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The Association Between Neighborhood Deprivation and Perinatal Cardiometabolic Outcomes, 2016 – 2019

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Bachelor of Science

University of Miami

2019

Thesis Committee Chair: Michael Kramer, PhD

An abstract of

A thesis submitted to the Faculty of the

Rollins School of Public Health of Emory University

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Abstract

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Background: Hypertensive disorders of pregnancy and gestational diabetes are leading contributors to mother and infant morbidity and mortality. Studies have indicated that neighborhood-level factors may increase the risk of developing a hypertensive disorder of pregnancy or gestational diabetes. This study investigated the effect of neighborhood deprivation on the odds of having a hypertensive disorder of pregnancy or gestational diabetes.

Methods: Data was obtained from the Georgia MCH Data Repository, which includes linked birth certificate data and publicly accessible Census data from 2016 – 2019 with neighborhood deprivation index (NDI) values. Logistic regress was performed using SAS procedures.

Results: The final dataset contained 350,369 observations. In the study population, 23,735 women (6.77%) had HDP, and 16,249 women (4.64%) had GD. The crude odds ratio for a 1 SD increase in NDI and HDP was 1.13 (95% CI: 1.12, 1.15) and 1.00 (95% CI: 0.98, 1.02) for a 1 SD increase in NDI and GD. There was significant statistical interaction on the multiplicative scale for NDI and maternal age. For HDP, at 18 years for maternal age, the aOR was 1.05 (95% CI: 1.02, 1.08), at 28 years, the aOR was 1.16 (95% CI: 1.14, 1.18), and at 38 years, the aOR was 1.28 (95% CI: 1.25, 1.32). For GD, at 18 years for maternal age, the aOR was 0.99 (95% CI: 0.94, 1.03), at 28 years, the aOR was 1.08 (95% CI: 1.06, 1.11), and at 38 years, the aOR was 1.19 (95% CI: 1.16, 1.23). No interaction was found by racial/ethnic groups or income.

Conclusion: High neighborhood deprivation is associated with increased odds of developing a hypertensive disorder of pregnancy or gestational diabetes, particularly among older women. Programs and interventions should be aimed at older women living in high deprivation neighborhoods.

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Literature Review

Summary

Perinatal cardiometabolic outcomes, such as hypertensive disorders of pregnancy (HDP) and gestational diabetes (GD), are associated with adverse birth outcomes and health issues that affect both the mother and child. For the mother, developing a hypertensive disorder of pregnancy and/or gestational diabetes during pregnancy has been linked to increased cardiovascular risk post-pregnancy, including metabolic syndrome, type 2 diabetes, cardiovascular disease, and more.[1-3] Additionally, there are adverse outcomes that impact the children of mothers who developed an HDP and/or GD during their pregnancy, such as preterm birth, fetal growth restriction, excessive or inadequate fetal development and growth, perinatal death, abnormal glucose metabolism, obesity, and other metabolic and cardiovascular morbidity as they grow.[4-6] Researchers have looked into possible factors that might increase the risk of HDP and GD to advise policy change and health recommendations to decrease the prevalence of these diseases.

Over the years, studies have shown that contextual environmental factors, such as the neighborhood environment, may play a part in shaping an individual's biological and behavioral risk factors, contributing to the variation of health outcomes in populations. Studies have shown that a neighborhood's environment can have a harmful effect on its residents' risks of mortality and morbidity, particularly neighborhood deprivation.[7-9]

One tool developed to aggregate data on neighborhoods' socioeconomic and demographic characteristics is the neighborhood deprivation index (NDI).[10] This index has been shown to be associated with an increased risk of adverse health and birth outcomes, including all-cause mortality, weight gain, preterm birth, and low birth weight.[10-13] Some studies have shown evidence that high deprivation in a neighborhood may compound the risk of cardiometabolic disease above individual-level and traditional cardiometabolic risk factors.[14, 15] Studies have shown that women who have a cardiometabolic disease before or during pregnancy, such as a hypertensive disorder of pregnancy or gestational diabetes, may be at an increased risk of adverse birth outcomes and pregnancy-related mortality and morbidity.[16-20] However, not much research has been done to investigate the effect of NDI on these perinatal cardiometabolic outcomes.

Perinatal Cardiometabolic Outcomes

Hypertensive Disorders of Pregnancy

Up to 15% of pregnancies in the United States are complicated by at least one hypertensive disorder of pregnancy (HDP), a leading contributor to infant and maternal morbidity and mortality.[21, 22] HDP can be classified into four categories: chronic hypertension, gestational hypertension, preeclampsia, and preeclampsia superimposed on chronic hypertension.[21, 22] Chronic hypertension is a debated addition, as chronic hypertension typically develops prior to pregnancy. Women who have had a pregnancy complicated by an HDP are at an up to 2-times increased risk of future cardiac disease, peripheral arterial disease, cerebrovascular disease, and even cardiovascular mortality, and a more than 2-times increased risk of developing type 2 diabetes mellitus.[3, 16, 23, 24] The offspring of women who developed an HDP have been shown to have increased of preterm birth, admittance to neonatal intensive care unit, increased all-cause mortality and morbidity, and more.[6, 25] Over the last decade, the association between HDP and maternal morbidity has continued to increase. However, maternal mortality from HDP has been on the decline.[26]

Research has shown that there are various health disparities related to HDP. A study conducted in Florida found that throughout the 10-year study period, African American women were consistently at a severe disadvantage when it came to HDP; when comparing non-African American women to African American women, they found the greatest disparities.[27] Similar findings can be found within studies conducted across the United States that show that women of color, particularly non-Hispanic black women, carry the highest burden of disease when looking at various HDP such as gestational hypertension and preeclampsia compared to non-Hispanic white women.[28-31]

Studies have shown that women who have a higher body mass index (obese or overweight), have a history of pregestational diabetes, or suffer from chronic hypertension are at an increased risk of developing a hypertensive disorder of pregnancy.[32] There has been evidence that suggests these risk factors are associated with socio-behavioral and neighborhood-level factors such as education level, neighborhood poverty, percentage of households on public assistance, access to supermarkets, access to healthcare, walkability scores, and percentage of green spaces available to residents.[33-38] Due to this, researchers have recently been interested in studying if these disparities might exist for women who experience an HDP. While evidence showing disparities have been found related to air- or noise- pollution, sociodemographic status, crime, and more, there is a lack of knowledge about how neighborhood deprivation as a composite might impact the risk of developing an HDP. [39-43]

Gestational Diabetes

Worldwide, the prevalence of gestational diabetes (GD) is widely varied, ranging from as small as 1% to greater than 30% in some countries, making it the most common pregnancy complication; in North America and the Caribbean, the median prevalence is 7%, with a range of 6.5-11.9%.[44] GD is diagnosed in women who develop hyperglycemia during pregnancy and have the issue resolved after giving birth. Women who have their pregnancies complicated by GD are at an increased risk of developing type 2 diabetes.[45] Studies have shown that there is a high risk for women to develop type 2 diabetes after GD, which can lead to a slew of other adverse outcomes long-term, and that their children are at an increased risk of cardiometabolic morbidity and mortality over the life course.[2, 4, 5]

Research has shown that there are various risk factors and health disparities linked to GD. One of the most well-documented risk factors for gestational diabetes is being overweight or obese before pregnancy.[44] When looking at race, Asian and Hispanic women are shown to carry the highest burden of GD compared to Non-Hispanic White women; however, Non-Hispanic Black women are shown to experience a higher burden than Non-Hispanic White women, as well.[46, 47] One metanalysis showed that observational studies looking at BMI and hypothyroidism showed convincing evidence for an association with GD.[48] Advanced maternal age, previous history of GD, family history of diabetes, and cigarette smoking during pregnancy are other strong predictors of GD.[45, 49] One observational study suggested that around 45% of GD cases could be prevented by incorporating some lifestyle changes like a healthy diet, avoiding smoking cigarettes, exercise, and maintaining a healthy weight.[44] A separate study showed that prenatal exercise reduced odds of developing GD (OR = 0.62, 95% CI = 0.52, 0.75).[50]

Similarly to HDP, lack of exercise, poor diet, and high BMI are all factors that have shown associations with various neighborhood-level and socio-behavioral factors such as education level, neighborhood poverty, percentage of households on public assistance, access to supermarkets, access to healthcare, walkability scores, and percentage of green spaces available to residents.[33-38] This has sparked interest in the impact that these neighborhood factors, as well as others such as air pollution, might have on GD.[51-54] Little research has been done to understand the direct impact of neighborhood deprivation as a whole on GD risk, but an existing study has shown no association using a different method of classifying neighborhood deprivation.[55]

Neighborhood Deprivation

Neighborhood contexts, such as social context (e.g., experiences of social capital, trust, unemployment, or interpersonal discrimination), the political/economic context (e.g., exclusionary zoning, location of social or health resources, income, education level, crime levels), and the physical/material context (e.g., houses for sale, amount of green space, walkability, living environment), are used to assess the how advantaged or disadvantaged a neighborhood is. Neighborhood deprivation is one specific domain of insufficient access or accumulation of material wealth.

Neighborhood Deprivation and Health

As interest in neighborhood deprivation has grown over the years, numerous studies have shown the adverse impact of high deprivation neighborhoods on health. So how might neighborhood deprivation be impacting health? Nancy Krieger coined a term called 'embodiment.' Embodiment is a concept that posits no aspect of our biology can be fully understood without knowledge of the unique ways we have experienced life socially, materially, and environmentally from conception to death.[56] This concept helps us understand how neighborhood environment might impact health and even compound on itself to have increased impact throughout life.

