing, and social – primarily describe dimensions of the social environment across Oakland neighborhoods, with the exception of select housing quality variables which are really reflections of the physical environment (% of households with complete kitchen and plumbing, % of owner-occupied housing units) (Culhane and Elo, 2005; Diez Roux and Mair, 2010). The neighborhood conditions and clean environment domains – whose patterns of quality differ from those of other domains – describe the physical, natural, and service environments across Oakland neighborhoods. Transportation, the third domain with a more variable visual pattern, reflects both the social environment (% of households with access to a car as an indication of wealth) and the physical environment (% of workers able to use public or non-motorized transit to get to work suggesting availability of public transit). The observed heterogeneity of quality across the social, physical, and service environments of Oakland neighborhoods supports the value of considering the diverse characteristics within local contexts and understanding how these domains work in concern with each other in order to understand what makes a healthy community (Diez Roux, 2001).

Our findings support the hypothesis that living in a neighborhood with higher overall quality is protective against preterm birth among Black women in Oakland. Through the HPI, neighborhood quality is characterized as the sum of physical, social, and service environment characteristics, weighted to predict longer life expectancy at birth. Studies that use a composite measure of neighborhood quality to assess the relationship between place and preterm birth tend to characterize only one dimensions of the neighborhood environment (physical, social, or service) (Vos et al., 2014) or include multiple dimensions as independent variables in a single model, an approach which does not capture the potential cumulative effects of different domains (Metcalfe et al., 2011). One exception is Wallace et al (2017), which used a Birth Equity Index combining characteristics of the physical, social, and service environments of metropolitan statistical areas (MSAs) across the country to assess racial inequities in infant mortality rates, finding that worse conditions was associated with increased infant mortality rate among Black women. Our results support the idea that, for Black women giving birth across Oakland neighborhoods during this time period, the whole is greater than the sum of its parts: improved HPI-based quality is associated with a lower magnitude of preterm birth risk by 44%, 2.4 times the largest single-domain reduction of 18% (housing domain). These findings support the need for further research into place-based community development interventions which seek to assess and intervene on multiple dimensions of neighborhood quality in order to have a long-term impact on birth outcome inequities (Bell and Rubin, 2007; Braunstein and Lavizzo-Mourey, 2011; Diez Roux and Mair, 2010; Pies et al., 2016).

Future research should unpack the significance of overall neighborhood quality in risk of preterm birth through collaborative qualitative research with Black women in Oakland. Some of this work has already begun. Women of color who participated in focus groups as part of the California Preterm Birth Initiative's Research Prioritization by Affected Communities (RPAC) process identified questions about maternal stress and preterm birth to be of highest priority for future studies (Franck et al., 2018). Giurgescu et al's (2013a) study of African American women's perceptions of factors impacting preterm birth highlighted dangerous neighborhoods as a key source of stress related to preterm birth. Research focused on understanding how Black women in Oakland perceive their neighborhoods' quality and its relationship to preterm birth can support the evolution of place-based interventions seeking to have a long-term impact on racial inequities in birth outcomes.

Limitations

Though the use of administrative census tract boundaries to define neighborhood is common, it is only a proxy for how neighborhoods may be defined by residents. We also do not assess how the quality of surrounding neighborhoods, both within and outside of Oakland, may impact a woman's risk of preterm birth. Additionally, in using the HPI, we were not able to include other variables, such as neighborhood crime rates, which are not available at a statewide level but are more accessible locally. Due to limitations of the data set, we were unable to account for the length of time in which women resided in their neighborhoods prior to becoming pregnant and giving birth, and thus cannot speak to a how that variation might impact the effect of neighborhood quality on risk of PTB. These limitations highlight directions for future research – the use of locally meaningful neighborhood boundaries, assessing place from a relational perspective (Cummins et al., 2007), and understanding how neighborhood quality changes over time. In addition, local jurisdictions like Oakland could follow the HPI process and work with a steering committee of local experts to adapt the HPI for incorporation of locally meaningful and available variables (Delaney et al., 2018).

Implications

The study's findings support the idea that interventions to improve neighborhood quality may help to reduce Black women's risk of experiencing preterm birth. For Oakland neighborhoods, the results identify domains for potential city-wide assessment and policy intervention, as well as highlighting the importance of studying and intervening on multiple intersecting dimensions of neighborhood quality. Cities and counties throughout California can access the publicly available HPI and its component domains to better understand the relationships between neighborhood quality and health outcomes like preterm birth in their own areas, furthering research and practice to address health inequities affected by the places where we live.

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Study 2 – Examining effect modification of the relationship between neighborhood quality and preterm birth among Black women in Oakland, California (2007-2011), by maternal characteristics

Introduction

Preterm birth (PTB), defined as birth prior to 37-weeks' gestation, remains a leading cause of infant mortality in the United States and increases the risk for adverse health outcomes across the life course.[1–4] The risk of preterm birth among Non-Hispanic Black and African American women (hereafter, Black women) in the United States remains 1.5 times that of Non-Hispanic White women (hereafter, White women), a gap which has persisted without much improvement for decades.[5–7] This racial inequity is largely unexplained by differences in individual-level risk factors such as maternal age, socioeconomic status, parity, interpregnancy interval, or health status.[6,8,9] This recognition has prompted researchers in recent decades to consider potential causes farther upstream in order to identify intervention opportunities which will reduce the risk of PTB among Black women and close the gap; the physical and social environments in which Black women live are one source of risk which is being increasingly examined.[10–13]

Regardless of individual socioeconomic characteristics, Black individuals are more likely to live in more impoverished and lower resourced neighborhoods than their White peers.[10,11,14,15] This phenomenon is non-random; it is due in large part to the racial residential segregation resulting from federal policies and compliant social institutions in the early 20th century.[16,17] The exclusionary policies which isolated Black and White individuals were coupled with differential investment in various places, with Black neighborhoods receiving fewer resources, poorer quality schools, and fewer employment opportunities. Lack of opportunities in resource-deprived neighborhoods contributed to what Williams and Collins call "truncated… socioeconomic mobility" (p.406) for Black individuals,[17] concentrating poverty in more segregated Black neighborhoods.[18] Though discriminatory housing was made illegal through the Civil Rights Act of 1968, racial residential segregation and the related racialized concentration of neighborhood deprivation remain a reality today.[16–18]

Studies have identified relationships between living in a more deprived or lower quality neighborhood and increased risk of preterm birth independent of maternal race.[19,20] However, neighborhood researchers also acknowledge that the same neighborhood environment may matter differently for different groups of residents.[21–23] For example, a person with a greater income may benefit more from the availability of expensive fresh produce in their local grocery store than someone with lesser income who may not be able to purchase the fresh produce as frequently. While that neighborhood may be characterized as higher quality because of its healthy food availability, the potential impact of that quality on the health of these two individuals would differ based on their individual resources. The interaction of a neighborhood's context [the physical and social environment] and composition [the characteristics and actions of its residents] is well-known.

Findings from studies which stratify by race demonstrate differences in the relationships between neighborhood quality and preterm birth between Black and White women.[12,19,24] However, relatively few studies have assessed whether there are differences in the relationship between neighborhood quality and PTB among different groups of Black women based on individual socioeconomic or demographic characteristics.[25–27] Assessing whether the relationship between neighborhood quality and risk of PTB varies among groups of Black women would generate a more nuanced understanding of the potential pathways through which neighborhood context may affect

Black women's PTB risk. Such research would inform developers of neighborhood change interventions to reduce Black women's risk of PTB, identifying for which groups such interventions might have the most impact and signaling when other complementary interventions might be necessary in order to support all Black women in a neighborhood.

Our study assesses whether the relationship between neighborhood quality and PTB among Black women in Oakland, California, is modified by individual-level socioeconomic (income, educational attainment for age), demographic (nativity, age), or maternal (parity) characteristics. We hypothesize a stronger relationship between neighborhood quality and PTB among women who are more socioeconomically advantaged (higher income, higher educational attainment for age) or who are not characterized by other PTB risk factors (being at the extremes of young or old maternal age, having had a previous live birth, having been born in United States).[11,28] This hypothesis is based on the recognition that the influence of upstream neighborhood factors may not be as meaningful among women who are grappling with challenges related to a more socioeconomically disadvantaged or other PTB risk factors.

Methods

This study population is drawn from all 2007-2011 singleton births to Non-Hispanic Black and African American women (hereafter described as Black women) in Oakland, California. Maternal and infant data was obtained from the California Biobank Program Linked Dataset for statewide births, maintained by the California Department of Public Health (CDPH).[29] This dataset includes available linked data from California certificates of live birth and the statewide Prenatal Screening Program.[30] Eligibility criteria for this study included recorded infant gestational age (between 20-44 weeks) in either birth certificate or prenatal screening data, no indicated infant congenital abnormalities, and birth certificate address located in an included Oakland census tract. One birth was randomly selected for inclusion if a mother had more than one eligible birth during the study time period. Births with missing covariates were excluded. The final study population consisted of 5549 mothers and infants.

Outcome

PTB is a dichotomous outcome (1=20 to <37 weeks gestation, 0=37-44 weeks gestation). Gestational age was determined based on the best available estimate from either the birth certificate or prenatal screen records, in the following order derived from previous data quality research: best estimate from prenatal screening data (based on ultrasound, last menstrual period, or physical exam), ultrasound, obstetric estimate at time of delivery (from birth records), or reported last menstrual period (from birth records).[29,31–33]

Exposure

Neighborhood quality is defined using the California Healthy Places Index (HPI).[34] The HPI was developed in 2017 by the Public Health Alliance of Southern California, the Virginia Commonwealth University Center of Society and Health, and a steering committee of subject matter experts and health department representatives. The index is derived from a weighted quantile sum regression of census tract life expectancy at birth (LEB) on eight policy action domains – economic, education, healthcare access, housing, neighborhood conditions, clean environment, social environment, and transportation. The HPI was constructed for census tracts across California using publicly available data from 2010-2015 to characterize a neighborhood's health promoting qualities. Additional information about the HPI can be found in Appendix 1.B.

Our study adapts the current 2010-2015 HPI to for the city of Oakland, California based on data primarily from the 2007-2011 time period of our study. The eight policy domains are constructed from 25 indicators. A full list of indicators by domain can be found in Appendix 1.B. We used data outside of the 2007-2011 time period for five indicators due to lack of data availability, identifying the next closest time period for which data was available. Additionally, values for two indicators (% of 15-17 year olds and % of 3- and 4-year olds enrolled in school) were imputed for six Oakland census tracts due to lack of calculated estimates for those tracts in the 2007-2011 American Community Survey (using a wesighted average of its 10 nearest neighborhoods in the DMwR package in R).[35] The calculation of the clean environment domain excluded the ozone indicator due to lack of variation across Oakland census tracts.

Indicators were standardized (mean=0, standard deviation=1) such that values greater than zero represent higher neighborhood quality. For each domain, indicator standardized values were averaged to create the domain score. The index was constructed by regressing the eight domains on LEB, using the miWQS package in R[36] to generate domain weights with a minimum weight of 0.05 (following current HPI construction protocol to acknowledge that all eight policy domains having been identified by subject matter experts for inclusion). An HPI score was calculated by summing the weighted domain scores for each census tract. Following the HPI requirement for eligible census tracts, five of the 113 Oakland neighborhoods were excluded due to having a 2010 census tract population of <1500. After removing an additional census tract without study births, 107 Oakland census tracts were included in the study. The primary exposure for this study was HPI-based neighborhood quality. Identified effect modifiers of the relationship between HPI-based quality and PTB were also assessed for effect modification of relationships between domain-based quality and PTB.

