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Investigating the association between small-area
violent crime and preterm birth in Atlanta, GA: 1998-2006

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Master of Science in Public Health

Global Epidemiology

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2008

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

Investigating the association between small-area
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By Lauren Messina

Background: Preterm birth causes considerable morbidity and mortality among children in the United States, but the risk of preterm birth is not fully explained by individual maternal risk factors. There is some evidence that living in a high crime neighborhood may contribute to an increased risk of preterm birth.

Methods: We used multilevel logistic regression to investigate the association between both census tract and census block group violent crime rate on the probability of preterm birth, controlling for potential individual and neighborhood-level confounders. We restricted our analysis to births within the City of Atlanta, GA in the years 1998-2006.

Results: Preterm births comprised 13.1% of 50,665 births in Atlanta. Violent crime rates at the block group level showed statistically significant interaction with maternal age. The odds of preterm birth among women in the highest two violent crime quartiles were increased compared to women in the lowest violent crime quartile among women 30 years and older; there was no association between living in the highest block group crime quartiles and preterm birth compared to living in the lowest crime quartile among women younger than 30. There was no significant interaction between tract-level violent crime and age category; all women living in any but the lowest crime quartile showed an increased odds of preterm birth compared to women living in the lowest crime quartile.

Discussion: There is evidence of an association between living in a high-crime area and an increased risk of preterm birth, when considering violent crime rate at either the block group scale or the tract scale.

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Introduction

In the United States, 12.7% of all births and 11.0% of singleton births were preterm (before the 37th week of gestation) in 2007, and the rate of preterm birth has increased 31% since 1981.(1) This increase in preterm births is due, in part, to an increasing number of births as the result of medical interventions to protect the health of the mother or baby. (2)

Infants that are born before they are fully developed suffer considerable morbidity and mortality during infancy and early childhood. Preterm birth and its associated complications accounts for 34.3% of infant mortality in the United States and an estimated 12% of all mortality in children under 5 years old worldwide.(3, 4) In general, the risk of death is highest among the most preterm infants and the probability of a neonate surviving increases with every additional week of gestation.(5)

Compared to full-term neonates, near-term infants born between 32 and 36 weeks gestation have higher rates of temperature instability, hypoglycemia, respiratory distress, and jaundice early in infancy. (6) Nearly half (45.7%) of infants born between 30 and 34 weeks gestation require supplemental oxygen in order to breathe.(7) Additionally, preterm infants spend a considerably longer amount of time in the hospital compared to term infants, contributing to high healthcare costs; the total duration of hospital admissions for infants born at <28 and at 28 to 31 gestational weeks is 85 and 16 times that for term infants, respectively.(8)

Longer term, preterm birth is associated with considerable challenges for children later in life. About one quarter of children who were born prematurely suffer from neuro-developmental impairments such as cerebral palsy, mental retardation, or auditory or visual deficits later in life. Though children born at all gestational ages, including children born at term, can suffer from these impairments, the rates of disease are highest in the children born at the earliest gestational ages.(9) Additionally, even among those infants without disability, longer gestational periods are associated with higher likelihoods of high educational achievement and high incomes (10).

Though very preterm infants experience the greatest burden of morbidity and mortality, nearly 75% of preterm infants are born between the 34th and 37th weeks and are therefore considered "late preterm" (2). Even though the absolute risks of morbidity and mortality in these infants are lower compared to the risks in early preterm infants, their large number represents a considerable burden of death and disability.

Various risk factors are consistently associated with an increased risk of preterm birth, including maternal characteristics such as advanced age, low BMI, low socio-economic status, periodontal disease, and prior preterm birth.(11) In addition, there is considerable racial disparity in preterm birth: the risk of preterm birth among black women in the United States 2007 was 18.3%, while the risk among white women the same year was 11.5% (1). This disparity of preterm birth between races cannot be fully explained by controlling for demographic confounders alone.

Residential environment is hypothesized to systematically pattern risk and exposures; the characteristics of the neighborhood in which a mother lives may contribute to adverse birth outcomes (12, 13). Meta-analysis has shown a consistent, moderate association between lower income in a mother's neighborhood and an increased odds of low birth weight (14). Additionally, maternal racial residential segregation is associated with an increased risk of giving birth to a low birth weight infant (15). Neighborhood social support also may be important; Buka et al found that higher levels of perceived social support were associated with higher birth weights among white women in Chicago (16).

Chronic stress is considered a potential risk factor for preterm birth; there is evidence that high levels of stress before and during pregnancy are associated with preterm birth. The effect of stress on preterm birth may be mediated by biological or behavioral mechanisms (12, 17). There are several theorized, potential biological mechanisms for how stress may lead to preterm birth. Maternal stress may affect immune function, thereby increasing susceptibility to infection or increasing the immune reaction to an existing infection; certain infections are associated with pre-term delivery (17-19). Alternatively, maternal stress may induce a greater or premature activation of the maternal or fetal endocrine system that is associated with labor (19).