One mechanism for how neighborhood deprivation and health might be connected is through stress response pathways. Researchers have explored the relationship between neighborhood deprivation and cortisol. High stress leads to high cortisol levels that can contribute to inflammation. Barrington et al. looked at individual's perceptions of neighborhood association with cortisol reactivity found that neighborhood deprivation was associated with blunted cortisol reactivity only in women.[57] Roe et al. found that the presence of green space contributes to healthier cortisol levels in women; lower mean cortisol levels were associated with increased green space areas in women.[58] Another mechanism is through inflammatory response pathways. Inflammatory markers, such as interleukin 6 (IL-6) and C-reactive protein (CRP), have been suggested as possible cardiovascular risk factors.[59] Through the effects of neighborhood-level factors on behavioral factors, such as diet or exercise, neighborhood-level factors may be associated with inflammation and stress-related physiological processes, which may impact inflammatory processes.[60-62] Nazmi and colleagues examined the longitudinal relationships between neighborhood factors and interleukin 6 (IL-6) levels changes in adults over a three- to four-year period and found increases in IL-6 were associated with higher levels of neighborhood deprivation.[63] Petersen et al. found that as neighborhood socioeconomic status decreases, CRP and IL-6 levels increase.[64]

The most researched areas on neighborhood deprivation's association with health (outside of birth outcomes) include some of the leading causes of mortality in the United States: cancer, cardiovascular disease, and diabetes. A study done by Major et al. showed that participants living in neighborhoods of the highest deprivation had an overall increased risk for all-cause-, cancer-, and cardiovascular disease-mortality, even after adjusting for risk factors.[13] Li et al. (2015) conducted a study that found the odds of lung cancer in the two most deprived neighborhoods were more than 1.25 times the odds of the low deprivation neighborhood.[65] A study by Climie et al. found carotid arterial stiffness to be adversely associated with neighborhood deprivation in males but not females.[66] Two studies found a positive association between type 2 diabetes mellitus and high deprivation neighborhoods.[67, 68]

One known risk factor for all these diseases is being overweight. Powell-Wiley et al. found that individuals living in the highest deprived neighborhoods gained more weight over time than individuals living in the lowest deprived neighborhoods.[12]

Even when looking at specific populations, disparities exist. In a low-income population, Akwo et al. found that, above the risk of individual socioeconomic status and established risk factors, neighborhood deprivation increases the risk of heart failure.[14] Laraia et al. found that in a cohort of adults with type 2 diabetes mellitus (DM), indicators for cardiometabolic risk were associated with high-deprivation neighborhoods.[15] A study by Li et al. (2020) found similar findings; in a cohort of individuals with DM, researchers found increased incidence rates of heart failure among participants living in more deprived neighborhoods.[69]

Neighborhood Deprivation and Birth Outcomes

Research has shown that there is racial, spatial, and economic variation in perinatal outcomes, and many of the cardiometabolic outcomes outside of pregnancy are also related to adverse perinatal outcomes. In recent years, researchers have started to explore if the same relationships found in cardiometabolic outcomes outside of pregnancy are reflected when looking at adverse perinatal outcomes. Specifically, most studies have looked at the association between neighborhood deprivation and primarily preterm birth, followed by infant birth weight (small- or large-for-gestational-age) in a much smaller quantity.

Preterm birth is defined as a birth at less than 37-weeks' gestation. Studies have shown that an increased risk of preterm birth is significantly associated with high neighborhood deprivation.[10] This association persists across ethnic groups and after controlling for other well-known risk factors.[70-72] One study looking at infant birth weight and preterm birth found that a significant adverse association only remained for the most deprived neighborhoods and risk of small-for-gestational-age births after controlling for individual factors.[73] However, a few other studies have shown sustained associations between increased incidence of small- or large-for-gestational-age births and neighborhood deprivation after further adjusting their models.[11, 71]

Neighborhood Deprivation and Perinatal Cardiometabolic Outcomes

Despite the increasing literature linking neighborhood deprivation to adverse health behaviors and outcomes, few studies have been conducted to examine the impact of neighborhood built, social, and economic factors on HDP and GD.

Hu et al. found that neighborhood crime, neighborhood socioeconomic status, meteorological factors, and air pollution were all independently associated with HDP.[40] In New York, neighborhood poverty was found to have a relationship with rates of preeclampsia hospitalization, but only among Hispanic women.[74] Another study conducted in the United States analyzed hospitalizations related to HDP and found that the poorest zip codes had 26% higher preeclampsia/eclampsia rates when compared to the wealthiest zip codes.[75] Agyemang et al. found no association between neighborhood income or unemployment and gestational hypertension in the Netherlands.[76] One study by Vinikoor-Imler et al. (2011) found that gestational hypertension was significantly associated with neighborhood factors but varied according to race/ethnicity; among non-Hispanic White women, a significant inverse relationship was seen between neighborhood walkability and gestational hypertension.[77] Another study by

Vinikoor-Imler et al. (2012) found that even after adjusting for race/ethnic origin, age, smoking status, and parity, positive associations were found between neighborhood deprivation and gestational hypertension.

Fonge et al. found that women who live in an average, above average, or good food environment had a lower prevalence of gestational diabetes and type 2 diabetes.[51] A different study found that although crude rates of GD increased by 50% among those living in the least deprived neighborhoods compared to the most deprived neighborhoods, neighborhood deprivation had no significant association with GD when adjusting for other covariates.[55] Sampson and colleagues that women who live in the most materially impoverished neighborhoods have higher glucose challenge test results at gestational diabetes diagnosis.[52]

Standardized Neighborhood Deprivation Index

A neighborhood deprivation index developed by Messer et al. has been widely used over the past 15 years.[10] NDI is a validated composite that assesses five socioeconomic and demographic domains of a neighborhood using eight variables from the census: percentage of unemployed adults, percentage of adults without a high school diploma or GED, percentage of households receiving welfare, percentage of males in management and professional occupations, percentage of crowded housing (>1 person/room), percentage of households living below the poverty line, percentage of households with an annual income less than $30,000, and percentage of female-headed households with dependents. Studies have tested this method of assessing neighborhood deprivation proposed by Messer et al. in various cities, with numerous studies finding higher NDI to harm health.[7, 10, 70, 78]

Study Objectives

Given the evidence of the association between neighborhood-level factors and both HDP and GD and evidence supporting embodiment mechanisms such as stress response pathways and inflammation response pathways linking neighborhood deprivation with health outcomes, this analysis aims to investigate the effect of neighborhood deprivation on both HDP and GD by answering the following question:

Research Question: Are women living in high-deprivation Georgia neighborhoods more likely to experience a hypertensive disorder of pregnancy and/or gestational diabetes?

Through the following aims:

Aim 1: Investigate the association between neighborhood deprivation and hypertensive disorders of pregnancy and gestational diabetes for adult women who had a live singleton birth in Georgia from 2016-2019.

Hypothesis 1: High-deprivation neighborhoods will have a positive association with hypertensive disorder of pregnancy or gestational diabetes among Georgia women.

Aim 2: Investigate the association between neighborhood deprivation index and hypertensive disorder of pregnancy or gestational diabetes when stratified by interesting covariates such as race/ethnicity or maternal age.

Exploring these aims will make a positive contribution to the field of perinatal epidemiology. This analysis will aim to fill in gaps in the literature and serve as a basis for future hypotheses examining the effect of neighborhood factors on adverse pregnancy outcomes in the state of Georgia and throughout the United States. The findings from this thesis begin to provide information that can be used to develop better interventions aimed at reducing disease prevalence and understand mechanisms.

Methods

Study Design

This study is a cross-sectional multi-level study design nesting individual women's births in the context of their residential neighborhoods in the state of Georgia. Geocoded birth certificate vital records from the Georgia Maternal and Child Health Data Repository were linked to publicly accessible Census data using Census tract IDs. The exposure of interest is neighborhood deprivation index; this is measured using the standardized Neighborhood Deprivation Index developed by Messer and colleagues[10]. The outcomes of interest are hypertensive disorders of pregnancy (including pregnancy-induced hypertension, preeclampsia, and eclampsia) and gestational diabetes measured using birth certificate vital record data. Approval to access data from the Georgia Maternal and Child Health Data Repository was received from the Emory University Institutional Review Board.

Study Population

The study population of interest is women 18 years or older who had a singleton live birth between January 1st, 2016, and December 31st, 2018, in Georgia. This study uses birth certificate vital records data to measure the outcome variables of hypertensive disorders of pregnancy and gestational diabetes. A dataset containing information on births in Georgia between January 1st, 2016, and December 31st, 2019, was linked to a dataset containing neighborhood deprivation index information for the corresponding period.

Measures and Variables

Outcome Variables

The outcomes of interest are hypertensive disorders of pregnancy and gestational diabetes. These outcomes were obtained from Georgia birth certificate vital record data. If eclampsia or gestational hypertension was marked 'yes' under question 41 on the birth certificate, the mother was considered to have a hypertensive disorder of pregnancy. If gestational diabetes was marked 'yes' under question 41 on the birth certificate, the mother was considered to have gestational diabetes.

Exposure Variable

Neighborhood-level deprivation was the exposure of interest. It was quantified using the Neighborhood Deprivation Index (NDI) developed by Messer and colleagues.[10] The NDI is composed of eight different variables acquired from the American Community Survey that quantify neighborhood deprivation at the census-tract level: percent of males in management and professional occupations, percent of crowded housing, percent of households in poverty, percent of female-headed households with dependents, percent of households on public assistance and households earning less than $30,000 per year, percent earning less than a high school education, and percent unemployed.[10]

The NDI scores were standardized for each census tract in the state of Georgia. A score of 0 represents a tract with the 'average' amount of deprivation among all Georgia tracts. A score of -1 indicates a neighborhood deprivation score that is one standard deviation lower than the mean score for all census tracts in the state of Georgia, and a score of +1 indicates a neighborhood deprivation score that is one standard deviation higher than the mean score for all census tracts in the state of Georgia.