Covariates

This study included the following *a-priori* specified maternal characteristics as confounders and potential effect modifiers based on previous literature: age,[25,37] parity,[38] educational attainment for age,[25,39] nativity,[27,39] and income status.[26,40] Maternal characteristics were constructed as follow: age (categorized as $\leq$ 22, 23-29, 30-34, and $\geq$35 years of age), parity (1=first live birth, 0=not first live birth), educational attainment-for-age (0=low [older than 13 with 8th grade or less, older than 19 with 9-11 years of education], 1=appropriate [19 or younger with 9-11 years, any age with high school graduation or some college], 2=high [any age with college graduation or beyond]),[41] nativity (1=foreign-born, 0=U.S. born), and low income status (1=used WIC and/or Medi-Cal during pregnancy, 0=did not use WIC or Medi-Cal during pregnancy). Due to small sample sizes, the age categories of $\leq$18 and 19-22 were merged. WIC, which stands for the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC), is classified based on women's self-reported responses on their birth certificate. Medi-Cal is the name used for in California for Medicaid, the public insurance option for low income individuals.[42] We also ran models in which use of WIC (yes, no, or unknown) and use of Medi-Cal (yes, no) replaced low income status to determine if aggregating WIC and Medi-Cal status might mask meaningful effect modification.

Statistical analysis

We described the distribution of maternal characteristics across the study sample and by preterm birth status. We used log-linear generalized estimating equation (GEE) models with exchangeable correlation structures to examine the relationship between HPI-based neighborhood quality and PTB while accounting for neighborhood clustering, first unadjusted (Model 1) and then adjusted for all potential effect modifiers as confounders (Model 2). We then assessed multiplicative effect

modification for each potential modifier in its own model by including an interaction term and controlling for all other maternal characteristics as confounders (Model 3). The interaction term was considered statistically significant at $p<0.1$.[43] For significant effect modifiers, we ran fully adjusted strata-specific GEE models (log-linear models unless there was convergence failure, in which case link logit models were used) for HPI-based neighborhood quality (Model 4). Forest plots were created to visualize the strata-specific risk ratios. The maternal characteristics of sub-strata for significant effect modifiers were also assessed. We then assessed whether significant effect modifiers for HPI-based neighborhood quality were also significant for any component domains by running fully adjusted strata-specific GEE models (Model 4) and creating strata-specific forest plots. If minimal differences were observed between models controlling for low income status vs. WIC and Medi-Cal status, only low-income status results were presented. Unless otherwise stated, statistical analysis was conducted in SAS 9.4.[44] Study approval was provided by the Committee for the Protection of Human Subjects of the California Health and Human Services Agency (Project 14-01-1466), with IRB reliance approval from University of California, Berkeley.

Results

There was an average of 52 study members per tract (Min=3, Max=183) across the 107 Oakland census tracts and an average of six PTBs per tract (Min=1, Max=23) across 93 census tracts (87% of included Oakland census tracts which contained any PTBs). Table 1 presents descriptive statistics for the study population of Black women residing in Oakland neighborhoods at the time of giving birth between 2007-2011, overall and by PTB status (N=5549).

Table 1: Description of maternal characteristics across study population and by preterm birth (N=5549)

	Total N(%)	Preterm Birth N(%)	Term Birth N(%)
Total population	**5549 (100)**	**576 (10.38)**	**4973 (89.62)**
Parity			
First live birth	2660 (47.94)	255 (44.27)	2405 (48.36)
Not first live birth	2889 (52.06)	321 (55.73)	2568 (51.64)
Nativity			
Foreign-born	460 (8.29)	32 (5.56)	428 (8.61)
US-born	5089 (91.71)	544 (94.44)	4545 (91.39)
Age at time of giving birth			
$\leq$ 22 years	1783 (32.13)	163 (28.30)	1620 (32.58)
23-29 years	1939 (34.94)	199 (34.55)	1740 (34.99)
30-34 years	1043 (18.80)	110 (19.10)	933 (18.76)
$\geq$ 35 years	784 (14.13)	104 (18.06)	680 (13.67)
Level of education for age			
High	750 (13.52)	56 (9.72)	694 (13.96)
Appropriate	4126 (74.36)	430 (74.65)	3696 (74.32)
Low	673 (12.13)	90 (15.63)	583 (11.72)
Low income status			
Yes	4256 (76.7)	459 (79.69)	3797 (76.35)
No	1293 (23.3)	117 (20.31)	1176 (23.65)
WIC			
Yes	3512 (63.29)	349 (60.59)	3163 (63.60)
No	1913 (34.47)	203 (35.24)	1710 (34.39)
Unknown	124 (2.23)	24 (4.17)	100 (2.01)
Medi-Cal			
Yes	3612 (65.09)	388 (67.36)	3224 (64.83)
No	1937 (34.91)	188 (32.64)	1749 (35.17)

The majority of women in the study population were US-born, younger than 29 years of age, had appropriate educational attainment for their age, were not experiencing their first live birth, and would be characterized as having low income status (most used WIC and/or Medi-Cal). Women with a PTB were less likely to be experiencing their first live birth or to use WIC, and were more likely to be US-born, to be older than 30, to have low educational attainment for their age, and to use Medi-Cal.

Living in an overall higher quality neighborhood was significantly protective against PTB birth in this population (Table 2).

Table 2: Relationship between HPI-based neighborhood quality and preterm birth – Risk Ratios (RR) and 95% Confidence Intervals (CI)

	Model 1			Model 2		
	RR	**95% CI**		**RR**	**95% CI**	
Intercept	**0.09**	**0.08**	**0.10**	**0.09**	**0.07**	**0.11**
HPI	**0.52**	**0.35**	**0.78**	**0.58**	**0.39**	**0.86**
≤ 22 years				**0.81**	**0.68**	**0.96**
30-34 years				1.15	0.95	1.40
≥ 35 years				**1.60**	**1.27**	**2.02**
Low ed-for-age				**1.25**	**1.05**	**1.49**
High ed-for-age				**0.71**	**0.52**	**0.96**
Foreign-born				**0.65**	**0.47**	**0.90**
First live birth				1.07	0.90	1.27
Low income status				1.11	0.91	1.35

-Model 1: Crude GEE model for overall neighborhood quality
-Model 2: Model 1 + parity, nativity, age, educational attainment for age, and low-income status
-Bolded values are statistically significant at p<0.05

Compared with women living in a neighborhood with a one-unit-lower HPI score, the risk of preterm birth was 42% lower (RR: 0.58, 95% CI: 0.39, 0.86) after controlling for covariates (results controlling for low income status vs. WIC and Medi-Cal were similar, and so only low-income status results are presented). Of the seven potential effect modifiers, significant effect modification was observed only between HPI-based neighborhood quality and WIC use (Appendix 2.A). Stratified analysis revealed that living in a higher quality neighborhood was only related to PTB among women who did not use WIC (RR: 0.41, 95% CI: 0.22, 0.75) (Table 3, Model 4).

Table 3: Model 4 – Relationship between HPI-based neighborhood quality and preterm birth – Strata-specific Risk Ratios (RR) and 95% Confidence Intervals (CI)

	RR	**95% CI**	
WIC use	0.83	0.51	1.37
No WIC use	**0.41**	**0.22**	**0.75**
Unknown WIC use^	0.38	0.04	3.54

^Link logit GEE model used to generate odds ratios, interpreted as approximating risk ratios
-Model 4 includes parity, nativity, age, educational attainment for age, and Medi-Cal status
-Bolded values are statistically significant at p<0.10

Compared with women who did not use WIC, a larger percentage of women who did use WIC were experiencing their first live birth, US-born, under 30 years old, had low or appropriate educational attainment for age, and were also using Medi-Cal (Table 4).

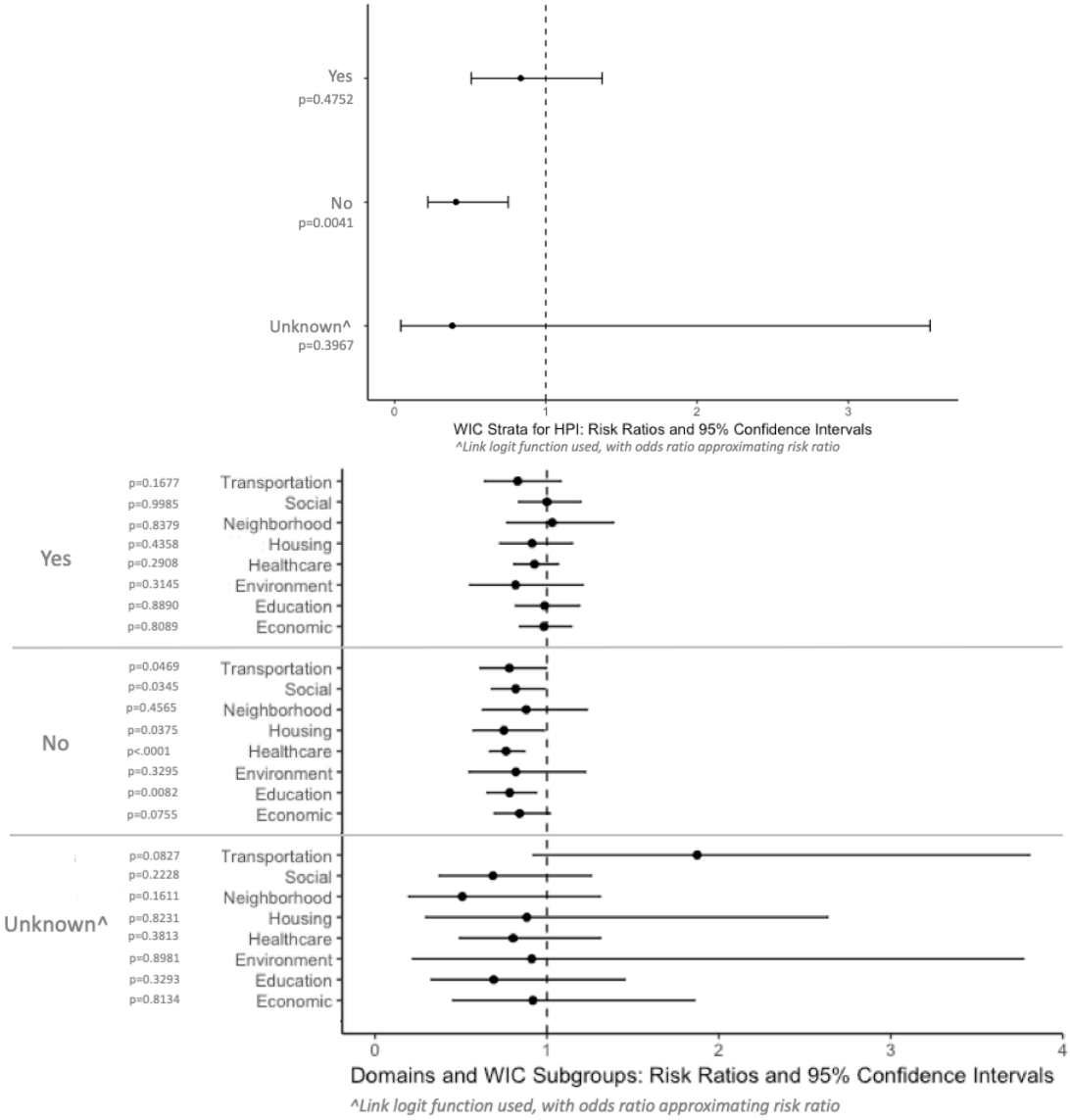
Table 4: Maternal characteristics by WIC use (N=5549)