Violent crime in a person's neighborhood can be a considerable source of stress and contributor to poor health. Exposure to high rates of violent crime in one's neighborhood may lead to a number of adverse health outcomes including lower levels of physical activity and increases in coronary artery disease, psychological distress, and depression. (20-22)

Though there is reason to believe that violent crime as a cause of maternal stress during pregnancy may be an important contributor to preterm birth, there is limited evidence to support this hypothesis. There is mixed evidence regarding the association between small-area violent crime and preterm birth. Messer et al found that maternal exposure to higher rates of community violence was associated with higher odds of preterm birth in both unadjusted and adjusted models.(23) However, Masi et al found that the association between neighborhood violent crime and preterm birth found in a multilevel, multivariable model disappeared when economic disadvantage was controlled for as an additional confounder.(24) There is, however, evidence that living in an area with high crime is associated with an increased risk of giving birth to an infant of low birth weight, either on an absolute scale or relative to gestational age: Masi et al found that violent crime was strongly associated with small for gestational age and, to a lesser extent, with lower birth weight (25).

Crime such as rape/sexual assault, robbery, assault, and murder are categorized as violent crime. (26) Property crimes such as burglary decreased by almost one third (32.6%) nationwide in the period from 1998 to 2007, but violent crime decreased an even more substantial portion: 43.4% nationwide from 1998 to 2007.(26) A decrease in violent crime in Atlanta mirrors the national trend; in Atlanta, violent crime fell from 3047 crimes per 100,000 residents in 1998 to 1624 crimes per 100,000 residents in 2007, a difference of 46.7%. (27) However, the rate of violent crime in Atlanta remains elevated compared to the rest of the country; in 2009, Atlanta had 2.7 times more violent crime than the national average.(28)

People identifying as black made up 31.4% of Georgia's population and 53.4% of Atlanta's population in 2010.(29, 30) Accordingly, the risk of preterm birth in Georgia is generally higher than the national average: 13.9% in 2007, compared to 12.7% nationally. (1)

This analysis aims to assess the association between violent crime and preterm birth in the City of Atlanta. Using multilevel logistic regression, we estimate the association between violent crime rates at both the census tract and census block group levels in the year preceding and including a woman's pregnancy with the probability of preterm birth.

Methods

Data

Birth data was extracted from Georgia birth certificates between the years 1998 and 2006. The analysis was limited to live, singleton births born to mothers residing within the boundary of the City of Atlanta, Georgia at the time of birth. Infants born before 20 weeks gestation or with a birth weight below 500g were excluded from analysis. Additionally, we excluded those infants whose mothers lived in a census block group or census tract without crime data. A total of 54,036 births were eligible.

For this analysis, infants born before the 37th week of gestation are considered preterm and infants born in the 37th week or later are considered term. Gestational age was estimated from the mother's last menstrual period. The mother's residential address is recorded on the birth certificate and subsequently geocoded to the block group by the Georgia Office of Health Indicators for Planning (OHIP) of the Department of Public Health.

Violent crime in this analysis is any instance of homicide, rape, assault, or robbery reported within the city of Atlanta, Georgia between the years of 1997 and 2006. Crime data was provided by the Atlanta Police Department as a count of crime events occurring within each block group or tract during each year. Crimes were pooled into overlapping 2-year crime rates (e.g. 1997-1998, 1998-1999, 1999-2000, etc.) by dividing the sum of the crimes in a block group over a given two year period by the population of that block group as determined from the 2000 U.S. Census. Because many block groups have few violent crimes, these rates can be statistically unstable. In order to stabilize rates which may be extreme due to small event numbers we applied a spatial smoothing algorithm using GeoDa© software (31). Spatial smoothing borrows statistical strength from neighboring areas while accounting for the observed event count. The smoothing process was applied separately to each 2-year rate. Each mother was assigned the 2-year smoothed crime rate of the block group in which she resided that corresponded with the period of time that covered the calendar year of the birth of her infant and the year preceding that. In other words, the measured crime rate is that in the year preceding pregnancy and throughout pregnancy. Crime rates were then divided into quartiles of the distribution of exposed women across all years. An analogous method was used to create census tract crime quartiles. We measured violent crime at two spatial scales in order to conduct two distinct, though similar, analyses. We intended to compare the difference in the relationship between violent crime and preterm birth when violent crime was measured at the block group level and when it was measured at the larger tract level.