Causal Diagrams

The goal of this study is to estimate the effect of neighborhood deprivation on cardiometabolic outcomes during pregnancy. Neighborhood-level deprivation is the exposure of interest; the outcomes of interests are hypertensive disorders of pregnancy and gestational diabetes. Individual risk factors may confound an association between the exposure and outcome variables, or individual risk factors may act as modifiers or intermediate variables in the association. The analysis will account for confounding variables. The data from the birth certificate vital records data contains several potential confounding and intermediate covariates.

Figures 1 and 2 show DAGs for the association between the exposure, NDI, and the outcomes, HDP and GD, used to determine which factors may need to be adjusted or controlled for in the analysis model.

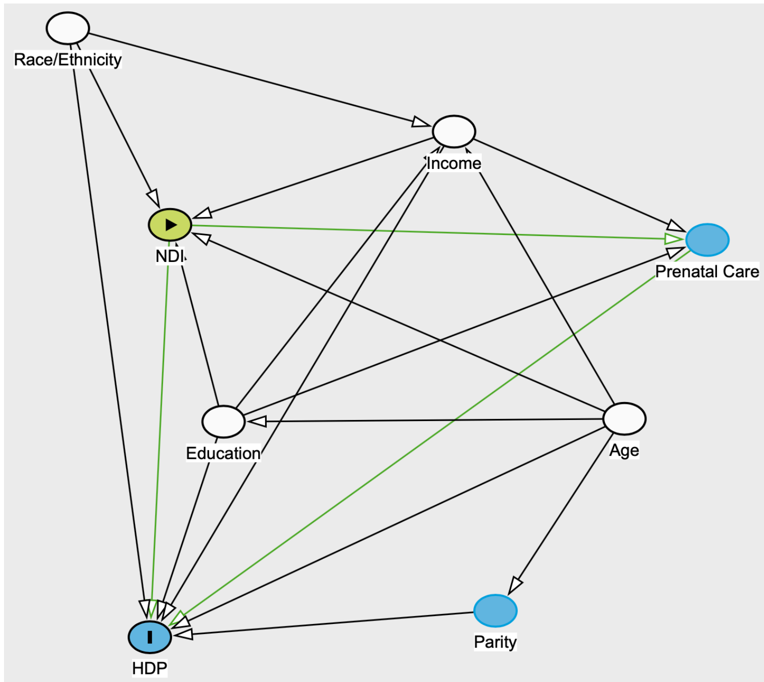


Figure 1. Conceptual Directed Acyclic Graph (DAG) with confounding of the association between NDI and HDP by race/ethnicity, age, income, and education. Parity and prenatal care are intermediate variables.

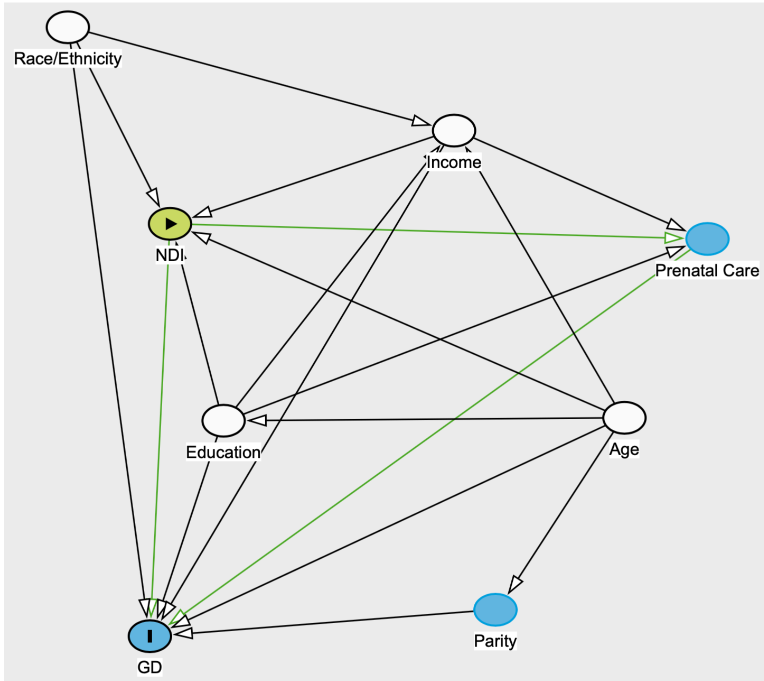


Figure 2. Conceptual Directed Acyclic Graph (DAG) with confounding of the association between NDI and GD by race/ethnicity, age, income, and education. Parity and prenatal care are intermediate variables.

Covariates

Maternal race/ethnicity, education, age, parity, income, and adequacy of prenatal care were included as potential effect modifiers or confounders based on information provided in the literature. All covariates are self-reported and obtained from the birth certificate.

On the birth certificate, mothers had fifteen categories for maternal race from which they could choose. For this study, we only included White and Black or African Americans. If unknown, maternal race data was set to missing. Maternal race information was missing for 0.48% (n = 1679) of the sample. On the birth certificate, mothers could indicate if they were of Hispanic origin or not. Maternal ethnicity data were missing for 0.99% (n = 3483) of the sample. Maternal race and ethnicity were combined to create a maternal race/ethnicity variable with three categories to use in analysis: non-Hispanic Black, non-Hispanic White, and Hispanic. Of the total Hispanic population, 92.1% (n = 45,674) of the population were White. Maternal race/ethnicity data was missing for 1.32% (n = 4628).

Maternal education was recorded as the last grade of formal education completed by the mother at the time of birth listed on the birth certificate. If unknown, maternal education was set to missing. For this study, maternal education is divided into four categories: less than 9th grade, 9th through 11th grade, High School/GED, and some college or higher. If unknown, maternal education data was set to missing. Maternal education data was missing for 0.64% (n = 2253) of the sample.

Maternal age was recorded as a continuous variable calculated from the mother's date of birth on the birth certificate. For tables 1 and 2, maternal age was separated into six categories: 18 – 19, 20 – 24, 25 – 29, 30 – 34, 35 – 39, and 40+. For the logistic regression models, maternal age was used as a continuous variable. There was no missing maternal age data in the sample.

Parity was recorded from the birth certificate as an indicator of how many previous births the mother had. If women were on their sixth birth or greater, they were combined into one variable: "sixth birth or greater." If unknown, parity was set to missing. Parity data was missing for 1.79% (n = 6276) of the sample.

Income was estimated using Medicaid enrollment as a proxy from the birth certificate. If Medicaid or Medicaid Managed Care was used for payment, we classified it as Medicaid for this study. All other options were classified as non-Medicaid. Income data was missing for 0.20% (n = 699) of the sample.

Adequacy of prenatal care is calculated based on gestational age at first prenatal appointment and gestational age at delivery, both obtained from the birth certificate, to generate the Kotelchuck Index. In prenatal care, it is assumed that the sooner one begins care, the better for the health of the mother and baby. The Kotelchuck Index has four levels: inadequate (received less than 50% of expected prenatal visits), intermediate (50% - 79%), adequate (80% - 109%), and adequate plus (110% or more).[79] If unknown, prenatal care data was set to missing. Prenatal care data was missing for 3.97% (n = 13905) of the sample.

Potential Interactions

Based on the literature, interactions between NDI and three covariates (income, age, and race/ethnicity) were hypothesized. Studies have shown that a deprived neighborhood environment does not have as detrimental an effect on wealthier individuals as it does on more impoverished individuals.[76, 80-82] Other literature have shown an interaction between neighborhood deprivation and both race/ethnicity and age in and out of the context of birth.[14, 27, 80, 83, 84]

Data Analysis

All analyses were performed using SAS 9.4. Descriptive statistics for the outcomes, exposure, and covariates were analyzed using PROC FREQ and PROC MEANS procedures. The PROC LOGISTIC procedure was used to perform logistic regression modeling for all relationships. A knowledge-based approach (e.g., prior literature, DAGs) was used to determine confounders. Collinearity assessment and interaction assessment were done to determine the best fitting models for both potential outcomes, HDP (women who had a hypertensive disorder of pregnancy = 1) and GD (women who had gestational diabetes = 1).

Collinearity is a regression diagnostic problem where one or more predictors in a model are highly correlated with other variables in a model. If there is perfect collinearity, the model will not run. When assessing collinearity, a model is fit with all confounding and interaction terms and condition indices (CIs), and variance decomposition proportions (VDPs) are calculated for the model. If the CI is greater than 30 AND there are at least two VDPs greater than 0.5, collinearity problems are indicated, and variables with the largest VDPs are dropped one at a time. In the case there are any interaction terms with collinearity, they will be dropped before covariates. After a variable is dropped, the model is re-run, and the remaining variables are reassessed for collinearity.

Following collinearity assessment, interaction assessment is initiated to assess the significance of the model and determine which interaction terms to keep in the model. First, a chunk test is conducted to assess the significance of all interaction terms at once, followed by backwards elimination using maximum likelihood estimation. If an interaction term has an insignificant likelihood ratio test, it is dropped from the model. The PROC PLM procedure and EFFECTPLOT statement are used next to assess how the effect of the exposure varies by each interaction term. If the plot suggests the interaction term is not qualitatively meaningful, the interaction term is dropped from the final model.

Results

Descriptive Statistics

The Georgia birth certificate vital record dataset contains births between January 1st, 2016, and December 31st, 2019, which had 525,691 observations. The dataset was then limited to births of women 18 and older and reduced to 517,523 observations. The dataset was further limited to only White and Black races and reduced to 478,960. After linking with the neighborhood deprivation information, the final study population was reduced to 350,369 observations due to missing geocode information for a portion of the sample. In the sample, 23,735 women had HDP, and 16,249 women had GD [Table 1].