	WIC use N(%)	No WIC use N(%)	Unknown WIC use N(%)
Total population	**3512 (63.29)**	**1913 (34.47)**	**124 (2.23)**
Parity			
First live birth	1766 (50.28)	843 (44.07)	51 (41.13)
Not first live birth	1746 (49.72)	1070 (55.93)	73 (58.87)
Nativity			
Foreign-born	203 (5.78)	247 (12.91)	10 (8.06)
US-born	3309 (94.22)	1666 (87.09)	114 (91.94)
Age at time of giving birth			
$\leq$ 22 years	1413 (40.23)	335 (17.51)	35 (28.23)
23-29 years	1245 (35.45)	645 (33.72)	49 (39.52)
30-34 years	533 (15.18)	492 (25.72)	18 (14.52)
$\geq$ 35 years	321 (9.14)	441 (23.05)	22 (17.74)
Level of education for age			
High	151 (4.30)	594 (31.05)	5 (4.03)
Appropriate	2860 (81.44)	1182 (61.79)	84 (67.74)
Low	501 (14.27)	137 (7.16)	35 (28.23)
Medi-Cal			
Yes	2868 (81.66)	629 (32.88)	115 (92.74)
No	644 (18.34)	1284 (67.12)	9 (7.26)

Compared with women who used WIC, women with unknown WIC use had a similar distribution of nativity, age (though a larger percent of women with unknown WIC use were $\geq$35 and a smaller percent were $\leq$22), educational attainment for age (though with a larger percentage of women with low attainment), and Medi-Cal. Women with unknown WIC use had similar parity distribution as women with no WIC use.

Stratifying by WIC use across the eight component domains of the HPI revealed a similar pattern of significant relationships between neighborhood quality and PTB for six of the eight domains: economic, education, healthcare, housing, social, and transportation (Appendix 2.B). Figure 1 presents the forest plot of the strata-specific relationships for HPI-based and domain-based neighborhood quality. Additionally, among the 124 women with unknown WIC use, living in a higher transportation-based quality neighborhood significantly increased the odds of PTB (link logit models were used for unknown WIC use); the confidence interval for this value is wide (0.92, 3.82) and includes the null.

Figure 1: Forest plots of risk ratios, confidence intervals, and p-values for relationship between HPI-based and domain-based neighborhood quality and preterm birth, stratified by WIC status



Discussion

This study reveals significant differences in the relationship between HPI-based neighborhood quality and PTB among Black women in Oakland by WIC use: neighborhood quality was only significantly protective against PTB among women who did not use WIC. This same relationship was identified for six of the eight component domains. We did not observe significant effect modification of the relationship between HPI-based neighborhood quality and PTB by other maternal characteristics – age, educational attainment for age, parity, nativity, low-income status, or Medi-Cal use.

The finding of significant effect modification by WIC use for the relationship between neighborhood quality and PTB among Black women is unique. While studies have found relationships between neighborhood quality and PTB among Black women when controlling for

WIC use,[37] to our knowledge this is the first study to assess differences in that relationship based on WIC status. One explanation for observing a significant relationship only among women who did not use WIC supports our original hypothesis: women who are better resourced will experience a stronger protective effect of living in a higher quality neighborhood. In our study, women who reported no WIC use appear to be more socioeconomically advantaged than their WIC-using counterparts: 31% have high educational attainment for age (compared with 4% among WIC users), and the majority did not use Medi-Cal (67%, compared with 18% among WIC users). This observation aligns with other findings from California during a similar time period: in their study of California births using Maternal and Infant Health Assessment (MIHA) data from 2010-2012, CDPH found that ineligible WIC non-users (with incomes >185% of the federal poverty line (FPL)) were more socioeconomically advantaged than WIC-users or eligible non-participants based on educationally attainment, use of private insurance, and lack of experienced financial hardship during pregnancy.[45]

Having greater personal advantage may in turn allow this group of women to better access and benefit from the physical and social environment of a higher quality neighborhood. This theory aligns with neighborhood researchers' recognition that a neighborhood's context and composition interact and influence each other with respect to residents' health.[21–23] Our findings are similar to that of a 2003 study which found that Black women without Medi-Cal coverage had lower likelihood of PTB in neighborhoods with lower unemployment, a relationship not observed among women with Medi-Cal.[26] Their findings suggest that the protective impact of a higher quality neighborhood (and the harmful impact of a lower quality one) may be more readily felt among better resourced women, akin to what we observed among Black women in Oakland who did not use WIC. This explanation depends on the validity of the claim that women not using WIC do in fact represent a better resourced population. Based on women's reported Medi-Cal use, we know that at least one-third of women not using WIC (11% of the total study population) appear to be eligible non-participants (ENPs) – women who qualify for but did not use WIC.[45,46] Studies characterizing ENPs found that while ENPs appear to be more socioeconomically disadvantaged than ineligible women, they are more advantaged that WIC participants.[45,46] This suggests that while our non-user population likely includes some women with less advantage, the group as a whole is still more advantaged than the population of WIC users. If anything, the protective relationship we observed among WIC non-users may be more conservative than what we would see if ENPs were instead classified as WIC users. Future research which explores the ways in which more socioeconomically advantaged Black women experience and navigate their neighborhood environments in Oakland would further our understanding of potential opportunities for place-based interventions to reduce risk of PTB among Black women.

A second explanation for our findings relates to the benefits of WIC enrollment specifically: WIC-related resources may protect against the harmful effects of living in a lower quality neighborhood, and so we would not observe a significant relationship between neighborhood quality and PTB among women who access WIC. Some studies have found a protective relationship between participation in WIC and risk of PTB among Black women.[47,48] This may be due to women's use of the resources provided by WIC –healthy foods, nutrition education, and referrals to other service providers[45] – as well as the potential stress reduction that may accompany easier access to these resources.[49] Extrapolating this to the neighborhood environment, it is possible that WIC participation supports women to mitigate the challenges of lower quality neighborhoods (and the potential inaccessibility of resources to less advantaged women living in higher quality neighborhoods) by directly connecting women to resources and services that may be protective

against PTB. In this case, we would not expect to see a relationship between neighborhood quality and PTB among women who use WIC. Additional research is necessary to understand the ways in which WIC participation may mitigate the challenges of a neighborhood environment for Black women in Oakland.

Examining the relationships between domain-based quality and PTB across WIC strata provided additional information regarding elements of the neighborhood environment which may be driving the overall quality relationship observed. The six HPI dimensions in which the similar pattern across WIC strata was observed – economic, education, healthcare access, housing, social, and transportation – all predominantly characterize elements of a neighborhood's social environment.[10,23] They describe the affordability of housing, the attainment of health insurance, neighborhood wealth and income, levels of civic engagement, and educational attainment and enrollment. The two remaining domains – neighborhood conditions and clean environment – predominantly describe a neighborhood's physical environment, including air and water pollution levels, the presence of food and liquor stores, access to parks, and job density. While the cumulative impact of both the physical and social environment appear to influence risk of PTB among Black women in Oakland, as evidenced by our HPI-based neighborhood quality findings, the domain-specific analysis suggests that among this population, socioeconomic advantage may enhance women's ability to benefit from a higher quality social environment in particular, and participation in WIC may mitigate the challenges of navigating the social environment specifically. Future research in Oakland should focus on understanding Black women's perspectives on and experience with their neighborhoods' social environments in order to unpack the pathways through which Oakland neighborhoods influence risk of PTB.

The finding that living in a higher transportation-based quality neighborhood was associated with increased risk of preterm birth among Black women in Oakland with unknown WIC status is perplexing. Though the estimate is imprecise (95% CI: 0.92, 3.81), it is statistically significant based on the criteria of $p<0.1$ ($p=0.0827$). Women with unknown WIC status in our study are more likely to be multiparous, have low educational attainment for age, and use Medi-Cal than WIC non-users and WIC users. It is possible that these women represent a more disadvantaged group than WIC users, and that being more disadvantaged in relation to others living in a higher transportation-based quality environment would increase risk, similar to what was found in the 2003 study examining Black women's risk of preterm birth stratified by Medi-Cal use (for women who used Medi-Cal, living in a higher quality neighborhood environment increased risk of PTB).[26] However, the small number of women with unknown WIC status in our study ($N=124$) and the observation of this relationship trend for only transportation-based quality suggest caution when interpreting this finding.

Our findings diverge from previous studies among Black women that have found significant effect modification of the relationship between neighborhood quality and PTB by maternal nativity[11,50], educational attainment,[51,52] and Medi-Cal.[26] The differences between our study findings and those of others may reflect unique characteristics of Oakland as well as differences in how neighborhood quality is measured. The heterogeneity of findings across the limited scholarship considering effect modification of neighborhood and PTB relationships by maternal characteristics among Black women demonstrates the need for more research. Future studies should continue to examine how these relationships vary across groups of Black women in order to better understand and inform the development of place-based interventions to reduce racial inequities in PTB.

There are several limitations of note for this study. Our choice of covariates was limited by the data available in the linked birth and prenatal screening records for 2007-2011; it is therefore possible that our results are affected by unmeasured confounding and that other characteristics not assessed may be significant effect modifiers for Black women in Oakland. In addition, we were unable to assess a woman's length-of-residence in her neighborhood prior to giving birth, and therefore could not account for differences in the dose of exposure to neighborhood environments. Future studies collecting original data can address these limitations.

Our findings are intentionally limited to the relationship between neighborhood quality and preterm birth among Black women and across Oakland neighborhoods, and therefore cannot be generalized to the larger community of Black women in California. Generalizing our findings to Black women in Oakland who gave birth after 2011 should also be done with caution, as the Great Recession took place during our study time period, making the 2007-2011 time period distinctive.[53] However, our methods are replicable for other areas in California considering effect modification by maternal characteristics to inform their own place-based work to reduce the risk of PTB among Black women.

This study presents unique findings regarding the ways in which neighborhood quality matters differently for PTB risk across groups of Black women in Oakland. These findings are relevant for researchers seeking to understand how neighborhood characteristics may impact racial inequities in risk of PTB and practitioners working to improve neighborhood environments in order to improve birth outcomes. More work is needed which examines the diversity of neighborhood effects, particularly with respect to understanding and developing interventions to reduce risk of PTB among all Black women.

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Study 3 – Assessing prenatal care use as a mediator of the relationship between neighborhood quality and preterm birth among Black women in Oakland, California (2007-2011), overall and stratified by WIC use

Introduction

Preterm birth (PTB) – birth before 37-weeks' gestation – is a leading cause of infant mortality and a risk factor for morbidity through adulthood that disproportionately affects Non-Hispanic Black and African American women, (hereafter, Black women) in the United States (Martin, Hamilton, Osterman, Driscoll, & Drake, 2018; Moster, Lie, & Markestad, 2008; Purisch & Gyamfi-Bannerman, 2017; Saigal & Doyle, 2008). The neighborhoods in which Black women live are increasingly assessed as potential upstream risk factors for PTB (Mutambudzi, Meyer, Reisine, & Warren, 2017; Ncube, Enquobahrie, Albert, Herrick, & Burke, 2016). Neighborhood environments may influence health behaviors which in turn increase risk of PTB through neighborhood cultural norms, resource availability, and stress (Culhane & Elo, 2005). Though it is hypothesized that health behaviors mediate the relationship between neighborhood quality and PTB, few studies directly investigate potential mediation (Kane, Miles, Yourkavitch, & King, 2017; Vinikoor-Imler, Messer, Evenson, & Laraia, 2011).