Maternal race (non-Hispanic white, non-Hispanic black, and other), age (in 5 categories: <20, 20-24, 25-29, 30-34, and 35+), education (less than high school education, high school graduate, and more than high school education), marital status (married or unmarried), and infant sex (male or female) were considered as potential individual-level confounders. Additionally, certain maternal health-related covariates were considered, including eclampsia, chronic or pregnancy-associated hypertension, anemia, diabetes, the number of previous births (0, 1, 2, or 3 or greater), and any previous births of children less than 2500g or greater than 4000g. Furthermore, we considered the adequacy of prenatal care as categorized by the Kotelchuk Index as well as alcohol use and tobacco use during pregnancy. All individual-level maternal covariates were determined from birth certificate data.

Finally, neighborhood deprivation (a measure comprising multiple variables including poverty, employment, and education within a census tract as described by Messer et al(32) standardized to the mean for all of Georgia), poverty (percent of residents in a census tract below the poverty line) and neighborhood racial composition (percent of residents in a census tract that were black), were considered as potential neighborhood-level confounders. Neighborhood deprivation, poverty, and percent black had been previously interpolated between the 1990, 2000, and 2005-2009 Census tract-level estimates in order to provide a year-specific value for each birth.

Statistics

Pearson chi square statistics were used to test for differences between categorical variables among preterm and term births, as well as between categorical variables among the violent crime quartiles.

Multilevel, multivariable logistic regression was used to estimate the association between violent crime and the proportion of preterm birth within a block group or tract for a given year in order to control for potential confounders on the individual and neighborhood levels. Multilevel logistic regression allows for a random intercept for each area (block group or census tract), allowing the model to account for otherwise unobserved variation in preterm birth risk. Therefore, one can study the effects of area-based characteristics or exposures on individual outcomes controlling for area- and individual-level confounders.

Violent crime rate quartiles at the neighborhood (block group or tract) level were considered as the exposure of interest in the multilevel model. All individual- and neighborhood-level covariates that were significantly associated with both preterm birth and with violent crime rate quartiles in descriptive analyses were included in the model. Additionally, the base model included all possible two-way interaction terms involving these potentially confounding covariates with the exposure, in order to assess the difference in the effect of crime on different levels of covariates. Besides the term allowing for a random intercept, we also included a term allowing for a random residual, thereby accounting for over or under dispersion.

We assessed the collinearity of the variables in the base model and removed highly collinear interaction terms and/or confounders from the model before further analysis commenced. Backwards elimination was then used to eliminate non-significant interaction terms at the $\alpha=0.01$ level in order to determine the best-fitting model. *A priori*, if interaction terms were deemed to be significant, no further assessment of confounding for the constituent terms was done and those covariates remained in the model. However, if no interaction terms were deemed to be significant, we conducted an assessment of confounding in order to identify a well-fitting, parsimonious model.

Spatial analyses were done using ArcGIS version 10 (ESRI; Redlands, CA) and GeoDa (ASU; Tempe, AZ). All statistical analyses were done using SAS version 9.3 (SAS Institute; Cary, NC), and multilevel random-intercept logistic regression was done in SAS using PROC GLIMMIX.

Results

Between 1998 and 2006, there were 56,877 births within the City of Atlanta. Of these, 629 were missing all data on crime and were excluded. An additional 2,145 multiple births were excluded from analysis and a further 67 were excluded because of a recorded birth weight <500g. All reported births were in or later than the 20th gestational week. A total of 54,036 singleton births were included in the analysis.

Over the study period, crime rates in the City of Atlanta decreased considerably; the overall violent crime rate decreased from 2730 crimes/100,000 people in 1998 to 1554 crimes/100,000 people in 2007 (Figure 1). As seen in Figure 2, there was a considerable density of census tracts in the highest crime quartile in the western and southeastern portions of Atlanta in 1998; however, there were many fewer tracts in the highest crime quartile in 2006. Conversely, there were many more tracts in the lowest crime quartile in 2006 compared to in 1998. Figures 3 and 4 depict the distributions of poverty and deprivation, respectively. Both poverty and deprivation are concentrated in the western and southeastern portions of the city in 1998, and remain concentrated in these areas of the city in 2006.

For all births, gestational age at birth ranged from 20 to 44 weeks with a median of 39 weeks (IQR: 38-40 weeks). Overall, between 1998 and 2006, 13.1% of infants (n =7,090) were born before the 37th gestational week and were considered preterm. Of the preterm births, 16.4% of infants (n = 1,159; 2.8% of all births) were born before the 32nd week of gestation and are considered “very preterm”.

The percent of births that were preterm in a given block group ranged from 6.0% to 20.1% between 1998 and 2006 (Figure 5). The block groups with the highest proportions of preterm births were concentrated in the western and southeastern portions of Atlanta, where there were also high levels of violent crime, poverty, and deprivation. The total number of births in the highest crime quartile decreased from 2,917 in 1998 to 397 in 2006, while the number of births in the lowest crime quartile increased from 948 in 1998 to 2,123 in 2006 (Figure 6).