The average NDI value for the study population was -0.097 (SE = 0.002). Women diagnosed with an HDP made up 6.8% of the study population, and women diagnosed with GD made up 4.6% of the study population. Non-Hispanic Black women diagnosed with HDP made up 2.78% of the study population, and Non-Hispanic Black women diagnosed with GD made up 1.55% of the study population. Non-Hispanic White women diagnosed with HDP made up 3.37% of the study population, and Non-Hispanic Black women diagnosed with GD made up 2.21% of the study population. Hispanic women diagnosed with HDP made up 0.56% of the study population, and Hispanic women diagnosed with GD made up 0.81% of the study population [Table 3]. The average maternal age was 28.4 (SE = 0.009), and most women in the study were in the 25-29 years old age group (30.2%). Non-Hispanic White women made up the largest portion of women (47.9%), and 86.9% of women had at least a high school education. Women who were delivering their first baby made up 36.7% of women in the study. The largest group of women had adequate plus prenatal care (39.1%), and a majority of women were not enrolled in a form of Medicaid (52.9%) [Table 1 and Table 2].

Among women living in the most deprived neighborhoods (fourth quartile) (N = 87,598), 7.6% of women were diagnosed with an HDP, and 4.6% were diagnosed with GD. The average maternal age was 27.0 years old (SE = 0.02), and the most populous age group was 25 – 29 years (31.5%). Non-Hispanic Black women made up a majority of this quartile (59.6%), and most women in this quartile had at least a high school education (78.9%). Women who were delivering their first baby made up 32.4% of the women in quartile four. About a third of women had adequate plus prenatal care (34.0%), and a majority of women were enrolled in a form of Medicaid (66.6%) [Table 1].

In the third quartile (medium to high deprived neighborhoods) (N = 87,601), 7.1% of women were diagnosed with an HDP, and 4.7% were diagnosed with GD. The average maternal age was 27.6 years old (SE = 0.02), and the most populous age group was 25 – 29 years (31.3%). Non-Hispanic White women were the largest group of this quartile (43.3%), and most women in this quartile had at least a high school education (84.2%). Women who were delivering their first baby made up 36.6% of the women in quartile three. More than a third of women had adequate plus prenatal care (38.7%), and a majority of women were enrolled in a form of Medicaid (54.1%) [Table 1].

In the low to medium deprived neighborhoods (second quartile) (N = 87,570), 6.7% of women were diagnosed with an HDP, and 4.8% were diagnosed with GD. The average maternal age was 28.4 years old (SE = 0.02), and the most populous age group was 25 – 29 years (31.3%). Non-Hispanic White women made up a majority of this quartile (55.9%), and a large majority of women in this quartile had at least a high school education (89.1%). Women who were delivering their first baby made up 38.5% of the women in quartile two. More than a third of women had adequate plus prenatal care (41.3%), and a majority of women were not enrolled in a form of Medicaid (56.3%) [Table 1].

Among women living in the least deprived neighborhood (first quartile) (N = 87,600), 5.6% of women were diagnosed with an HDP, and 4.4% were diagnosed with GD. The average maternal age was 30.5 years old (SE = 0.02), and the most populous age group was 30 – 34 years (28.8%). Non-Hispanic White women made up a majority of this quartile (68.8%), and a large majority of women in this quartile had at least a high school education (95.4%). Women who were delivering their first baby made up 39.3% of the women in quartile one. More than a third of women had adequate plus prenatal care (42.5%), and a majority of women were not enrolled in a form of Medicaid (76.3%) [Table 1].

Among women who had an HDP, the average NDI value was 0.0005 (SE = 0.005), and the largest group of women lived in the most deprived neighborhoods (28.2%). The average maternal age was 28.6 (SE = 0.04), and the largest age group of women was the 25-29 years old age group (30.2%). Non-Hispanic White women made up the largest portion of women with an HDP (49.7%), and 89.0% of women with an HDP had at least a high school education. Women who were delivering their first baby made up 46.2% of women with an HDP. A majority of women with an HDP had adequate plus prenatal care (55.5%), and a slight majority of women were not enrolled in a form of Medicaid (50.8%) [Table 2].

Among women who had GD, the average NDI value was -0.097 (SE = 0.007), and the largest group of women lived in the low to medium deprived neighborhoods (25.8%). The average maternal age was 30.8 (SE = 0.05), and the largest age group of women was the 25-29 years old age group (26.7%). Non-Hispanic White women made up the largest portion of women with GD (47.7%), and 86.6% of women with GD had at least a high school education. Women who were delivering their first baby made up 32.3% of women with GD. Most women with GD had adequate plus prenatal care (54.0%), and a majority of women were not enrolled in a form of Medicaid (56.2%) [Table 2].

Model Results

The crude model for the relationship between NDI and HDP suggests that the odds of having an HDP increases as neighborhood deprivation increases (OR = 1.13, 95% CI: 1.12, 1.15) [Table 4]. No evidence of collinearity was found for the full model adjusting for age, race/ethnicity, education, income, NDI*age, NDI*race/ethnicity, and NDI*income. A chunk test was performed showing that the interaction terms were significant (DF = 3, LR = 108.76, P-value < .0001). Backwards elimination of the interaction terms was conducted and resulted in both the interaction between NDI and age and NDI and income being retained. After assessing the plots for each interaction term, the plots for the interaction between NDI and age were the only ones that were qualitatively meaningful. The interaction between NDI and income was dropped from the model, and the plots were reassessed for the final model containing all confounders and the interaction term for NDI and age [Figure 3]. Among women who were 18 years old, a one standard deviation increase in neighborhood deprivation was associated with an odds ratio of having an HDP of 1.02 (95% CI: 0.99, 1.05) [Table 5]. This value is not statistically significant, and the odds ratio is almost exactly 1, suggesting there is no association between NDI and HDP among 18-year-olds. Among women who were 28 years old, a one standard deviation increase in neighborhood deprivation was associated with an odds ratio of having an HDP of 1.12 (95% CI: 1.10, 1.14) [Table 5]. Among women who were 38 years old, a one standard deviation increase in neighborhood deprivation was associated with an odds of having an HDP of 1.23 (95% CI: 1.20, 1.27) [Table 5].

The crude model for the relationship between NDI and GD produced an odds ratio of 1.001 (95% CI: 0.98, 1.02), suggesting no association between NDI and GD under the unadjusted model [Table 4]. No evidence of collinearity was found for the full model adjusting for age, race/ethnicity, education, income, NDI*age, NDI*race/ethnicity, and NDI*income. A chunk test was performed showing that the interaction terms were significant (DF = 3, LR = 129.62, P-value < .0001). Backwards elimination of the interaction terms was conducted and resulted in all the interaction terms being retained. After assessing the plots for each interaction term, the plots for the interaction between NDI and age were the only ones that were qualitatively meaningful. The interactions between NDI and income and NDI and race/ethnicity were dropped from the model, and the plots were reassessed for the final model containing all confounders and the interaction term for NDI and age [Figure 4]. Among women who were 18 years old, a one standard deviation increase in neighborhood deprivation was associated with an odds of having GD of 0.99 (95% CI: 0.95, 1.03) [Table 5]. This value is not statistically significant, and the odds ratio is almost exactly 1, suggesting there is no association between NDI and GD among 18-year-olds. Among women who were 28 years old, a one standard deviation increase in neighborhood deprivation was associated with an odds of having GD of 1.09 (95% CI: 1.06, 1.11) [Table 5]. Among women who were 38 years old, a one standard deviation increase in neighborhood deprivation was associated with an odds of having GD of 1.19 (95% CI: 1.16, 1.23) [Table 5].

Model Fit

Maximum Likelihood Ratio test statistics were used to assess the fit of the final models for both outcomes. The model of the association between neighborhood deprivation and HDP, controlling for age, race/ethnicity, education, income, and including the interaction term NDI*age was significant (LR = 55.83, $p < .0001$), indicating this final model had a good fit. The model of the association between neighborhood deprivation and GD, controlling for age, race/ethnicity, education, income, and including the interaction term NDI*age, was significant (LR = 37.27, $p < .0001$), indicating this final model had a good fit.

Discussion

This analysis suggests that living in a neighborhood with higher levels of neighborhood deprivation is significantly associated with increased odds of HDP for the crude model. The crude odds ratio for the relationship between neighborhood deprivation and GD was essentially 1, suggesting no association was seen for the unadjusted model. After adjustment for race/ethnicity, age, education, income, and NDI*age, the analysis suggests that as age increases, the effect of NDI seems to have a stronger effect on HDP and GD. These findings lend support to the weathering hypothesis, which hypothesizes that rather than stress or neighborhood deprivation being an incidental point-in-time exposure, the accumulation of chronic exposure to factors over the life course accelerates the decline of health outcomes, such that we see the effect of the exposure more impactful for older women than younger women.[85] This may help explain some of the disparities seen in various health conditions, including perinatal outcomes, such as the ones analyzed in this study.