Inadequate use or late initiation of prenatal care (PNC), as defined by the American College of Obstetricians and Gynecologists' (ACOG) standards, is one health behavior often studied in relation to PTB, though the evidence on the impact of PNC on PTB is inconclusive (Denney, Culhane, & Goldenberg, 2008; DeSisto, Hirai, Collins, & Rankin, 2018; Vintzileos, Ananth, Smulian, Scorza, & Knuppel, 2002; Walford, Trinh, Wiencrot, & Lu, 2011). Black women are less likely than White women to begin PNC in the first trimester of pregnancy (66.6% vs 82.4% in 2017, respectively) (Martin et al., 2018). A recent disparity decomposition study estimates that timing of PNC entry explains a small but significant percentage of the disparity in PTB between US-born Black and Non-Hispanic White women (hereafter, White women) (DeSisto et al., 2018). PNC utilization and timing of initiation may be influenced by neighborhood characteristics that affect the availability and accessibility of PNC, such as neighborhood transportation infrastructure (Bloch, Cordivano, Gardner, & Barkin, 2018; Braveman, 2000; Perloff & Jaffee, 1999).

We hypothesize that the relationship between neighborhood quality and PTB among Black women is partially mediated by adequacy of PNC initiation and use. To the authors' knowledge, this is the first study to assess whether PNC initiation and use mediate the relationship between neighborhood quality and risk of PTB among Black women. A Baltimore-based study did find evidence of mediation by late or no PNC of the relationship between neighborhood quality (defined by an index including characteristics of the neighborhood social and physical environment) and the odds of a low birthweight (<2500g) birth (Schempf, Strobino, & O'Campo, 2009), a birth outcome related to PTB (Heron, 2019). Specific investigation of PNC initiation and use as potential mediators would further our understanding of the pathways between neighborhood quality and PTB. Additionally, knowledge of the extent to which neighborhood quality and PTB relationships are mediated by PNC could provide information about possible intermediate outcomes which could be examined and tracked by neighborhood transformation interventions seeking to reduce Black women's risk of PTB in Oakland, California, and in other urban environments.

Methods

Our study population is drawn from all 2007-2011 singleton births to Black women in Oakland, California. The source for maternal and infant data is the California Biobank Program Linked

Dataset for statewide births, maintained by the California Department of Public Health (CDPH) (Pearl et al., 2018). Included in this data set are available linked data from California certificates of live birth and the statewide Prenatal Screening Program (Cunningham & Tompkinson, 1999). Births to Black women during the time period were eligible for inclusion based on the following criteria: (1) recorded gestational age between 20-44 weeks, (2) no indicated congenital abnormalities, and (3) birth certificate address geocoded to an included Oakland census tract. Among this population, one birth was randomly selected if a mother had more than one live birth between 2007-2011. In order to conduct a complete-case analysis, individuals with any missing covariates (N=391, 6.8% of eligible participants) were excluded, resulting in the final study population of 5343 mothers and births.

Outcome

Preterm birth (PTB) is defined as an infant with a gestational age of <37 weeks. Gestational age was identified in order of the best available estimate from the linked dataset: (1) prenatal screening ultrasound, (2) obstetric estimate at time of delivery, or (3) reported last menstrual period (Barradas et al., 2014; Dietz et al., 2007; Pearl et al., 2018).

Exposure

We define overall neighborhood quality using the multidimensional California Healthy Places Index (HPI) (Delaney et al., 2018). The 2017 HPI was created by the Public Health Alliance of Southern California, the Virginia Commonwealth University Center of Society and Health, and a steering committee of subject matter experts and health department representatives in order to characterize a "healthy place" as one which best predicts life expectancy at birth (LEB). Using census tracts to approximate neighborhoods and publicly available 2010-2015 data across California, the HPI was derived from the sum of eight policy action domain scores – economic, education, healthcare access, housing, neighborhood conditions, clean environment, social environment, and transportation – weighted to best predict census tract LEB. Domain scores were generated based on the average z-scores of component indicators selected by the HPI creators based on expertise and reviews of the literature – 25 indicators in all (see Appendix 1.B for a list of indicators, domains, and data sources). To ensure stability when calculating the statewide index, California census tracts were eligible for inclusion in calculating the HPI if their 2010 population was >1500 people.

Because the current HPI data was predominantly drawn from time periods subsequent to that of our study, we recreate the HPI for the 108 Oakland census tracts eligible for inclusion, using indicator data from the 2007-2011 time period whenever possible and the closest available time period otherwise (five indicators use data outside the 2007-2011 time period, see Appendix 1.B). Following the approach used for the current HPI (Delaney et al., 2018), we use the weighted average imputation method from the DMwR package in R (Torgo, 2010) to impute six census tracts' values for two education-domain indicators that were not available in the 2007-2011 American Community Survey. We also exclude the ozone indicator in the clean environment domain due to its lack of variation across Oakland census tracts. To construct the domains, each indicator is standardized (mean=0, standard deviation=1), and the average of component indicators' standardized scores serves as the domain score for that census tract. We then use the miWQS package in R (Hargarten & Wheeler, 2018) to run a weighted quantile sum regression to generate weights for each domain that maximize prediction of census tract LEB, ensuring a minimum domain weight of 0.05. Summing the weighted domain scores produces the HPI score for a given census tract. After calculating the HPI scores, one census tract was removed because no study births were linked to the tract.

Mediators

This study examines four different PNC measures as potential mediators of the relationship between neighborhood quality and PTB among Black women in Oakland. Each mediator is assessed in a separate series of models. Three measures are based on the commonly used Adequacy of Prenatal Care Utilization (APNCU) Index (Kotelchuck, 1994). The first measure, adequacy of PNC initiation, is defined by the month in which a woman initiated PNC: months 1-2 (adequate plus), months 3-4 (adequate), months 5-6 (intermediate), and either never initiated or months 7 and beyond (inadequate).

The second measure, adequacy of received services, characterizes the percent of expected PNC visits a woman attended. The number of expected PNC visits is calculated by identifying the American College of Obstetricians and Gynecologists' (ACOG) recommended number of PNC visits for an infant's gestational age (every four weeks through week 28 of pregnancy, then every two weeks through week 36, then weekly for each subsequent week (Kotelchuck, 1994)) and subtracting the number of visits a woman would be expected to have missed given her month of PNC initiation. The number of PNC visits listed on the birth record is then divided by the number of expected PNC visits and multiplied by 100 to calculate the percent of expected visits a woman attended. Adequacy of received services is defined as follows: $\geq$109.9% of expected visits attended (adequate plus), $\geq$ 79.9% and <109.9% (adequate), $\geq$50% and <79.9% (intermediate), and no PNC initiated or <50% (inadequate). One woman who had an infant at 21 weeks attended two PNC visits but initiated PNC during the 6th month. Because the recommended number of visits (5) and number of missed visits due to her initiation at 6 months (5) are equal, expected visits count was zero, resulting in an illogical adequacy of received services percent calculation of 2/0. This woman was manually coded as having an adequacy of received services score of 40% (accounting for her attending 2 out of the 5 visits recommended by 21 weeks).

The third measure, adequacy of prenatal care use (APNCU), is a combination of the previous two measures. A woman is categorized as having adequate plus APNCU if she initiated PNC during months 1-4 of her pregnancy and received $\geq$109.9% of expected visits. The adequate APNCU category is defined as having initiated PNC during months 1-4 and having attended between 79.9% and 109.9% of expected visits. The intermediate APNCU category is defined as having initiated PNC between months 1-4 and having attended between 50% and 79.9% of expected visits. Lastly, a woman is categorized as having inadequate APNCU if she initiated PNC during month 5 or later or if she received fewer than 50% of expected visits. For these three measures, the adequate category is used as the reference group.

The fourth measure assessed was the number of PNC visits a woman received during her pregnancy. We categorize the number of PNC visits as follows: <5 visits, 5-11 visits, 12-19 visits, and 20+ visits. The categorization is both data-driven and conceptual. The crude relationship between number of PNC visits and PTB is non-uniform. Based on a loess plot of the crude relationship between number of PNC and risk of PTB, there appears to be a negative relationship between PTB and number of PNC visits through 11 visits (Appendix 3.A). However, beginning with 12 visits, the relationship reverses direction, suggesting a plateaued or slightly positive relationship between increasing numbers of visits and risk of PTB. In addition, based on ACOG recommendations, by week 20 a woman would be expected to have attended at least 5 PNC visits. By week 36, the cutoff week of PTB, a woman would be expected to have attended at least 11 visits,

and by week 44, the oldest gestational age included in our study, at least 19. We use 12-19 visits, the minimum numbers for term births in our sample, as the reference group.

Covariates

The following *a-priori*-specified confounders are controlled for in adjusted models based on prior evidence of relationship between neighborhood quality and PTB (Basu, Pearson, Ebisu, & Malig, 2017; DeFranco, Lian, Muglia, & Schootman, 2008; Laurent et al., 2016; Ma et al., 2015; Mason et al., 2011; Messer, Kaufman, Dole, Herring, & Laraia, 2006): age (continuous), parity (1=first live birth, 0=not first live birth), educational attainment-for-age (0=low [older than 13 with 8th grade or less, older than 19 with 9-11 years of education], 1=appropriate [19 or younger with 9-11 years, any age with high school graduation or some college], 2=high [any age with college graduation or beyond] (Fraser, 1995)), use of Medi-Cal (1=yes, 0=no), and nativity (1=foreign-born, 0=U.S. born). These covariates have also been associated in other studies with adequacy of initiation and use of PNC (Cubbin et al., 2008; El-Sayed & Galea, 2012; Feijen-de Jong et al., 2012; Goldfarb, Smith, Epstein, Burrows, & Wingate, 2017). Based on findings from Study 2, models are run for the full population and stratified by WIC use (yes and no).

Statistical analysis

PTB, neighborhood quality, maternal characteristics, and potential mediators are described across the total population and by WIC use. Based on the approach developed by Baron and Kenny, a variable mediates the relationship between an exposure and an outcome if the following conditions are met: Condition 1 – the exposure and outcome are associated, Condition 2 – the exposure and mediator are associated, Condition 3 – the mediator and outcome are associated, and Condition 4 – including both the exposure and mediator in a model results in a meaningful change to the exposure-outcome relationship (Baron & Kenny, 1986; Lorch, Kroelinger, Ahlberg, & Barfield, 2012). This approach estimates the extent to which the exposure-outcome relationship is mediated by a third variable when there is no interaction between the exposure and the mediator (VanderWeele, 2010). All models were run for the total study population and stratified by WIC use. A p-value <0.05 is considered statistically significant unless otherwise specified. Fully adjusted models include all covariates. Calculated odds ratios for PTB are expected to approximate risk ratios due to the low percent of PTBs in the total population (9.96%).