Table 1 lists descriptive comparisons between infants born preterm and those born at term. Preterm infants were significantly more likely to be male than were term infants. Preterm birth was most common among women less than 20 years old (14.9% of births in this age group), and was least likely among women 30-34 (10.7% of births in this age group). Black women were more likely to give birth to preterm infants than were white women or women of another race (15.8%, 7.2%, and 9.9% of births, respectively). Mothers of preterm infants were also significantly more likely to report tobacco and alcohol use during pregnancy as well as more likely to be afflicted with eclampsia, diabetes, and chronic or pregnancy-associated high blood pressure compared to mothers of term infants. During pregnancy, mothers of preterm infants were more likely to receive inadequate or "adequate plus" prenatal care (as determined by the Kotelchuk index) compared to mothers of term infants. Mothers of preterm infants were also more likely to have had more than two previous live birth events or to have given birth to an infant weighing less than 2500g compared to mothers of term infants.

Table 2 lists demographic and health factors of all women and their infants living in each block group crime quartile. Those women living in a high-crime block group (the 4th, or highest, crime quartile) were more likely to be black, unmarried, in the youngest (<20 years old) age category, to have a high school education or less, to use tobacco during pregnancy, to report more than two previous birth events, and to receive inadequate prenatal care compared to women in the lowest-crime neighborhoods. However, women in high-crime neighborhoods were less likely to drink alcohol during pregnancy and to have previously given birth to an infant weighing less than 2500g than women in low-crime neighborhoods.

In multilevel logistic regression, controlling for maternal race, age, education, marital status, alcohol use, tobacco use, pregnancy-associated hypertension, parity, any previous births of children less than 2500g and adequacy of prenatal care, as well the percent of people in a tract that were black, the tract's deprivation index score, and an age by crime interaction term, violent crime at the block group level was shown to be significantly associated with preterm birth ($p = 0.0157$). There was evidence of statistically significant interaction between crime quartile and age category ($p = 0.0018$), indicating that the effect of crime on preterm birth differs by age. As there was a statistically significant interaction term in the model, no assessment of confounding was conducted and all potential confounders were left in the model.

Table 3 describes the relationship between block-group level violent crime rate exposure and the adjusted odds of preterm birth, stratified by maternal age category; Figure 7 displays this visually. Among women aged 30-34, the odds of preterm birth were 1.34 times higher (95% CI: 1.06, 1.69) among women in the highest (4^{th}) crime quartile compared to women in the lowest crime quartile, and, similarly, were 1.37 times higher (95% CI: 1.10, 1.71) among women in the next-highest (3^{rd}) crime quartile compared to women in the lowest crime quartile. Additionally, among women aged 35 or older, the odds of preterm birth were 1.49 times higher (95% CI: 1.18, 1.88) among women in the highest (4^{th}) crime quartile compared to women in the lowest crime quartile, and were 1.50 times higher (95% CI: 1.19, 1.88) among women in the next-highest (3^{rd}) crime quartile compared to women in the lowest crime quartile. There was no statistically significant association between preterm birth and exposure to the second quartile of violent crime at any age; though the odds of preterm birth were highest in women over 30, the odds ratios comparing the women in the second crime quartile with the women in the lowest crime quartile did not reach statistical significance. Among women less than 30 years old, there was no significant association between crime and preterm birth at any level of crime exposure compared to women in the lowest crime quartile. No other comparisons were statistically significant. Removing the age-crime interaction term from the model, overall, any woman of any age living in an elevated-crime block group quartile was no more likely to give birth to a preterm infant than a peer in the lowest crime quartile.

Table 4 lists the odds ratios comparing the odds of preterm birth for women in each age-crime quartile category compared to the odds of preterm birth for a woman in the lowest quartile, Q1, aged 30-34; women aged 30-34 have the lowest odds of preterm birth of all women in the lowest crime quartile. Of note, women aged 25-29 living in the lowest quartile had a 1.27 (95% CI: 1.07, 1.52) times the odds of preterm birth compared to women aged 30-34 in the same crime quartile. There was no evidence of any statistically significant difference in the odds of preterm birth between any other age group in the lowest crime quartile and women aged 30-34. In the second block group crime quartile, only women aged 35 or greater showed an increased odds of preterm birth compared to women aged 30-34 in the lowest crime quartile; the older women who were exposed to slightly more crime were

1.35 times (95% CI: 1.09, 1.67) as likely to give birth to preterm infants as younger women in lower crime block groups. Similarly, women 35 years and older in the 3rd and 4th block group violent crime quartiles have a 1.70 (95% CI: 1.36, 2.14) and 1.32 (95% CI: 1.06, 1.65) time higher odds of preterm birth compared to women 30-34 in the 1st, lowest block group violent crime quartile. Among women aged 30-34, the odds of preterm birth were 1.34 times higher (95% CI: 1.06, 1.69) among women in the highest (4th) crime quartile compared to women in the lowest crime quartile, and, similarly, were 1.37 times higher (95% CI: 1.10, 1.71) among women in the next-highest (3rd) crime quartile compared to women in the lowest crime quartile. The odds of preterm birth were elevated in all age categories among women less than 30 living in the 2nd, 3rd, or 4th violent crime block group quartiles compared to the referent group (with the exception of women aged 20-24 in the 2nd crime quartile), though no comparisons reached statistical significance.