Studies have shown that non-Hispanic Black women carry the highest disease burden when looking at various health outcomes, including HDP and GD.[29, 31, 46] Surprisingly, our findings did not support this in Georgia. Non-Hispanic White women had a higher prevalence of both HDP and GD when compared to Non-Hispanic Black women, 3.37% vs. 2.78% and 2.21% vs. 1.55%, respectively. Unlike other studies that have looked at how race plays a role in neighborhood-level factors' association with perinatal outcomes, the findings of this study did not support any evidence of interaction by race in Georgia. A study conducted in Florida found that African Americans face a significant disadvantage in HDP, with significant spatial variation.[27] A separate study in Miami-Dade, Florida by Winter supported this, showing Non-Hispanic Black women's odds of having an HDP was 1.25 times the odds of Non-Hispanic White women.[86] This study did find racial/ethnic disparity in exposure to neighborhood deprivation. Most of the women living in the most deprived neighborhoods were Non-Hispanic Black, and a majority of the women living in the least deprived neighborhoods were Non-Hispanic White. These findings align with what the literature has shown: Non-Hispanic Black women are disproportionately exposed to higher deprivation.[87, 88]

Overall, for HDP, the findings of this analysis suggest a significant association with NDI for the unadjusted model and significant associations with NDI when controlling for age, race/ethnicity, education, and income at three age points: 18, 28, and 38 years. This suggests that neighborhood deprivation does impact the risk of developing an HDP during pregnancy. For GD, significant associations with NDI were seen for the model adjusted for age, race/ethnicity, education, and income at only two age points: 28 and 38 years. The odds ratios for the unadjusted model and the adjusted model at the 18-year age point were both essentially one and not significant. Stressors of living in poverty, being unemployed, inadequate housing, or any other factors could all contribute to increased cortisol and inflammatory biomarkers that could lead to these adverse outcomes.

Strengths and Limitation

This study contributes to a growing body of research on the effects of neighborhood deprivation on adverse perinatal outcomes. The use of Georgia birth certificate data provides a strength to the study in that the study sample was able to be large and population-based. It provides an almost complete count of all births occurring in Georgia; however, the data also has significant limitations. Compared to medical records, there is wide variation in the data quality due to underreporting, misreporting, and recall bias due to self-reported items.[89] Additionally, when using geocoded addresses, a portion of women are dropped from the sample due to being un-geocoded. Certain women may be more likely not to have their addresses linked due to certain characteristics, and this could indicate selection bias. Of the women who fit the study criteria, 26.8% could not be geocoded and subsequently were dropped from the study.

The cross-sectional design of this study creates an additional area of weakness for the study. Because the exposure and outcomes variables are only considered at one point in time, a temporal relationship cannot be assessed between the variables. As a result, there is no way to make causal inference or establish a true causal relationship between the exposure and outcome, making it difficult to draw conclusions. This study also has some limitations in the way income was measured using Medicaid enrollment as a proxy. Not all women considered "low-income" are guaranteed to be enrolled in Medicaid. In order to qualify for Medicaid in Georgia, household income is generally at or below the cutoff, which is currently at 133% of the federal poverty line. Therefore, women who have an income that would be considered low in this economy, but miss this cutoff, would not be captured in this analysis as low-income. Women might also only qualify for Medicaid during their pregnancy if their income exceeds the income limits for full Medicaid coverage but is below the state's income cutoff for this program. If this is the case, it will not give an accurate estimate of their income level pre-pregnancy.

Public Health Implications and Future Directions

After consideration of strengths and limitations, there are recommendations for future research and interventions on this topic. This analysis suggests that neighborhood-level factors affect HDP and GD during pregnancy, particularly for older women, due to the accumulation of these effects over the life course. Moving forward, when developing programs and interventions, it is important to focus on older women living in the most deprived neighborhoods. Additionally, policymakers should focus on implementing policies aimed at improving disadvantaged neighborhoods across the state of Georgia to limit the impact of a deprived neighborhood on women's health over time.

Future researchers on this subject matter should utilize a prospective population-based longitudinal study to find a more accurate measure of the association between perinatal outcomes and NDI and other neighborhood- and individual-level factors over periods of time. Researchers may also be interested in seeing how moving to a more or less deprived area might impact perinatal health. Finally, future research might also find benefit in assessing more interactions to specifically target populations in need.

In conclusion, there is evidence of a significant association between NDI and HDP for the unadjusted model, and when looking at the model adjusting for age, race/ethnicity, income, and education, this effect grows stronger as age increases. There is also evidence of a significant association between NDI and GD when controlling for age, race/ethnicity, income, and education, but only for older women in the study. The association was not significant for the unadjusted model or when looking at the adjusted model when the age is 18.

References

1. Gunderson EP, Sun B, Catov JM, et al. Gestational diabetes history and glucose tolerance after pregnancy associated with coronary artery calcium in women during midlife: the CARDIA study. *Circulation.* 2021;143(10):974-987.

2. Burlina S, Dalfrà M, Chilelli N, Lapolla A. Gestational diabetes mellitus and future cardiovascular risk: an update. *International journal of endocrinology.* 2016;2016.

3. Melchiorre K, Thilaganathan B, Giorgione V, Ridder A, Memmo A, Khalil A. Hypertensive disorders of pregnancy and future cardiovascular health. *Frontiers in cardiovascular medicine.* 2020;7:59.

4. Sibai BM, Ross MG. Hypertension in gestational diabetes mellitus: pathophysiology and long-term consequences. *The Journal of Maternal-Fetal & Neonatal Medicine.* 2010;23(3):229-233.

5. Metzger BE. Long-term outcomes in mothers diagnosed with gestational diabetes mellitus and their offspring. *Clinical obstetrics and gynecology.* 2007;50(4):972-979.

6. Hollegaard B, Lykke JA, Boomsma JJ. Time from preeclampsia diagnosis to delivery affects future health prospects of children. *Evolution, medicine, and public health.* 2017;2017(1):53-66.

7. Headen I, Mujahid M, Deardorff J, Rehkopf DH, Abrams B. Associations between cumulative neighborhood deprivation, long-term mobility trajectories, and gestational weight gain. *Health Place.* Jul 2018;52:101-109.

8. Messer LC, Kaufman JS, Dole N, Savitz DA, Laraia BA. Neighborhood crime, deprivation, and preterm birth. *Ann Epidemiol.* Jun 2006;16(6):455-462.

9. Cubbin C, Sundquist K, Ahlén H, Johansson S-E, Winkleby MA, Sundquist J. Neighborhood deprivation and cardiovascular disease risk factors: protective and harmful effects. *Scandinavian journal of public health.* 2006:228-237.

10. Messer LC, Laraia BA, Kaufman JS, et al. The development of a standardized neighborhood deprivation index. *J Urban Health.* Nov 2006;83(6):1041-1062.

11. Wentz AE, Messer LC, Nguyen T, Boone-Heinonen J. Small and large size for gestational age and neighborhood deprivation measured within increasing proximity to homes. *Health Place.* Nov 2014;30:98-106.

12. Powell-Wiley TM, Ayers C, Agyemang P, et al. Neighborhood-level socioeconomic deprivation predicts weight gain in a multi-ethnic population: longitudinal data from the Dallas Heart Study. *Preventive medicine.* 2014;66:22-27.

13. Major JM, Doubeni CA, Freedman ND, et al. Neighborhood socioeconomic deprivation and mortality: NIH-AARP diet and health study. *PloS one.* 2010;5(11):e15538.

14. Akwo EA, Kabagambe EK, Harrell FE, et al. Neighborhood Deprivation Predicts Heart Failure Risk in a Low-Income Population of Blacks and Whites in the Southeastern United States. *Circulation: Cardiovascular Quality and Outcomes.* 2018;11(1):e004052.

15. Laraia BA, Karter AJ, Warton EM, Schillinger D, Moffet HH, Adler N. Place matters: neighborhood deprivation and cardiometabolic risk factors in the Diabetes Study of Northern California (DISTANCE). *Social science & medicine.* 2012;74(7):1082-1090.

16. Wu R, Wang T, Gu R, et al. Hypertensive Disorders of Pregnancy and Risk of Cardiovascular Disease-Related Morbidity and Mortality: A Systematic Review and Meta-Analysis. *Cardiology.* 2020;145(10):633-647.

17. Creanga AA, Syverson C, Seed K, Callaghan WM. Pregnancy-related mortality in the United States, 2011–2013. *Obstetrics and gynecology.* 2017;130(2):366.

18. Kramer CK, Campbell S, Retnakaran R. Gestational diabetes and the risk of cardiovascular disease in women: a systematic review and meta-analysis. *Diabetologia.* Jun 2019;62(6):905-914.

19. Ukah UV, Bayrampour H, Sabr Y, et al. Association between gestational weight gain and severe adverse birth outcomes in Washington State, US: A population-based retrospective cohort study, 2004-2013. *PLoS Med.* Dec 2019;16(12):e1003009.

20. Santos S, Voerman E, Amiano P, et al. Impact of maternal body mass index and gestational weight gain on pregnancy complications: an individual participant data meta-analysis of European, North American and Australian cohorts. *Bjog.* Jul 2019;126(8):984-995.

21. Obstetricians ACo, Gynecologists. Gestational hypertension and preeclampsia: ACOG Practice Bulletin, number 222. *Obstetrics and gynecology.* 2020;135(6):e237-e260.

22. Shah S, Gupta A. Hypertensive Disorders of Pregnancy. *Cardiol Clin.* Aug 2019;37(3):345-354.

23. McDonald SD, Malinowski A, Zhou Q, Yusuf S, Devereaux PJ. Cardiovascular sequelae of preeclampsia/eclampsia: a systematic review and meta-analyses. *American heart journal.* 2008;156(5):918-930.

24. Wu P, Kwok CS, Haththotuwa R, et al. Pre-eclampsia is associated with a twofold increase in diabetes: a systematic review and meta-analysis. *Diabetologia.* 2016;59(12):2518-2526.

25. Antza C, Cifkova R, Kotsis V. Hypertensive complications of pregnancy: a clinical overview. *Metabolism.* 2018;86:102-111.

26. Grobman WA, Bailit JL, Rice MM, et al. Frequency of and factors associated with severe maternal morbidity. *Obstet Gynecol.* Apr 2014;123(4):804-810.

27. Hu H, Xiao H, Zheng Y, Yu BB. A Bayesian spatio-temporal analysis on racial disparities in hypertensive disorders of pregnancy in Florida, 2005-2014. *Spat Spatiotemporal Epidemiol.* Jun 2019;29:43-50.