To assess Condition 1, we ran an unadjusted generalized estimating equation (GEE) model with a link logit function and an exchangeable correlation structure (Model A). Condition 1 is satisfied if the HPI coefficient is statistically significant. We assess Condition 2 using ANOVA procedures examining differences in mean HPI scores across potential mediator categories. Condition 2 is satisfied if the test statistic p-value for a given mediator is statistically significant. To assess Condition 3, we run unadjusted GEE models for each mediator and the PTB outcome (Model B). Condition 3 is satisfied if the mediator's coefficient is statistically significant. Variables which satisfy Conditions 1,2, and 3, are then tested for effect modification with neighborhood quality in unadjusted GEE models (Model C). Variables for which effect modification is significant at $p<0.1$(Selvin, 2004) are excluded from further analysis.

Condition 4 was assessed for remaining variables through calculation of the extent to which each variable mediates the neighborhood quality-PTB relationship as quantified by the mediation percentage (Lorch et al., 2012). We ran a fully adjusted GEE model of neighborhood quality and PTB to quantify the baseline relationship (Model D). We then added the identified mediators (each in a separate model) (Model E). The mediation percentage is calculated as follows:

$$\frac{Risk\ Ratio_{Model\ D} - Risk\ Ratio_{Model\ E}}{1 - Risk\ Ratio_{Model\ D}}\ x\ 100$$

We use non-parametric bootstrapping of Models D and E to calculate the 95% confidence intervals for all mediation percentages based on 200 random samples of the study population, sampled with replacement first at the neighborhood level and then at the individual level. The 97.5th and 2.5th percentiles of the mediation percentages across the 200 samples define the upper and lower bounds, respectively, of the 95% confidence interval for the study population mediation percentage. Condition 4 is satisfied if the 95% confidence interval does not contain the null (0%). Statistical analysis was conducted in SAS 9.4("SAS(R) 9.4 -- Today and Tomorrow," n.d.) unless otherwise specified. The Committee for the Protection of Human Subjects of the California Health and Human Services Agency (Project 14-01-1466) provided study approval, with IRB reliance approval from University of California, Berkeley.

Results

Women in the study were more likely to have had 5-11 PNC visits, adequate plus PNC initiation, adequate PNC received services and APNCU, and appropriate educational attainment for age, to have been born in the US US-born, and to have used Medi-Cal (Table 1). The average age of the study population 26.67. Compared with women who did not use WIC, women who used WIC were more likely on average to live in a lower quality neighborhood, be younger, be experiencing their first live birth, have low or appropriate educational attainment for age, be US-born, and use Medi-Cal.

Table 1: Description of preterm birth, neighborhood quality, potential mediators, and maternal characteristics across the total population and by WIC use – number(N) and percent(%) or mean(M) and standard deviation(SD)

	Total N(%) or M(SD)	WIC use N(%) or M(SD)	No WIC use N(%) or M(SD)
Total population	5343(100)	3455(64.66)	1888(35.34)
HPI score (continuous)	-0.14(0.23)	-0.18(0.20)	-0.07(0.26)
Preterm birth			
Yes	532(9.96)	341(9.87)	191(10.12)
No	4811(90.04)	3114(90.13)	1697(89.88)
# of PNC visits			
<5	167(3.13)	89(2.58)	78(4.13)
5-11	2895(54.18)	1887(54.62)	1008(53.39)
12-19	2215(41.46)	1432(41.45)	783(41.47)
20+	66(1.24)	47(1.36)	19(1.01)
PNC initiation			
Adequate plus	3117(58.34)	2047(59.25)	1070(56.67)
Adequate	1748(32.72)	1101(31.87)	647(34.27)
Intermediate	294(5.50)	210(6.08)	84(4.45)
Inadequate	184(3.44)	97(2.81)	87(4.61)
PNC received services			
Adequate plus	1024(19.17)	669(19.36)	355(18.80)
Adequate	2568(48.06)	1650(47.76)	9.18(48.62)
Intermediate	1596(29.87)	1058(30.62)	538(28.50)
Inadequate	155(2.90)	78(2.26)	77(4.08)
APNCU			
Adequate plus	884(16.55)	569(16.47)	315(16.68)
Adequate	2444(45.74)	1563(45.24)	881(46.66)
Intermediate	1474(27.59)	981(28.39)	493(26.11)
Inadequate	541(10.13)	342(9.90)	199(10.54)
Age (continuous)	26.67(6.55)	25.24(6.16)	29.28(6.44)
Parity			
First live birth	2568(48.06)	1738(50.30)	830(43.96)
Not first live birth	2775(51.94)	1717(49.70)	1058(56.04)
Educational attainment			
Low	618(14.07)	486(14.07)	132(6.99)
Appropriate	2818(39.82)	2818(81.56)	1164(61.65)
High	743(13.91)	151(4.37)	592(31.36)
Nativity			
Foreign-born	442(8.27)	200(5.79)	242(12.82)
US-born	4901(91.73)	3255(94.21)	1646(87.18)
Medi-Cal			
Yes	3438(64.35)	2820(81.62)	618(32.73)
No	1905(35.65)	635(18.38)	1270(67.27)

Condition 1 – significant relationship between neighborhood quality and PTB – was satisfied for the total population and WIC non-users but not for WIC users, precluding the assessment of mediation among WIC users (Appendix 3.B). All four potential mediators satisfied Condition 2 – significant difference in neighborhood quality across potential mediator categories – (Appendix 3.C) and Condition 3 – significant relationship between a potential mediator and PTB – (Appendix 3.D) for the total population and WIC non-users. There was evidence of effect modification by number of PNC visits for the total population, and by number of PNC visits and adequacy of PNC initiation for WIC non-users (Appendix 3.E), and so these variables were removed from further analysis. We assessed Condition 4 – relationship between neighborhood quality and PTB is significantly different

with the addition of the potential mediator – for adequacy of PNC initiation, PNC received services, and APNCU in the total population, and for adequacy of PNC received services and APNCU among WIC non-users (Table 2).

Table 2: Fully adjusted models of relationship between neighborhood quality(HPI) and preterm birth(PTB), without and with potential mediators – HPI coefficients(Coef), risk ratios(RR) and 95% confidence intervals(CI)

	Total				WIC non-users			
	Coef	**RR**	**95% CI**		**Coef**	**RR**	**95% CI**	
HPI	**-0.5768**	**0.56***	**0.35**	**0.89**	**-1.0518**	**0.35***	**0.17**	**0.71**
HPI	**-0.6060**	**0.55***	**0.34**	**0.87**				
PNC initiation – Adequate plus		1.28*	1.03	1.61				
PNC initiation – Intermediate		1.43	0.93	2.19				
PNC initiation – Inadequate		2.12*	1.39	3.24				
HPI	**-0.6560**	**0.52***	**0.31**	**0.87**	**-1.1340**	**0.32***	**0.15**	**0.69**
PNC received services – Adequate plus		7.38*	6.02	9.05		10.17*	6.93	14.95
PNC received services – Intermediate		0.41*	0.29	0.57		0.69	0.41	1.17
PNC received services – Inadequate		3.70*	2.62	5.22		4.86*	2.67	8.86
HPI	**-0.6254**	**0.54***	**0.32**	**0.89**	**-1.0692**	**0.34***	**0.16**	**0.73**
APNCU – Adequate plus		8.73*	6.97	10.94		11.28*	7.62	16.70
APNCU – Intermediate		0.40*	0.28	0.59		0.65	0.36	1.17
APNCU – Inadequate		2.52*	1.86	3.40		3.39*	2.11	5.44

All models are link logit GEE models with exchangeable correlation structures and adjusted for maternal educational attainment for age, nativity, age, parity, and Medi-Cal
**p<0.05*

In the total population, risk of PTB was significantly higher among those categorized as having adequate plus or inadequate PNC initiation, PNC received services, and APNCU as compared with those in adequate categories, independent of covariates and neighborhood quality (Table 2). Women categorized as having intermediate received services or intermediate APNCU had significantly lower risk of PTB as compared to adequate categories. Among WIC non-users, the magnitude of increased risk PTB for women with adequate plus or inadequate received services or APNCU was greater than in the total population. The inclusion of each potential mediator in a full model resulted in a small percent reduction in the risk of PTB associated with neighborhood quality (Table 3). Adequacy of received services in the total population mediated the largest percent of the relationship between neighborhood quality and PTB (9.09%). However, no potential mediators met the requirements for Condition 4, as the 95% confidence intervals for all estimate mediation percentages contained the null value of zero.

Table 3: Mediation percentages(MP) with bootstrapped 95% confidence intervals(CI)

	Total			WIC non-users		
	MP	**95% CI**		**MP**	**95% CI**	
Adequacy of initiation	2.27%	-3.48%	27.53%			
Adequacy of received services	9.09%	-58.81%	91.24%	4.62%	-25.85%	33.44%
Adequacy of APNCU	4.55%	-67.30%	87.20%	1.54%	-33.16%	25.93%

All models are GEE link logit models with exchangeable correlation structures and adjusted for maternal educational attainment for age, nativity, age, parity, and Medi-Cal

Discussion

This is the first study, to the authors' knowledge, that examines whether PNC use mediates the relationship between neighborhood quality and PTB among Black women. Adequacy of PNC initiation, received services, and APNCU score, variables which met Conditions 1-3 and for which there was no evidence of significant effect modification (with the exception of initiation among WIC non-users), were significantly associated with PTB independent of neighborhood quality. Our study did not find evidence that PNC significantly mediated the relationship between neighborhood quality and PTB.

Our findings that Black women categorized as having inadequate PNC initiation (total population), PNC received services (total and WIC non-users), or APNCU score (total and WIC non-users) have an increased risk of PTB compared to women in adequate categories is consistent with findings from other studies among Black women (Cox, Zhang, Zotti, & Graham, 2011; DeSisto et al., 2018; Vintzileos et al., 2002). Our findings suggest that among Black women in Oakland, inadequate or no PNC use may increase risk of PTB independent of neighborhood quality. One possible explanation for inadequate use of PNC relates to the quality of the PNC itself. Black women are more likely than their White peers to experience mistreatment when receiving maternity care (Vedam et al., 2019). Black women and other women of color describe disrespect, discrimination, not being believed, and not being listened to as frequent occurrences in their experiences of PNC (Coley et al., 2018; Edmonds, Mogul, & Shea, 2015; McLemore et al., 2018). The anticipation and/or prior experience of these conditions may understandably deter women of color from pursuing PNC as early or as often as White women. A well-documented limitation of the APNCU is its inability to capture the quality or experience of PNC (Phillippi, 2009; Walford et al., 2011). Building on work already happening in Oakland (McLemore et al., 2018), more research should engage directly with Black women to understand how experiences of PNC affect access to and use of PNC, and the role that neighborhood quality may play in determining the quality of care available to Black women. This research would inform the development of interventions within healthcare systems which may in turn improve use of PNC and decrease risk of PTB among Black women.

Our findings of increased risk of PTB among women in the adequate plus categories as compared with adequate also aligns with other studies' findings (Cox et al., 2011; Debiec, Paul, Mitchell, & Hitti, 2010; Partridge, Balayla, Holcroft, & Abenhaim, 2012). As the ACOG recommendations for PNC visits are based on a pregnancy without significant complications, it is possible that women whose PNC use exceeds the adequacy standards are also experiencing other challenges in their pregnancies, which in turn may increase their risk of PTB – an unmeasured confounder in this analysis (Cox et al., 2011). The findings that intermediate PNC received services and APNCU score were significantly protective compared adequate categories in the total study population (and similar, non-significant findings among WIC non-users) are unique and difficult to explain. Given that findings of the relationship between PNC use and PTB are inconsistent throughout the literature (Denney et al., 2008; Walford et al., 2011), further research into how and why adequacy of PNC use may impact PTB risk among Black women in Oakland is necessary.