The results from three multilevel logistic models relating census tract violent crime rate quartiles with the odds of preterm birth are shown in Table 5. There was no statistically significant interaction between crime and any individual or neighborhood-level confounder; in contrast to the model with block group crime rate quartiles as the exposure, the effect of crime did not differ by maternal age, nor did it differ by level of any other covariate. We, therefore, were able to conduct an assessment of confounding.

Model 1, the "gold standard", shown in Table 5, adjusts for year and all possible individual and neighborhood-level factors. Controlling for all possible confounders, living in the 2nd or 3rd census tract violent crime rate quartile is associated with a 1.13 (95% CI: 1.02, 1.26) and 1.19 (95% CI: 1.05, 1.33) times higher odds (respectively) of preterm birth compared to living in the 1st quartile. The odds of preterm birth is 1.14 (95% CI: 1.00, 1.30) times higher for women living in the highest, 4th, crime quartile compared to women living in the 1st, lowest crime quartile, though the comparison does not reach statistical significance ($p = 0.0501$).

We eliminated neighborhood-level confounders in Model 2 and obtained results similar to those of Model 1. Controlling for year and for individual-level confounders, living in the 2nd, 3rd, or 4th census tract violent crime rate quartile is associated with a 1.14 (95% CI: 1.04, 1.26), 1.20 (95% CI: 1.09, 1.33), or 1.16 (95% CI: 1.04, 1.29) times higher odds (respectively) of preterm birth compared to living in the 1st quartile; all comparisons were statistically significant with this model. Model 3 estimates the association between preterm birth and tract-level crime quartiles when only controlling for demographic factors (i.e. maternal race/ethnicity, marital status, education, and age). The results of Model 3 are similar to those of Models 1 and 2; living in the 2nd, 3rd, or 4th census tract violent crime rate quartile is associated with a 1.14 (95% CI: 1.04, 1.26), 1.18 (95% CI: 1.07, 1.30), or 1.15 (95% CI: 1.03, 1.28) times higher odds (respectively) of preterm birth compared to living in the 1st quartile. Again, as with Model 2, all comparisons were statistically significant. In all adjusted models, tract-level violent crime in quartiles was overall statistically significantly associated with preterm birth ($p < 0.05$).

Discussion

The risk of preterm birth in Atlanta, GA is elevated compared to the national average; 13.1% of singleton infants were born before the 37th gestational week in the years 1998 through 2006, compared to 12.7% of births nationally in 2007 (1). In this study, preterm birth in Atlanta was associated with low levels of education and marriage, and high levels hypertension, tobacco or alcohol consumption, and diabetes. Additionally, black women were more than twice as likely to give birth to infants before term compared to white women. All of these results are consistent with prior findings.

By controlling for these individual risk factors in multilevel logistic regression, we were able to estimate the association between temporally-varying violent crime and preterm birth above and beyond the effect of individual and other area-based risk factors. We find modest evidence to support an association between high levels of violent crime in a mother's neighborhood and an increased odds of giving birth to a preterm infant, though the association differs slightly with different definitions of "neighborhood". In multilevel logistic regression, when controlling for all individual- and neighborhood-level covariates, living in any neighborhood but the lowest tract violent crime rate quartile is associated with a significant increase in the odds of preterm birth compared to living in the lowest crime rate quartile. This association holds when controlling for various subsets of confounders (Table 5).

Similarly, block group violent crime rates are associated with preterm birth in multilevel logistic regression, when controlling for individual and neighborhood-level confounders. Women aged 30 or older living in the 3rd or 4th, high crime or very high crime quartiles have an increased odds of giving birth to infants before the 37th gestational week.

However, the association between preterm birth and exposure to violent crime only holds for women over the age of 30; women younger than 30 living in high-crime block groups have no increased odds of preterm birth compared to women of similar age living in low-crime block groups (Table 3). The interaction between age and crime can be seen further in Table 4; older women in high crime quartiles show an increased odds of preterm birth compared to women aged 30-34 in the lowest crime quartile, but young women in the highest crime quartiles are not at increased risk of preterm birth compared to this referent group.