28. Ying W, Catov JM, Ouyang P. Hypertensive disorders of pregnancy and future maternal cardiovascular risk. *Journal of the American Heart Association.* 2018;7(17):e009382.

29. Grobman WA, Parker CB, Willinger M, et al. Racial disparities in adverse pregnancy outcomes and psychosocial stress. *Obstetrics and gynecology.* 2018;131(2):328.

30. Breathett K, Muhlestein D, Foraker R, Gulati M. Differences in preeclampsia rates between African American and Caucasian women: trends from the National Hospital Discharge Survey. *Journal of women's health.* 2014;23(11):886-893.

31. Miranda ML, Swamy GK, Edwards S, Maxson P, Gelfand A, James S. Disparities in maternal hypertension and pregnancy outcomes: evidence from North Carolina, 1994–2003. *Public Health Reports.* 2010;125(4):579-587.

32. Jeyabalan A. Epidemiology of preeclampsia: impact of obesity. *Nutrition reviews.* 2013;71(suppl_1):S18-S25.

33. Claudel SE, Adu-Brimpong J, Banks A, et al. Association between neighborhood-level socioeconomic deprivation and incident hypertension: A longitudinal analysis of data from the Dallas heart study. *American heart journal.* 2018;204:109-118.

34. Sarkar C, Webster C, Gallacher J. Neighbourhood walkability and incidence of hypertension: Findings from the study of 429,334 UK Biobank participants. *International journal of hygiene and environmental health.* 2018;221(3):458-468.

35. Pantell MS, Prather AA, Downing JM, Gordon NP, Adler NE. Association of Social and Behavioral Risk Factors With Earlier Onset of Adult Hypertension and Diabetes. *JAMA network open.* 2019;2(5):e193933-e193933.

36. Moreira TC, Polizel JL, Santos IdS, et al. Green spaces, land cover, street trees and hypertension in the megacity of São Paulo. *International journal of environmental research and public health.* 2020;17(3):725.

37. Dzhambov AM, Markevych I, Lercher P. Greenspace seems protective of both high and low blood pressure among residents of an Alpine valley. *Environment international.* 2018;121:443-452.

38. Müller G, Harhoff R, Rahe C, Berger K. Inner-city green space and its association with body mass index and prevalent type 2 diabetes: a cross-sectional study in an urban German city. *BMJ open.* 2018;8(1):e019062.

39. Sears CG, Braun JM, Ryan PH, et al. The association of traffic-related air and noise pollution with maternal blood pressure and hypertensive disorders of pregnancy in the HOME study cohort. *Environment international.* 2018;121:574-581.

40. Hu H, Zhao J, Savitz DA, Prosperi M, Zheng Y, Pearson TA. An external exposome-wide association study of hypertensive disorders of pregnancy. *Environment International.* 2020;141:105797.

41. Mayne SL, Pool LR, Grobman WA, Kershaw KN. Associations of neighbourhood crime with adverse pregnancy outcomes among women in Chicago: analysis of electronic health records from 2009 to 2013. *J Epidemiol Community Health.* 2018;72(3):230-236.

42. Mayne SL, Pellissier BF, Kershaw KN. Neighborhood Physical Disorder and Adverse Pregnancy Outcomes among Women in Chicago: a Cross-Sectional

Analysis of Electronic Health Record Data. *J Urban Health.* Dec 2019;96(6):823-834.

43. Mayne SL, Yellayi D, Pool LR, Grobman WA, Kershaw KN. Racial Residential Segregation and Hypertensive Disorder of Pregnancy Among Women in Chicago: Analysis of Electronic Health Record Data. *Am J Hypertens.* Oct 15 2018;31(11):1221-1227.

44. McIntyre HD, Catalano P, Zhang C, Desoye G, Mathiesen ER, Damm P. Gestational diabetes mellitus. *Nat Rev Dis Primers.* Jul 11 2019;5(1):47.

45. Szmuilowicz ED, Josefson JL, Metzger BE. Gestational Diabetes Mellitus. *Endocrinol Metab Clin North Am.* Sep 2019;48(3):479-493.

46. Hunsberger M, Rosenberg KD, Donatelle RJ. Racial/ethnic disparities in gestational diabetes mellitus: findings from a population-based survey. *Women's Health Issues.* 2010;20(5):323-328.

47. Hedderson M, Ehrlich S, Sridhar S, Darbinian J, Moore S, Ferrara A. Racial/ethnic disparities in the prevalence of gestational diabetes mellitus by BMI. *Diabetes care.* 2012;35(7):1492-1498.

48. Giannakou K, Evangelou E, Yiallouros P, et al. Risk factors for gestational diabetes: An umbrella review of meta-analyses of observational studies. *PloS one.* 2019;14(4):e0215372.

49. Lin P-C, Hung C-H, Chan T-F, Lin K-C, Hsu Y-Y, Tzeng Y-L. The risk factors for gestational diabetes mellitus: A retrospective study. *Midwifery.* 2016;42:16-20.

50. Davenport MH, Ruchat S-M, Poitras VJ, et al. Prenatal exercise for the prevention of gestational diabetes mellitus and hypertensive disorders of pregnancy: a systematic review and meta-analysis. *British journal of sports medicine.* 2018;52(21):1367-1375.

51. Fonge YN, Jain VD, Harrison C, Brooks M, Sciscione AC. Examining the relationship between food environment and gestational diabetes. *American Journal of Obstetrics & Gynecology MFM.* 2020;2(4):100204.

52. Sampson L, Dasgupta K, Ross N. The association between sociodemographic marginalization and plasma glucose levels at diagnosis of gestational diabetes. *Diabetic medicine.* 2014;31(12):1563-1567.

53. Choe S-A, Eliot MN, Savitz DA, Wellenius GA. Ambient air pollution during pregnancy and risk of gestational diabetes in New York City. *Environmental research.* 2019;175:414-420.

54. Liao J, Chen X, Xu S, et al. Effect of residential exposure to green space on maternal blood glucose levels, impaired glucose tolerance, and gestational diabetes mellitus. *Environmental research.* 2019;176:108526.

55. Janghorbani M, Stenhouse E, Jones R, Millward B. Is neighbourhood deprivation a risk factor for gestational diabetes mellitus? *Diabetic medicine.* 2006;23(3):313-317.

56. Krieger N. Embodiment: a conceptual glossary for epidemiology. *Journal of Epidemiology & Community Health.* 2005;59(5):350-355.

57. Barrington WE, Stafford M, Hamer M, Beresford SA, Koepsell T, Steptoe A. Neighborhood socioeconomic deprivation, perceived neighborhood factors, and cortisol responses to induced stress among healthy adults. *Health & place.* 2014;27:120-126.

58. Roe JJ, Thompson CW, Aspinall PA, et al. Green space and stress: evidence from cortisol measures in deprived urban communities. *International journal of environmental research and public health.* 2013;10(9):4086-4103.

59. Willerson JT, Ridker PM. Inflammation as a cardiovascular risk factor. *Circulation.* 2004;109(21_suppl_1):II-2-II-10.

60. Roux A-VD. Neighborhoods and health: where are we and were do we go from here? *Revue d'epidemiologie et de sante publique.* 2007;55(1):13-21.

61. McDade TW, Hawkley LC, Cacioppo JT. Psychosocial and behavioral predictors of inflammation in middle-aged and older adults: the Chicago health, aging, and social relations study. *Psychosomatic medicine.* 2006;68(3):376-381.

62. Ranjit N, Diez-Roux AV, Shea S, et al. Psychosocial factors and inflammation in the multi-ethnic study of atherosclerosis. *Archives of Internal Medicine.* 2007;167(2):174-181.

63. Nazmi A, Roux AD, Ranjit N, Seeman TE, Jenny NS. Cross-sectional and longitudinal associations of neighborhood characteristics with inflammatory markers: findings from the multi-ethnic study of atherosclerosis. *Health & place.* 2010;16(6):1104-1112.

64. Petersen KL, Marsland AL, Flory J, Votruba-Drzal E, Muldoon MF, Manuck SB. Community socioeconomic status is associated with circulating interleukin-6 and C-reactive protein. *Psychosomatic medicine.* 2008;70(6):646-652.

65. Li X, Sundquist J, Zöller B, Sundquist K. Neighborhood deprivation and lung cancer incidence and mortality: a multi-level analysis from Sweden. *Journal of thoracic oncology.* 2015;10(2):256-263.

66. Climie RE, Boutouyrie P, Perier M-C, et al. individual and neighborhood deprivation and carotid stiffness: the Paris Prospective Study III. *Hypertension.* 2019;73(6):1185-1194.

67. Mezuk B, Chaikiat Å, Li X, Sundquist J, Kendler KS, Sundquist K. Depression, neighborhood deprivation and risk of type 2 diabetes. *Health & place.* 2013;23:63-69.

68. Zhang X, Chen X, Gong W. Type 2 diabetes mellitus and neighborhood deprivation index: A spatial analysis in Zhejiang, China. *Journal of diabetes investigation.* 2019;10(2):272-282.

69. Li X, Sundquist J, Forsberg P-O, Sundquist K. Association Between Neighborhood Deprivation and Heart Failure Among Patients With Diabetes Mellitus: A 10-Year Follow-Up Study in Sweden. *Journal of Cardiac Failure.* 2020;26(3):193-199.

70. O'Campo P, Burke JG, Culhane J, et al. Neighborhood deprivation and preterm birth among non-Hispanic Black and White women in eight geographic areas in the United States. *Am J Epidemiol.* Jan 15 2008;167(2):155-163.

71. Janevic T, Stein CR, Savitz DA, Kaufman JS, Mason SM, Herring AH. Neighborhood deprivation and adverse birth outcomes among diverse ethnic groups. *Ann Epidemiol.* Jun 2010;20(6):445-451.