The relationships between neighborhood quality and PTB among WIC non-users are stronger than those in the total population. This finding is similar to that of another study which found a relationship between living in a higher quality neighborhood and reduced risk of PTB among women who did not use Medi-Cal but did not find the same relationship among women who did use Medi-Cal (Ahern, Pickett, Selvin, & Abrams, 2003). This may suggest that for WIC non-users – a potentially more socioeconomically advantaged segment of the total population (California

Department of Public Health, 2016) – the quality of the neighborhood environment in which one lives is particularly important with respect to risk of PTB. It is also possible that an unmeasured characteristic which allows WIC non-users in this population to live in a higher quality neighborhood also reduces risk of PTB. Similarly, the statistically significant relationships between PNC and PTB independent of neighborhood quality are stronger among WIC non-users. This finding begs the question of why women in this more socioeconomically advantaged group were not able to receive adequate PNC services. Future research to better understand the intersection of higher socioeconomic status, neighborhood quality, and use of PNC services is needed to unpack these findings for Black women in Oakland and to see if similar relationships are observed in other urban environments.

Contrary to our hypothesis, PNC use did not appear to mediate the relationship between neighborhood quality and PTB among Black women in Oakland. This may be due to a limitation of our data set: we do not know where specifically women in our study sought PNC. While our neighborhood quality characterization does include a transportation domain – a neighborhood-related barrier to accessing and using PNC identified in the literature (Bloch et al., 2018; Braveman, 2000; Edmonds et al., 2015; Phillippi, 2009) – we do not know the proximity to a woman's PNC site or the availability of transit routes for that site in her neighborhood. It is possible that despite availability of transit options in a woman's neighborhood, the PNC site she is using may not be accessible through those avenues. In addition, as Bloch et al (2018) simulate in their assessment PNC access in Philadelphia, travel to a nearby PNC site may still involve lengthy travel times depending on available routes, a potential barrier for women without flexible work schedules. Future research using original data collection of PNC sites, women's routes to care, and GIS mapping technology could illuminate a more nuanced picture of how neighborhood context may influence PNC access and use, allowing for a more precise assessment of the potential pathway between neighborhood quality, PNC, and PTB.

Our study presents the first analysis of PNC use as a potential mediator of the relationship between neighborhood quality and PTB. This study has some important limitations. While the maternal characteristics included in full models have also been associated with PNC use in other studies (Cubbin et al., 2008; El-Sayed & Galea, 2012; Feijen-de Jong et al., 2012; Goldfarb et al., 2017), it is possible that unmeasured confounding with respect to PNC use and PTB risk may explain some of the observed relationships between PNC and PTB independent of neighborhood quality. Future research that employs more sophisticated methods for assessing mediation while accounting for separate confounder sets between neighborhood-level exposures, potential individual-level mediators, and individual-level outcomes would allow for a richer assessment of potential mediation pathways (VanderWeele, 2010). In addition, our intentional focus on Black women's experiences in Oakland, California limits the generalizability of our findings to other populations in other urban environments. Given the limited research on mediation pathways between neighborhood quality and PTB among Black women, research in other urban settings with which these results could be compared would be valuable.

Health behaviors such as use of PNC may represent intermediate, modifiable outcomes along the pathway between neighborhood quality and risk of PTB. As investigators and practitioners continue to search for intervention opportunities to disrupt the disproportionately high burden of PTB experienced by Black women, more research which considers why place might matter is needed. Understanding the pathways through which neighborhood quality may affect risk of PTB among

Black women through mediation analysis is important for the development and evaluation of neighborhood transformation efforts to address racial inequities in PTB.

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Conclusion and Future Research

The places where one lives affect one's health and wellbeing, including risk of PTB among Black women in the United States. As the findings from Study 1 demonstrate, living in a higher quality neighborhood is protective against risk of PTB among Black women in Oakland, California. This relationship is not homogeneous across the population. As Study 2 findings show, WIC status modifies the relationship between neighborhood quality and PTB for this population, with only women who do not use WIC experiencing a higher neighborhood quality as a significant protective factor. The mechanisms through which neighborhoods affect risk of PTB are complex, and while Study 3 shows that prenatal care use was a risk factor for PTB among Black women in Oakland independent of neighborhood quality, we found no evidence of significant mediation of the relationship between neighborhood quality and PTB.

This dissertation contributes to scholarship focused on addressing racial inequities in PTB by focusing on the ways in which neighborhood environments impact Black women's risk of PTB specifically. The findings of Studies 1, 2, and 3 can inform efforts in Oakland to improve neighborhood quality in order to have a long-term impact on risk of PTB among Black women. Building on these findings, future quantitative and qualitative research is warranted to understand in greater detail the specific pathways through which neighborhood quality influences Black women's risk of PTB in Oakland.

Our use of the Healthy Places Index (HPI) to characterize neighborhood quality captures areas of Oakland with clusters of domain-specific and overall high and low neighborhood quality. While use of a multidimensional construct like the HPI can mask the independent contributions of specific domains, the construct itself captures neighborhood quality in a more complex way. In-depth qualitative research in partnership with Black women living in these neighborhoods can further contextualize the meaning and impact of the HPI scores and unpack how neighborhood quality may relate to PTB for this community. Following the procedures for developing the HPI at statewide level, Oakland-specific experts and scholars could tailor the HPI to capture policy areas of unique import to the city, allowing for more specific place-based analyses to drive intervention development. In addition, further exploration into the modifying role which WIC use plays in the relationship between neighborhood quality and PTB among Black women in Oakland is also warranted, as Study 2 is the first to our knowledge which examines WIC in this capacity. Future research using original data collection of PNC sites, women's routes to care, and GIS mapping technology in Oakland could illuminate a more nuanced picture of how neighborhood context may influence PNC access and use, allowing for a more precise assessment of the potential pathway between neighborhood quality, PNC, and PTB.

The protective nature of higher quality neighborhood environments against risk of PTB among Black women in Oakland is a significant finding, and one which merits additional consideration. In order to understand whether neighborhood transformation is causally related to reduced risk of PTB among Black women, it would be necessary to assess community transformation interventions that simultaneously protect against displacement. Ongoing place-based community development in Oakland could provide opportunities for evaluating the impact of transforming neighborhoods on racial inequities in preterm birth. As public health practitioners and scholars, we have an obligation to push forward this line of research in an effort to close the Black-White gap in experiences of PTB for good

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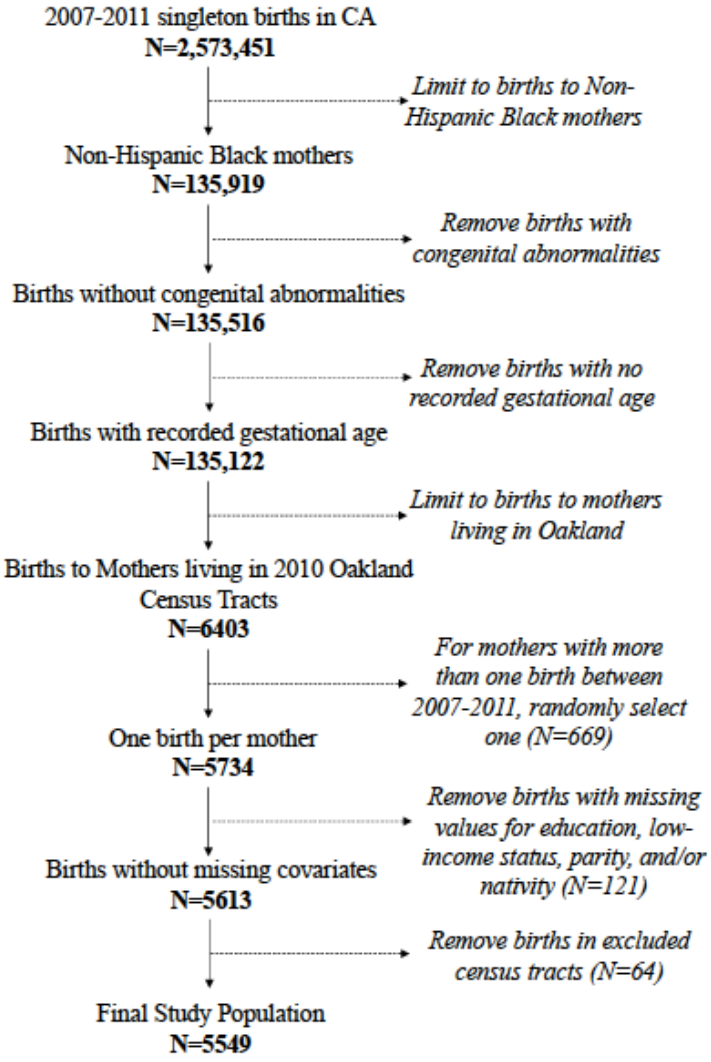
Appendices

Appendix 1.A. Establishing Study Population



Appendix 1.B. Healthy Places Index Domains, Indicators, Data Sources, and Time Periods Used

Domain	Indicator	Data Source	Time Period
Economic	% of population with income > 200% of federal poverty line	Table S1701 American Community Survey	2008-2012[a]
	% of population aged 25-64 who are employed	Table S2301 American Community Survey	2007-2011
	Median household income	Table DP03 American Community Survey	2007-2011
Education	% of population over 25 with a bachelor's education or higher	Table DP02 American Community Survey	2007-2011
	% of 15-17-year-olds enrolled in school	Table S1401 American Community Survey	2007-2011
	% of 3- and 4-year-olds enrolled in preschool	Table S1401 American Community Survey	2007-2011
Healthcare Access	% of adults ages 18-64 currently insured	Table S2701 American Community Survey	2008-2012[a]
Housing	% of occupied housing units occupied by property owners	Table DP04 American Community Survey	2007-2011
	% of households with complete kitchen facilities and plumbing	Tables 15A, 15B, and 15C Comprehensive Housing Affordability Strategy (CHAS) data	2007-2011
	% of low-income homeowners paying more than 50% of income on housing costs	Healthy Places Index	2007-2011
	% of low-income renter households paying more than 50% of income on housing costs	Healthy Places Index	2007-2011
	% of households with ≤ 1 occupant per room	Table DP04 American Community Survey	2007-2011
Neighborhood Conditions	% of population living within ½-mile of a park, beach, or open space great than 1 acre	California Health and Human Services Open Data platform	2010
	Population-weighted % of census tract area with tree canopy	Healthy Places Index	2011
	% of urban and small town population resident less than ½ - mile from a supermarket/large grocery store, and percent of rural population living less than 1 mile from a supermarket/large grocery store	United States Department of Agriculture Food Access Research Atlas (archived)	2010
	% of population residing within ¼ mile of an off-site sales alcohol outlet	Healthy Places Index	2014[b]
	Combined employment density for retail, entertainment, and educational uses (jobs/acre)	Health Deprivation Index	2010
Clean Environment	Spatial distribution of gridded diesel PM emissions from on-road and non-road sources for a 2010 summer day in July (kg/day) – census tracts ordered by diesel PM concentration values and assigned a percentile based on the statewide distribution of values	Cal EnviroScreen 2.0	2010