Women generally experience a higher risk of preterm birth at very young maternal ages and again at older ages, but there is evidence to support the theory that women who are chronically exposed to stress “age” more quickly thereby increasing their risk of preterm birth more quickly than their less-stressed counterparts. (33, 34) The results of this study support this “weathering hypothesis”, in that the effect of block group level crime on preterm birth was only seen in older women. These older women living in high-crime neighborhoods were, perhaps, exposed to long periods of crime, poverty, segregation, and other stressing factors associated with living in high-crime neighborhoods. Measuring exposure to high levels of crime in the year of pregnancy may, therefore, be a proxy for measuring exposure to high levels of environmental stressors over longer periods of time. Though we controlled for concurrent deprivation and segregation in the analysis, we did not and could not measure long-term stress in the women giving birth, a limitation of our study.

Though we adjusted for all potential confounders available, we were limited by the data provided by the birth certificates. It is possible that the association between preterm birth and violent crime is due to some unmeasured factor confounding the association.

Further analyses using different datasets with richer data may find different or non-significant associations.

Additionally, we considered exposure to violent crime at the census block-group level and the census tract level to be the exposure of interest. Though the analysis at two different spatial scales was a strength of our study, there is no information on whether these block groups or tracts are "neighborhoods" as the residents experience them. It may be that the relevant level of exposure to crime is something smaller or larger in scale than a census block group or census tract, or that distance from crime rather than overall crime rate in one's neighborhood is the important factor. Further research is needed to assess the impact of violent crime on different scales.

Moreover, our analysis of violent crime was limited to reported crimes, and not all violent crimes are reported to the police, so crime rates in some block groups may be higher than reported (35). Reporting rates differ by the race, age, and sex of the victim, as well as on the type of crime, resulting in potential misclassification bias.

The diverse population of Atlanta allowed us to calculate results that may be more generalizable to the general population than the results of previous studies. In contrast to prior studies, we were able to consider women who were non-Hispanic white and non-Hispanic black, as well as women who didn't identify as either of those races.

During the study period, crime decreased considerably in Atlanta and nationwide, though preterm birth rates remained stable or even increased nationwide. Additionally, though crime decreased, poverty and deprivation remained largely unchanged (Figures 2, 3, and 4). This suggests that crime decreased independent of the population demographic composition of neighborhoods; that the population didn't have to change in order for crime to go down. This situation provided a unique opportunity to study the effect of a decrease in an exposure in a relatively static population on a health outcome; we were able to look at the associations between preterm birth and violent crime over a 9-year period.

Overall, our multilevel logistic regression analyses showed a significant association between high violent crime rates on two distinct scales (block group and tract) and an increased odds of preterm birth. This study adds to previous evidence that neighborhood characteristics, and violent crime in particular, may be an important contributor to the risk of preterm birth.

Future Directions

In these analyses, we conducted multilevel multivariable logistic regression that allowed for a random intercept for each neighborhood (tract or block group) in the model. We plan to conduct additional analyses that also allow for a random slope for age within block group or tract. In this way, we can test for a difference effect of crime on preterm birth within each block group or tract by age.

In modeling odds ratios, these analyses allowed for interaction on the multiplicative scale, but interaction on the additive scale may also be present. Interaction on the additive scale may be more analogous to biological interaction in this case than interaction on the multiplicative scale. We plan to test for interaction on the additive scale by modeling risk ratios instead of odds ratios.

Finally, we hope to conduct analyses that control for potential residual confounding, a method described by Flanders et al (36). By controlling for the crime rates in the years after exposure, we can control for any factors related to crime in the year of exposure and the years after exposure that may have gone unmeasured or unrecognized.

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Table 1: Demographics and health characteristics of infants and mothers of infants born at term and preterm in Atlanta, GA, 1998-2006

	Term		Preterm		
	N	**%**	**N**	**%**	**p-value**
Overall	46946	86.9%	7090	13.1%	
Infant demographics					
Infant Sex					
Male	23730	86.4%	3734	13.6%	0.0009
Female	23216	87.4%	3356	12.6%	
Maternal demographics					
Race/ethnicity					
Non-Hispanic white	10438	92.8%	811	7.2%	<.0001
Non-Hispanic black	29112	84.2%	5469	15.8%	
Other/unknown	7396	90.1%	810	9.9%	
Education					
<HS education	13420	84.3%	2504	15.7%	<.0001
High school grad/GED	12807	84.8%	2301	15.2%	
>HS education	18758	90.3%	2008	9.7%	
Marital status					
Married	19397	91.1%	1898	8.9%	<.0001
Unmarried	27537	84.1%	5190	15.9%	
Age Category					
≤19	7472	85.1%	1313	14.9%	<.0001
20-24	13104	86.2%	2102	13.8%	
25-29	12418	87.2%	1830	12.8%	
30-34	7662	89.3%	914	10.7%	
35+	6290	87.1%	931	12.9%	