72. Ma X, Fleischer NL, Liu J, Hardin JW, Zhao G, Liese AD. Neighborhood deprivation and preterm birth: an application of propensity score matching. *Ann Epidemiol.* Feb 2015;25(2):120-125.

73. Hesselman S, Wikström AK, Skalkidou A, Sundström-Poromaa I, Wikman A. Neighborhood deprivation and adverse perinatal outcomes in Sweden: A population-based register study. *Acta Obstet Gynecol Scand.* Aug 2019;98(8):1004-1013.

74. Tanaka M, Jaamaa G, Kaiser M, et al. Racial disparity in hypertensive disorders of pregnancy in New York State: a 10-year longitudinal population-based study. *Am J Public Health.* Jan 2007;97(1):163-170.

75. Fingar KR, Mabry-Hernandez I, Ngo-Metzger Q, Wolff T, Steiner CA, Elixhauser A. Delivery hospitalizations involving preeclampsia and eclampsia, 2005–2014: statistical brief# 222. 2017.

76. Agyemang C, Vrijkotte T, Droomers M, Van der Wal M, Bonsel G, Stronks K. The effect of neighbourhood income and deprivation on pregnancy outcomes in Amsterdam, The Netherlands. *Journal of Epidemiology & Community Health.* 2009;63(9):755-760.

77. Vinikoor-Imler L, Messer L, Evenson K, Laraia B. Neighborhood conditions are associated with maternal health behaviors and pregnancy outcomes. *Social science & medicine.* 2011;73(9):1302-1311.

78. Cubbin C, Marchi K, Lin M, et al. Is neighborhood deprivation independently associated with maternal and infant health? Evidence from Florida and Washington. *Matern Child Health J.* Jan 2008;12(1):61-74.

79. Health NJDo. The Kotelchuck Index. Available at: https://www-doh.state.nj.us/doh-shad/query/Kotelchuck.html. Accessed 07/13/2021.

80. Diez Roux AV. Investigating neighborhood and area effects on health. *American journal of public health.* 2001;91(11):1783-1789.

81. Diez Roux AV, Mair C. Neighborhoods and health. 2010.

82. Mouratidis K. Neighborhood characteristics, neighborhood satisfaction, and well-being: The links with neighborhood deprivation. *Land Use Policy.* 2020;99:104886.

83. Pearl M, Braveman P, Abrams B. The relationship of neighborhood socioeconomic characteristics to birthweight among 5 ethnic groups in California. *American journal of public health.* 2001;91(11):1808-1814.

84. Chambers BD, Baer RJ, McLemore MR, Jelliffe-Pawlowski LL. Using index of concentration at the extremes as indicators of structural racism to evaluate the association with preterm birth and infant mortality—California, 2011–2012. *Journal of Urban Health.* 2019;96(2):159-170.

85. Forde AT, Crookes DM, Suglia SF, Demmer RT. The weathering hypothesis as an explanation for racial disparities in health: a systematic review. *Annals of epidemiology.* 2019;33:1-18. e13.

86. Winter KM. Elucidating the Role of Neighborhood Deprivation in Hypertensive Disorders of Pregnancy. 2018.

87. Laraia BA, Messer L, Kaufman JS, et al. Direct observation of neighborhood attributes in an urban area of the US south: characterizing the social context of pregnancy. *International journal of health geographics.* 2006;5(1):1-11.

88. Williams DR, Collins C. Racial residential segregation: a fundamental cause of racial disparities in health. *Public health reports.* 2016.

89. DiGiuseppe DL, Aron DC, Ranbom L, Harper DL, Rosenthal GE. Reliability of birth certificate data: a multi-hospital comparison to medical records information. *Maternal and child health journal.* 2002;6(3):169-179.

Tables and Figures

Table 1. Demographics of study sample and distribution by hypertensive disorders of pregnancy and gestational diabetes

	Total (N = 350,369)		HDP (N = 23,735)		GD (N = 16,249)	
Individual Characteristics	*N*	*%/Mean (SE)*	*N*	*%/Mean (SE)*	*N*	*%/Mean (SE)*
NDI Continuous	350369	-0.097 (0.002)	23735	0.0005 (0.005)	16249	-0.097 (0.007)
NDI Quartiles						
Q1 - least deprived	87600	25	4941	20.82	3870	23.82
Q2	87570	24.99	5883	24.79	4198	25.84
Q3	87601	25	6218	26.2	4118	25.34
Q4 - most deprived	87598	25	6693	28.2	4063	25.0
Maternal Age Continuous	350369	28.38 (0.009)	23735	28.55 (0.038)	16249	30.82 (0.045)
Maternal Age Groups						
18 - 19	16559	4.73	1150	4.85	270	1.66
20 - 24	82472	23.54	5430	22.88	2158	13.28
25 - 29	105803	30.2	7156	30.15	4333	26.67
30 - 34	75135	21.44	4931	20.78	3992	24.57
35 - 39	45087	12.87	3180	13.4	3503	21.56
40+	25313	7.22	1888	7.95	1993	12.27

Maternal Race/Ethnicity						
Hispanic	49618	14.16	1963	8.27	2834	17.44
Non-Hispanic Black	128365	36.64	9747	41.07	5443	33.5
Non-Hispanic White	167758	47.88	11795	49.69	7746	47.67
Maternal Education						
< 9th Grade	11572	3.3	473	1.99	716	4.41
9th - 11th Grade	32099	9.16	2006	8.45	1379	8.49
High School	110365	31.5	7670	32.32	4742	29.18
Some College or Higher	194080	55.39	13456	56.69	9324	57.38
Parity						
First Birth	128573	36.7	10958	46.17	5251	32.32
Second Birth	105672	30.16	5665	23.87	4734	29.13
Third Birth	61134	17.45	3323	14	3081	18.96
Fourth Birth	28051	8.01	1570	6.61	1582	9.74
Fifth Birth	11621	3.32	716	3.02	703	4.33
Sixth Birth or greater	9042	2.58	632	2.66	498	3.06
Method of Payment						
Medicaid	164476	46.94	11660	49.13	7106	43.73
Non-Medicaid	185194	52.86	12056	50.79	9132	56.2
Adequacy of Prenatal Care						
Inadequate	63400	18.1	3777	15.91	2287	14.07

Intermediate	23084	6.59	984	4.15	692	4.26
Adequate	112914	32.23	4922	20.74	3926	24.16
Adequate Plus	137066	39.12	13183	55.54	8780	54.03

Table 2. Demographics of study sample and prevalence of outcomes by Neighborhood Deprivation Index quartiles

	Total (N = 350,369)		Q1: Lowest NDI | Least Deprived (N = 87,600)		Q2: Low-Med NDI (N = 87,570)		Q3: Med-High NDI (N = 87,601)		Q4: High NDI | Most Deprived (N = 87,598)	
Individual Characteristics	*N*	*%/Mean (SE)*	*N*	*%/Mean (SE)*	*N*	*%/Mean (SE)*	*N*	*%/Mean (SE)*	*N*	*%/Mean (SE)*
Outcome										
HDP	23735	6.77	4941	5.64	5883	6.72	6218	7.1	6693	7.64
GD	16249	4.64	3870	4.42	4198	4.79	4118	4.7	4063	4.64
Maternal Age Continuous	350369	28.38 (0.009)	87600	30.54 (0.018)	87570	28.35 (0.019)	87601	27.62 (0.019)	87598	27.02 (0.019)
Maternal Age Groups										
18 - 19	16559	4.73	1773	2.02	3846	4.39	4987	5.69	5953	6.8
20 - 24	82472	23.54	10904	12.45	20542	23.46	24120	27.53	26906	30.72
25 - 29	105803	30.2	23349	26.65	27401	31.29	27449	31.33	27604	31.51
30 - 34	75135	21.44	25253	28.83	18936	21.62	16348	18.66	14598	16.66
35 - 39	45087	12.87	16842	19.23	10762	12.29	9380	10.71	8103	9.25
40+	25313	7.22	9479	10.82	6083	6.95	5317	6.07	4434	5.06

Maternal Race/Ethnicity										
Hispanic	49618	14.16	9043	10.32	12278	14.02	14526	16.58	13771	15.72
Non-Hispanic Black	128365	36.64	17022	19.43	25133	28.7	33968	38.78	52242	59.64
Non-Hispanic White	167758	47.88	60222	68.75	48920	55.86	37965	43.34	20651	23.57
Maternal Education										
< 9th Grade	11572	3.3	902	1.03	2217	2.53	3709	4.23	4744	5.42
9th - 11th Grade	32099	9.16	2671	3.05	6754	7.71	9572	10.93	13102	14.96
High School	110365	31.5	15323	17.49	26806	30.61	31661	36.14	36575	41.75
Some College or Higher	194080	55.39	68254	77.92	51259	58.53	42065	48.02	32502	37.1
Parity										
First Birth	128573	36.7	34462	39.34	33685	38.47	32031	36.56	28395	32.42
Second Birth	105672	30.16	29254	33.39	26725	30.52	25461	29.06	24232	27.66
Third Birth	61134	17.45	15075	16.07	14940	17.06	15631	17.84	16488	18.82
Fourth Birth	28051	8.01	5168	5.9	6472	7.39	7436	8.49	8975	10.25
Fifth Birth	11621	3.32	1800	2.05	2507	2.86	3105	3.54	4209	4.8
Sixth Birth or greater	9042	2.58	1094	1.25	1757	2.01	2434	2.78	3757	4.29
Method of Payment										
Medicaid	164476	46.94	20565	23.48	38135	43.55	47407	54.12	58369	66.63
Non-Medicaid	185194	52.86	66819	76.28	49258	56.25	40029	45.69	29088	33.21
Adequacy of Prenatal Care										
Inadequate	63400	18.1	9276	10.59	14017	16.01	17621	20.12	22486	25.67