Domain	Indicator	Data Source	Time Period
	Cal EnviroScreen 2.0 drinking water contaminated index for selected contaminants	Cal EnviroScreen 2.0	2005-2013[c]
	Mean summer months (May-October) of the daily maximum 8-hour ozone concentration (ppm), averaged over three years (2012-2014) – census tracts were ordered by ozone concentration values and assigned a percentile based on statewide distribution of values	Healthy Places Index	2012-2014[d]
	Annual mean concentration of PM2.5 (average quarterly means, mg/m^3) over three years (2009-2011) – census tracts were ordered by PM2.5 concentration values and assigned a percentile based on the statewide distribution of values	Cal EnviroScreen 2.0	2009-2011
Social	% of registered voters voting in the 2010 general election	Health Deprivation Index	2010
	% of family households with children < 18 with two parents	Table B09008 American Community Survey	2007-2011
Transportation	% of households with access to an automobile	Table DP04 American Community Survey	2007-2011
	% of workers (16 years +) commuting by walking, cycling, or transit (excluding working from home)	Table B08301 American Community Survey	2007-2011
Life Expectancy at Birth	Life expectancy at birth in 2010	Healthy Places Index	2010

a. Data first made available in American Community Survey for 2008-2012 5-year estimates

b. Indicator constructed for HPI, methods for constructing indicator from raw data not available

c. Water contaminant compliance period used in Cal Enviroscreen 2.0

d. *The ozone indicator from Cal EnviroScreen 3.0 (2012-2014) used in the HPI differs from that of Cal EnviroScreen 2.0 (covering an earlier time period), and so the HPI indicator was used.*

Appendix 1.C. Correlation coefficients and p-values across domains

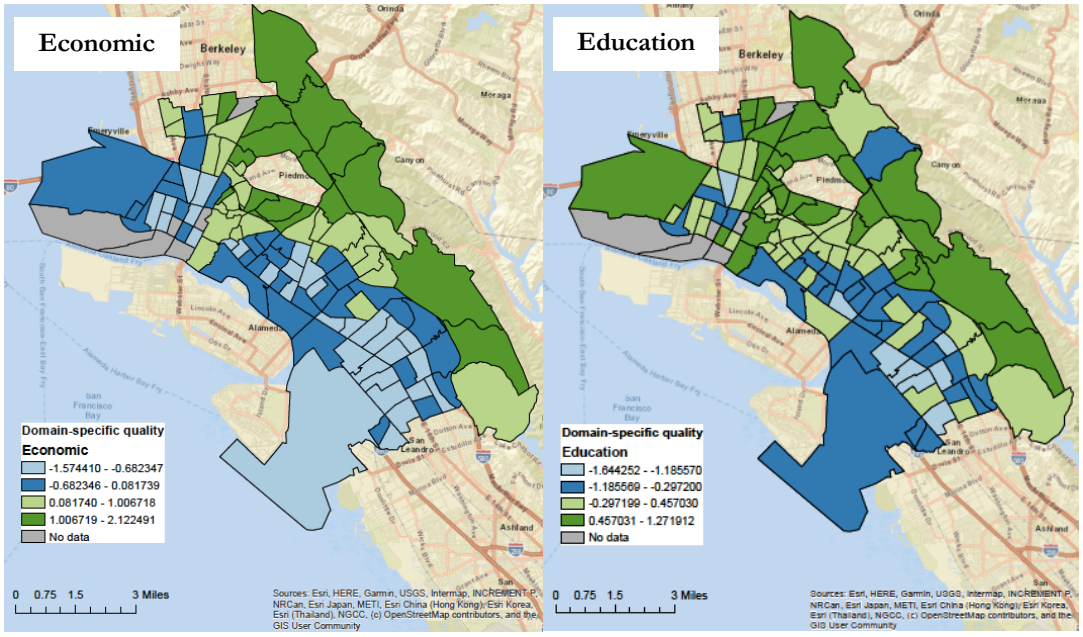
	Economic	Education	Healthcare	Housing	Neighborhood	Clean Environment	Social
Economic							
Education	**0.73085 p<.0001**						
Healthcare	**0.821 p<.0001**	**0.65769 p<.0001**					
Housing	**0.86457 p<.0001**	**0.67969 p<.0001**	**0.78528 p<.0001**				
Neighborhood	**0.37689 p<.0001**	**0.26684 p=0.0052**	**0.3578 p=0.0001**	**0.3908 p<.0001**			
Clean Environment	0.06492 p=0.5045	**0.21263 p=0.0272**	0.11377 p=0.2411	0.13118 p=0.176	-0.1005 p=0.3007		
Social	**0.83217 p<.0001**	**0.68373 p<.0001**	**0.64025 p<.0001**	**0.66659 p<.0001**	**0.34765 p=0.0002**	0.06856 p=0.4808	
Transportation	**0.23505 p=0.0143**	**0.30059 p=0.0016**	**0.25485 p=0.0078**	0.15326 p=0.1133	0.03113 p=0.7491	0.13173 p=0.1742	**0.22442 p=0.0195**

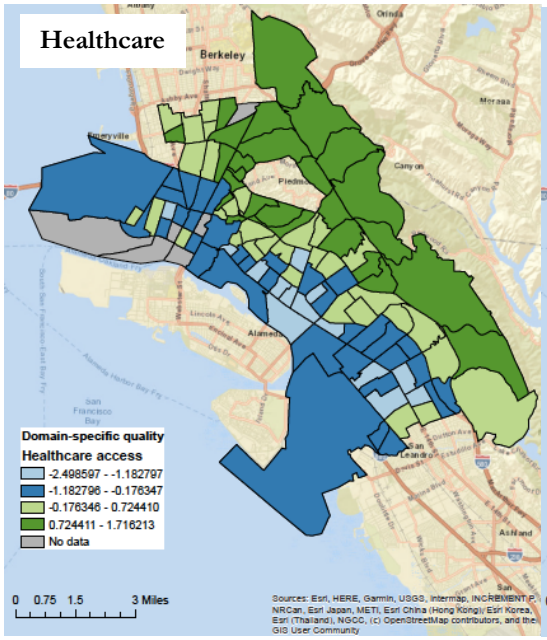
-Bolded values are statistically significant at p<0.05

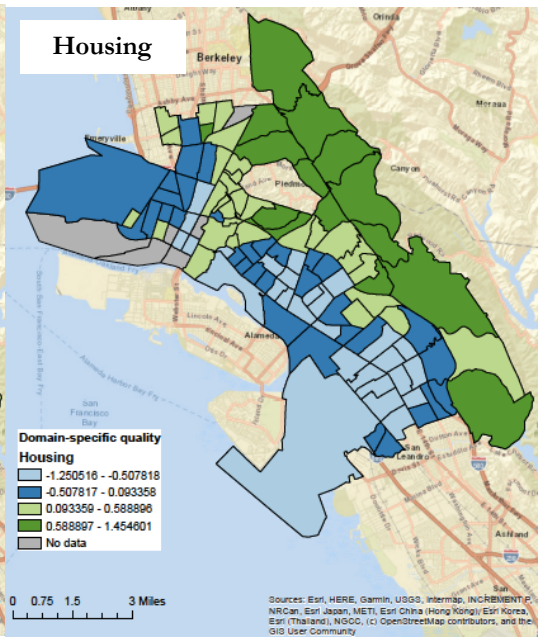
Appendix 1.D. Weights for HPI, with minimum weight of 0.05

Domain	Weight	Standard Error
Economic	0.08022676	0.06725188
Education	0.06042718	0.05993398
Healthcare	0.05988001	0.06101774
Housing	0.05313614	0.05757174
Neighborhood	0.05012408	0.05174359
Clean Environment	0.05047183	0.05201843
Social	0.11699075	0.06501947
Transportation	0.05705423	0.05713218

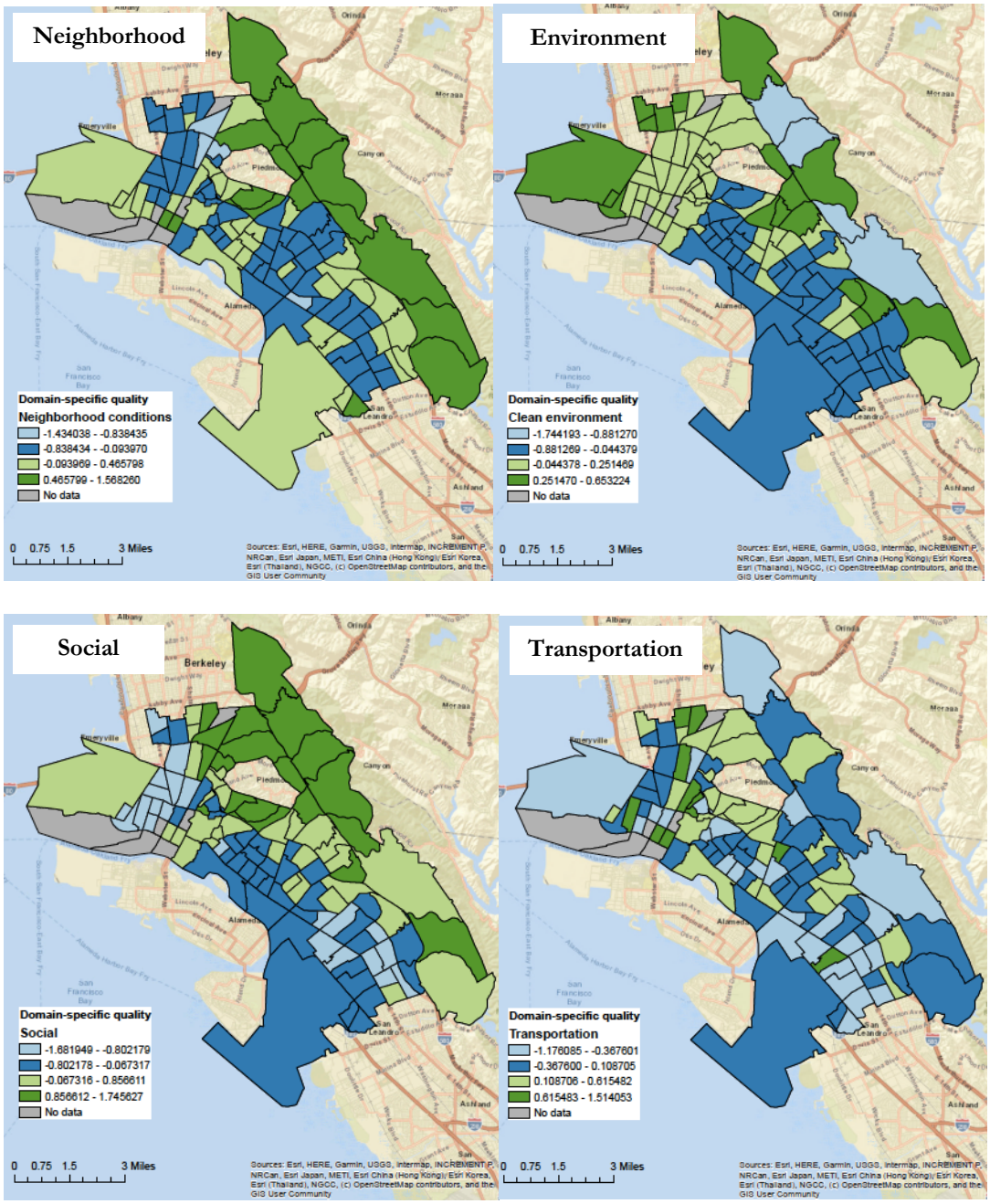
Appendix 1.E Maps of domain-based neighborhood quality across 107 Oakland census tracts