Maternal health-related covariates					
Alcohol use during pregnancy					
yes	731	81.6%	165	18.4%	<.0001
no	45847	87.0%	6840	13.0%	
Tobacco use during pregnancy					
yes	1976	76.4%	611	23.6%	<.0001
no	44602	87.5%	6392	12.5%	
Anemia					
yes	1420	87.0%	213	13.0%	0.925
no	45526	86.9%	6877	13.1%	
Diabetes					
yes	453	79.5%	117	20.5%	<.0001
no	46493	87.0%	6973	13.0%	
Eclampsia					
yes	101	56.4%	78	43.6%	<.0001
no	46845	87.0%	7012	13.0%	
Chronic hypertension					
yes	171	71.5%	68	28.5%	<.0001
no	46775	86.9%	7022	13.1%	
Pregnancy-associated hypertension					
yes	518	75.1%	172	24.9%	<.0001
no	46428	87.0%	6918	13.0%	
Previously gave birth to infant weighing >4000g					
yes	108	91.5%	10	8.5%	0.1345
no	46838	86.9%	7080	13.1%	
Previously gave birth to infant weighing <2500g					
yes	189	67.5%	91	32.5%	<.0001
no	47303	87.0%	7082	13.0%	
Parity					
Mother's first birth	20054	88.9%	2500	11.1%	<.0001
1 previous birth event	13159	87.2%	1923	12.8%	
2 previous birth events	7339	86.3%	1167	13.7%	
>2 previous birth events	6394	81.0%	1500	19.0%	
Adequacy of prenatal care					
Unknown	3501	84.1%	660	15.9%	<.0001
Inadequate	7164	82.4%	1532	17.6%	
Intermediate	5300	93.3%	383	6.7%	
Adequate	18471	95.2%	933	4.8%	
Adequate Plus	12510	77.7%	3582	22.3%	

Table 2: Distribution of all births in spatially-smoothed block group violent crime rate quartiles of Atlanta, GA, 1998-2006

	Q1		Q2		Q3		Q4		
	N	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**p-value**
Overall	13460	25.1%	13396	25.0%	13403	25.0%	13416	25.0%	-
Infant demographics									
Infant sex									
Male	6869	25.2%	6786	24.9%	6794	24.9%	6823	25.0%	0.9229
Female	6591	25.0%	6610	25.0%	6609	25.0%	6593	25.0%	
Maternal demographics									
Race/ethnicity									
Non-Hispanic white	7154	63.6%	2431	21.6%	948	8.4%	715	6.4%	<.0001
Non-Hispanic black	2932	8.6%	8674	25.3%	11275	32.9%	11347	33.2%	
Other/unknown	3374	41.2%	2291	27.9%	1180	14.4%	1354	16.5%	
Marital status									
Married	10205	48.0%	5185	24.4%	3146	14.8%	2743	12.9%	<.0001
Unmarried	3248	10.0%	8209	25.4%	10256	31.7%	10669	32.9%	
Education									
< HS education	1535	9.8%	3834	24.4%	4882	31.1%	5444	34.7%	
HS grad/GED	1617	10.8%	3954	26.4%	4684	31.2%	4747	31.6%	
> HS education	9372	45.2%	5051	24.3%	3460	16.7%	2862	13.8%	
Age									
≤19 years	718	8.3%	2052	23.7%	2788	32.2%	3108	35.9%	<.0001
20-24 years	1766	11.7%	3946	26.2%	4644	30.8%	4722	31.3%	
25-30 years	3614	25.5%	3681	26.0%	3518	24.8%	3358	23.7%	
31-34 years	3850	45.0%	2097	24.5%	1374	16.1%	1233	14.4%	
35+ years	3512	48.7%	1620	22.5%	1079	15.0%	995	13.8%	

Maternal health-related covariates									
Alcohol use during pregnancy									
yes	362	40.6%	161	18.0%	157	17.6%	212	23.8%	<.0001
no	12931	24.7%	13143	25.1%	13166	25.2%	13090	25.0%	
Tobacco use during pregnancy									
yes	195	7.6%	478	18.7%	791	30.9%	1094	42.8%	<.0001
no	13097	25.9%	12827	25.3%	12532	24.7%	12206	24.1%	
Anemia									
yes	384	23.6%	472	29.0%	433	26.6%	341	20.9%	<.0001
no	13076	25.1%	12924	24.8%	12970	24.9%	13075	25.1%	
Diabetes									
yes	154	27.0%	149	26.1%	139	24.4%	128	22.5%	0.4314
no	13306	25.1%	13247	24.9%	13264	25.0%	13288	25.0%	
Eclampsia									
yes	41	22.9%	48	26.8%	46	25.7%	44	24.6%	0.888
no	13419	25.1%	13348	25.0%	13357	25.0%	13372	25.0%	
Chronic hypertension									
yes	57	23.9%	67	28.2%	68	28.6%	46	19.3%	0.1441
no	13403	25.1%	13329	24.9%	13335	25.0%	13370	25.0%	
Pregnancy-associated hypertension									
yes	182	26.5%	201	29.3%	154	22.4%	150	21.8%	0.0161
no	13278	25.1%	13195	24.9%	13249	25.0%	13266	25.0%	
Previously gave birth to infant weighing >4000g									
yes	52	44.1%	29	24.6%	15	12.7%	22	18.6%	<.0001
no	13408	25.0%	13367	25.0%	13388	25.0%	13394	25.0%	
Previously gave birth to infant weighing <2500g									
yes	86	31.7%	71	26.2%	61	22.5%	53	19.6%	0.0311
no	13374	25.0%	13325	25.0%	13342	25.0%	13363	25.0%	