Intermediate	23084	6.59	5068	5.79	5385	6.15	5909	6.75	6722	7.67
Adequate	112914	32.23	32443	37.04	28362	32.39	26881	30.69	25228	28.8
Adequate Plus	137066	39.12	37199	42.46	36136	41.27	33910	38.71	29821	34.04

Table 3. Prevalence of outcomes by racial group

	Total (N = 350,369)	
Outcome	*N*	*%*
Non-Hispanic Black with HDP	9747	*2.78%*
Non-Hispanic Black with GD	5443	*1.55%*
Non-Hispanic White with HDP	11795	*3.37%*
Non-Hispanic White with GD	7746	*2.21%*
Hispanic with HDP	1963	*0.56%*
Hispanic with GD	2834	*0.81%*

Table 4. The association between 1 SD increase in NDI and outcomes for crude models

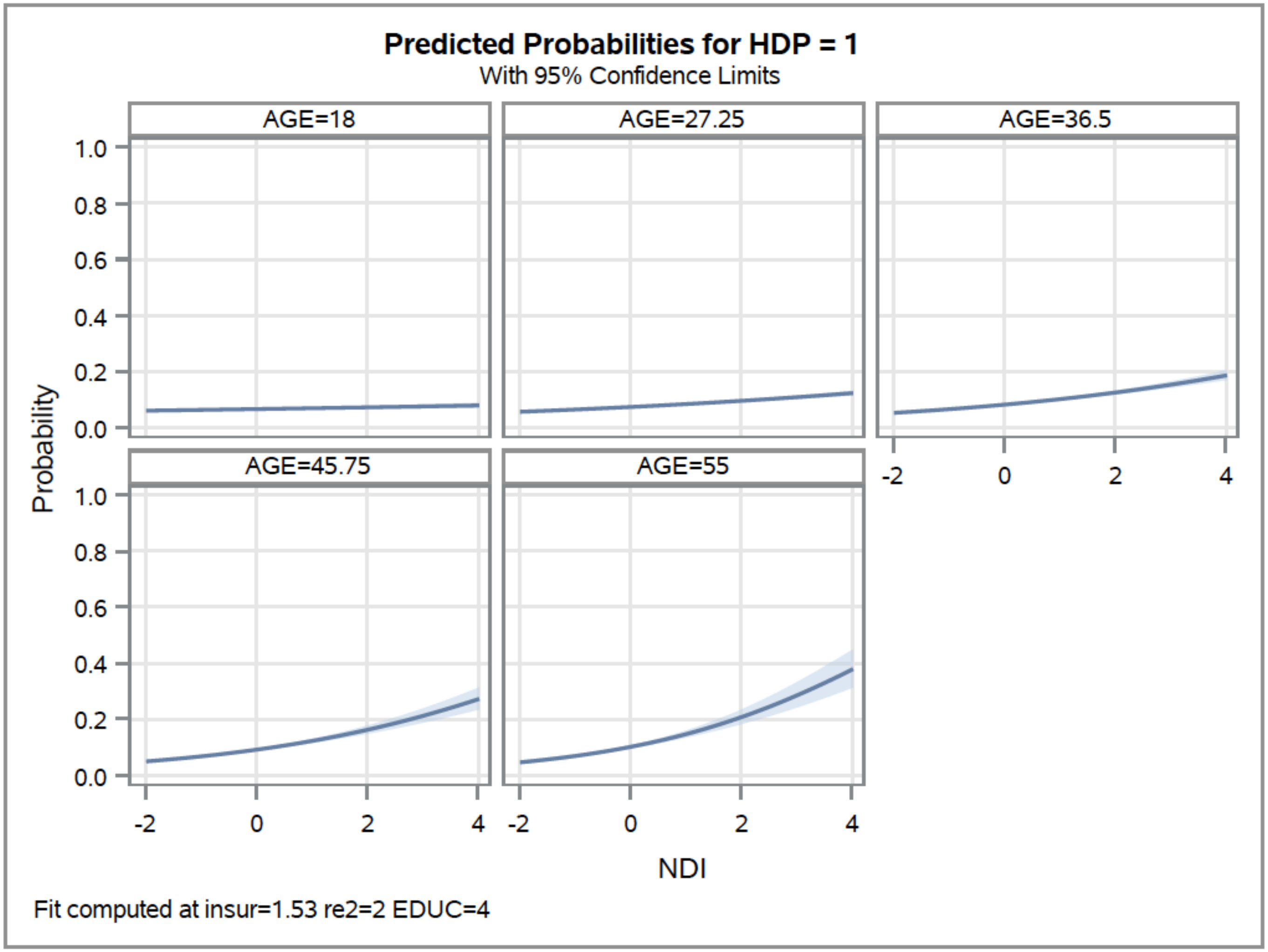
Outcome	*Odds Ratio (95% CI)*
Hypertensive Disorders of Pregnancy	1.132 (1.116, 1.149)
Gestational Diabetes	1.001 (0.983, 1.019)

Table 5. Odds ratio estimates for association between 1 SD increase in NDI and outcomes for adjusted models with interaction between NDI and age

Outcome	*Interaction Group*	*Odds Ratio (95% CI)*
HDP	18 Years Old	1.05 (1.02, 1.08)
	28 Years Old	1.16 (1.14, 1.18)
	38 Years Old	1.28 (1.25, 1.32)
GD	18 Years Old	0.99 (0.94, 1.03)
	28 Years Old	1.08 (1.06, 1.11)
	38 Years Old	1.19 (1.16, 1.23)

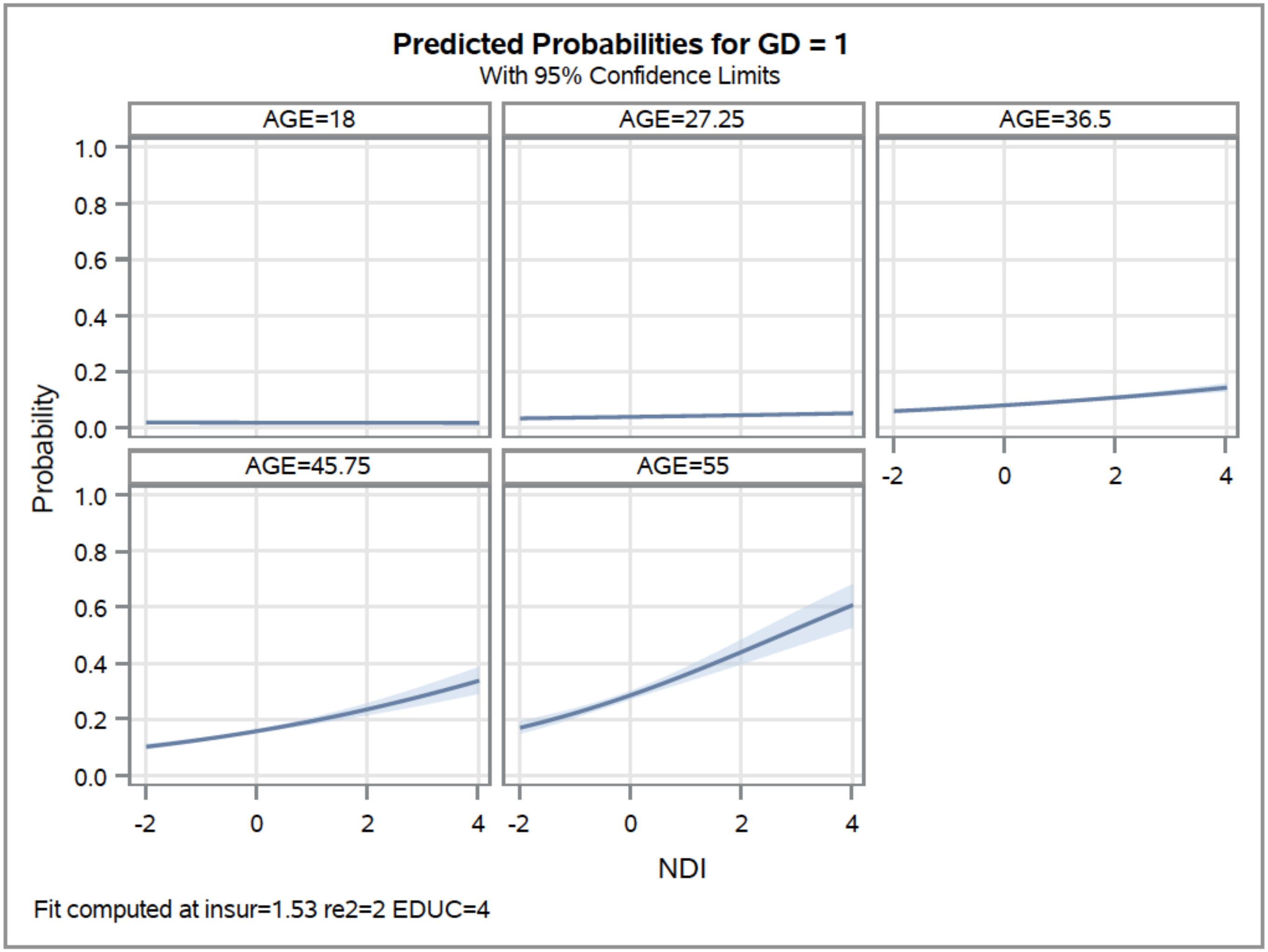
*Adjusted for Age, Race/Ethnicity, Income, Education, and NDI*Age

Figure 3. Probability Plots for the Effect of Age on the Association Between NDI and HDP



*Model adjusted for Age, Race/Ethnicity, Income, Education, and NDI*Age

Figure 4. Probability Plots for the Effect of Age on the Association Between NDI and GD



*Model adjusted for Age, Race/Ethnicity, Income, Education, and NDI*Age