Appendix 1.E (cont)



Appendix 1.F. Relationship between neighborhood quality and preterm birth – Risk Ratios (RR) and 95% Confidence Intervals (CI) [Models 1 and 2A]

	Model 1			Model 2A		
	RR	**95% CI**		**RR**	**95% CI**	
HPI	**0.52**	**0.35**	**0.78**	**0.58**	**0.39**	**0.86**
Economic	**0.86**	**0.76**	**0.98**	0.90	0.79	1.02
Education	**0.84**	**0.74**	**0.96**	0.88	0.77	1.01
Healthcare Access	**0.83**	**0.75**	**0.91**	**0.85**	**0.77**	**0.94**
Housing	**0.79**	**0.66**	**0.95**	0.83	0.69	1.00
Neighborhood	0.92	0.72	1.17	0.94	0.75	1.20
Clean Environment	0.84	0.59	1.19	0.81	0.59	1.12
Social	**0.87**	**0.76**	**0.99**	0.90	0.79	1.03
Transportation	**0.82**	**0.68**	**1.00**	0.84	0.70	1.00

-Model 1: Crude GEE model for each individual domain
-Model 2A: Model 1 for each individual domain adjusting fro parity, nativity, age, educational attainment for age, and low-income status
-Bolded values are statistically significant at p<0.05

Appendix 2.A. Model 3 – Interaction terms for relationship between HPI-based neighborhood quality and preterm birth – Risk Ratios (RR), 95% Confidence Intervals (CI)

	RR	**95% CI**	
≤ 22 years old x HPI	0.82	0.32	2.12
30-34 years old x HPI	0.99	0.36	2.67
≥ 35 years old x HPI	0.55	0.22	1.36
Low education for age x HPI	0.57	0.17	1.98
High education for age x HPI	0.68	0.27	1.70
Foreign-born nativity x HPI	0.74	0.18	2.94
First live-born child x HPI	1.11	0.88	1.39
Low income status x HPI	1.20	0.57	2.53
WIC use x HPI	**2.62**	**1.24**	**5.53**
Unknown WIC use x HPI	1.81	0.28	11.54
Medi-Cal use x HPI	0.67	0.33	1.37

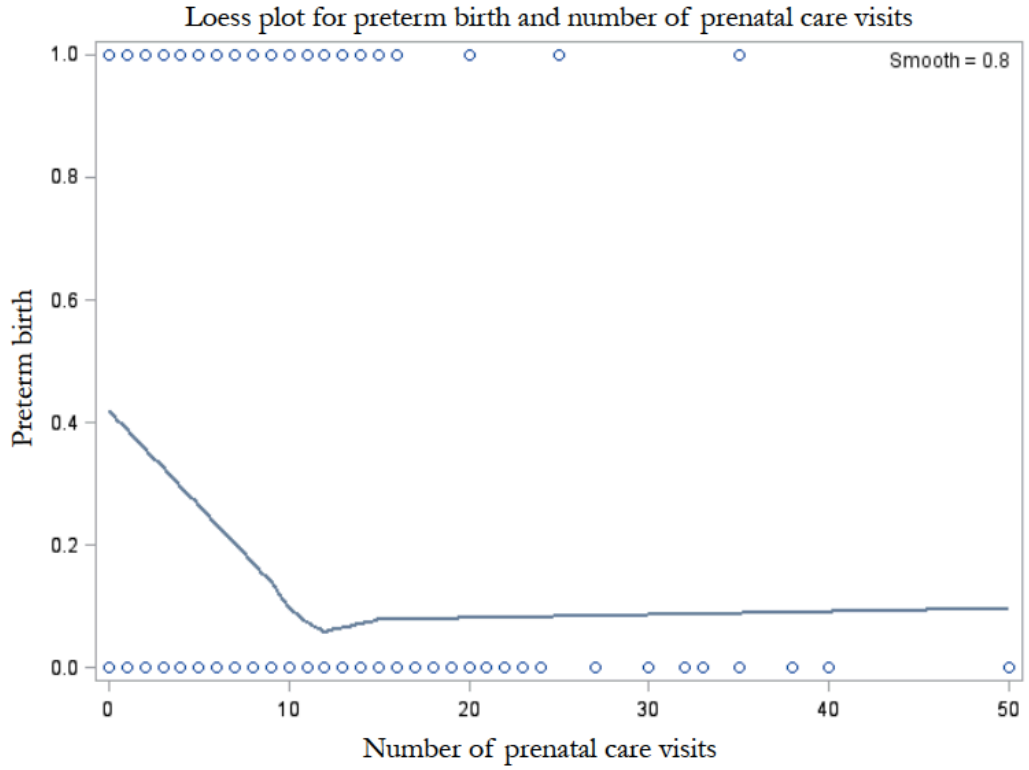
-Model 3: Interaction terms included for each potential effect modifier separately, controlling for parity, nativity age, educational attainment for age, and low-income status unless otherwise noted
-When testing for interaction with WIC, controlled for parity, nativity, age, educational attainment for age, and Medi-Cal
-When testing for interaction with Medi-Cal, controlled parity, nativity, age, educational attainment for age, and WIC
-Bolded values are significant at p<0.10

Appendix 2.B. Model 4 – Relationship between domain neighborhood quality and preterm birth stratified by WIC status–Risk Ratios (RR) and 95% Confidence Intervals (CI)

	WIC Use			No WIC Use			Unknown WIC Use^		
	RR	95% CI		RR	95% CI		RR	95% CI	
Economic	0.98	0.84	1.14	**0.84**	**0.70**	**1.02**	0.92	0.45	1.86
Education	0.99	0.82	1.19	**0.78**	**0.65**	**0.94**	0.69	0.33	1.45
Environment	0.82	0.55	1.21	0.82	0.55	1.22	0.91	0.22	3.77
Healthcare	0.93	0.81	1.07	**0.76**	**0.67**	**0.87**	0.80	0.49	1.31
Housing	0.91	0.73	1.15	**0.75**	**0.57**	**0.98**	0.88	0.30	2.63
Neighborhood	1.03	0.77	1.39	0.88	0.63	1.23	0.51	0.20	1.31
Social	1.00	0.84	1.20	**0.82**	**0.68**	**0.99**	0.69	0.37	1.26
Transportation	0.83	0.64	1.08	**0.78**	**0.61**	**1.00**	**1.87**	**0.92**	**3.81**

^Link logit GEE model used to generate odds ratios, interpreted as approximating risk ratios
-Model 4 run for each domain separately and includes all other covariates and Medi-Cal status
-Bolded values are statistically significant at p<0.10

Appendix 3.A. Crude relationship between risk of PTB and number of PNC visits



Appendix 3.B. Condition 1 (Model A) – Unadjusted relationship between neighborhood quality(HPI) and PTB, for total population and by WIC use – risk ratio(RR) and 95% confidence interval(CI)

	Total			WIC users			WIC non-users		
	RR	**95% CI**		**RR**	**95% CI**		**RR**	**95% CI**	
HPI[1]	0.51*	0.33	0.80	0.83	0.47	1.48	0.27*	0.14	0.53

1. Unadjusted link logit GEE model with exchangeable correlation structure
**p<0.05*

Appendix 3.C. Condition 2 – Crude relationship between neighborhood quality(HPI) and potential mediators, for total population and for WIC non-users – mean(M), standard deviation(SD), and p-value

	Total		WIC non-users	
	M(SD)	p-value	M(SD)	p-value
# PNC visits[2]				
<5	-0.19(0.20)	0.0057	-0.21(0.17)	<0.0001
5-11	-0.15(0.23)		-0.08(0.26)	
12-19	-0.13(0.24)		-0.06(0.27)	
20+	-0.15(0.23)		-0.11(0.24)	
PNC initiation[2]				
Adequate plus	-0.14(0.23)	0.0169	-0.06(0.27)	<0.0001
Adequate	-0.15(0.23)		-0.08(0.26)	
Intermediate	-0.18(0.21)		-0.16(0.19)	
Inadequate	-0.14(0.23)		-0.15(0.22)	
PNC received services				
Adequate plus	-0.15(0.23)	0.0184	-0.08(0.26)	<0.0001
Adequate	-0.14(0.23)		-0.06(0.26)	
Intermediate	-0.15(0.23)		-0.07(0.26)	
Inadequate	-0.19(0.21)		-0.21(0.18)	
APNCU[2]				
Adequate plus	-0.15(0.23)	0.0161	-0.08(0.26)	<0.0001
Adequate	-0.14(0.23)		-0.06(0.26)	
Intermediate	-0.14(0.23)		-0.06(0.27)	
Inadequate	-0.17(0.22)		-0.16(0.21)	

1. P-value from Cochran t-test to account for unequal variance

2. P-value from ANOVA F-test

Appendix 3.D. Condition 3 (Model B[1]) – Crude relationship between potential mediator and PTB, for total population and WIC non-users – risk ratio(RR) and 95% confidence interval(CI)

	Total			WIC non-users		
	RR	95% CI		RR	95% CI	
# PNC visits						
<5	6.96*	5.14	9.42	5.88*	3.61	9.58
5-11	1.80*	1.45	2.23	1.60*	1.14	2.26
12-19	Ref	--	--	Ref	--	--
20+	1.16	0.46	2.91	2.48	0.72	8.56
PNC initiation						
Adequate plus	1.29*	1.03	1.61	1.57*	1.12	2.20
Adequate	Ref	--	--	Ref	--	--
Intermediate	1.45	0.96	2.19	2.13*	1.03	4.39
Inadequate	2.18*	1.42	3.33	2.66*	1.44	4.93
PNC received services						
Adequate plus	7.40*	6.04	9.07	10.38*	7.09	15.19
Adequate	Ref	--	--	Ref	--	--
Intermediate	0.40*	0.28	0.57	0.70	0.41	1.19
Inadequate	3.97*	2.78	5.67	6.06*	3.53	10.40
APNCU						
Adequate plus	8.77*	7.02	10.96	11.55*	7.82	17.05
Adequate	Ref	--	--	Ref	--	--
Intermediate	0.40*	0.27	0.58	0.65	0.35	1.19
Inadequate	2.59*	1.95	3.44	4.08*	2.68	6.22

1. Unadjusted link logit GEE model with exchangeable correlation structure
**p<0.05 Ref: reference category*

Appendix 3.E. Model C – Assessment of effect modification of neighborhood quality(HPI) and PTB by potential mediators, by total population and WIC non-users

	Total p-value	**WIC non-users** p-value
HPI x <5 PNC visits	0.1848	0.1326
HPI x 5-11 PNC visits	0.7489	0.3572
HPI x 20+ PNC visits	0.0540*	0.0897*
HPI x adequate+ initiation	0.5359	0.3913
HPI x intermediate initiation	0.1248	0.0926*
HPI x inadequate initiation	0.7179	0.6143
HPI x adequate+ received services	0.7755	0.8919
HPI x intermediate received services	0.4692	0.4313
HPI x inadequate received services	0.6302	0.6541
HPI x adequate+ APNCU	0.6066	0.8137
HPI x intermediate APNCU	0.4503	0.4980
HPI x inadequate APNCU	0.2289	0.2909

All models are link logit GEE models with exchangeable correlation structure, including HPI, potential mediator, and interaction terms between HPI and potential mediators
**p<0.10*