Parity									
Mother's first birth	6742	30.0%	5706	25.4%	5082	22.7%	4906	21.9%	<.0001
1 previous birth event	4126	27.5%	3723	24.8%	3563	23.7%	3607	24.0%	
2 previous birth events	1735	20.5%	2145	25.4%	2283	27.0%	2288	27.1%	
>2 previous birth events	857	11.0%	1822	23.5%	2475	31.9%	2615	33.7%	
Adequacy of prenatal care									
Unknown	1234	29.7%	928	22.4%	986	23.8%	1003	24.2%	<.0001
Inadequate	930	10.8%	2369	27.6%	2616	30.4%	2679	31.2%	
Intermediate	1187	21.0%	1466	25.9%	1553	27.5%	1446	25.6%	
Adequate	5693	29.5%	4772	24.7%	4497	23.3%	4341	22.5%	
Adequate Plus	4416	27.6%	3861	24.2%	3751	23.5%	3947	24.7%	

Table 3: The odds of preterm birth of women in medium, high, and very high spatially-smoothed block group crime quartiles compared to women in the lowest crime quartiles, stratified by age category

	Q1	Q2	Q3	Q4
Age <20	1.0 (ref)	1.10 (0.84, 1.43)	1.10 (0.84, 1.43)	1.14 (0.87, 1.48)
Age 20-24	1.0 (ref)	0.92 (0.76, 1.11)	1.01 (0.84, 1.22)	0.97 (0.80, 1.18)
Age 25-29	1.0 (ref)	0.80 (0.68, 0.95)*	0.92 (0.78, 1.09)	0.84 (0.70, 1.01)
Age 30-34	1.0 (ref)	1.14 (0.93, 1.40)	1.37 (1.10, 1.71)*	1.34 (1.06, 1.69)*
Age 35+	1.0 (ref)	1.19 (0.96, 1.47)	1.50 (1.19, 1.88)*	1.49 (1.18, 1.88)*
Overall	1.0 (ref)	1.00 (0.90, 1.11)	1.11 (1.00, 1.25)	1.08 (0.95, 1.22)

*Indicates a statistically significant comparison at the α=0.05 level.
The referent group for each comparison is the group in the first, lowest crime quartile in the same age group.
The “overall” comparison is a model without any interaction terms; the comparison, is, therefore, for all age categories.

Table 4: The odds of preterm birth of women in all maternal age categories and all spatially-smoothed block group crime quartiles compared to women aged 30-34 in the lowest crime quartile.

	Q1		**Q2**		**Q3**		**Q4**	
	N (preterm/term)	aOR (95% CI)	N (preterm/term)	aOR (95% CI)	N (preterm/term)	aOR (95% CI)	N (preterm/term)	aOR (95% CI)
Age <20	91/627	1.06 (0.80, 1.41)	321/1731	1.16 (0.94, 1.44)	410/2378	1.17 (0.94, 1.44)	472/2636	1.20 (0.97, 1.49)
Age 20-24	210/1556	1.07 (0.87, 1.33)	534/3966	0.98 (0.82, 1.19)	678/3966	1.09 (0.90, 1.31)	656/4066	1.04 (0.86, 1.27)
Age 25-29	370/3244	**1.27 (1.07, 1.52)**	460/3221	1.02 (0.85, 1.23)	524/2994	1.17 (0.97, 1.41)	462/2896	1.07 (0.88, 1.31)
Age 30-34	275/3575	1.0 (ref.)	226/1871	1.14 (0.93, 1.40)	212/1162	**1.37 (1.10, 1.71)**	197/1036	**1.34 (1.06, 1.69)**
Age 35+	301/3211	1.13 (0.94, 1.36)	213/1407	**1.35 (1.09, 1.67)**	211/868	**1.70 (1.35, 2.14)**	206/789	**1.32 (1.06, 1.65)**

An odds ratio in **bold** indicates a statistically significant comparison at the $\alpha=0.05$ level.
The referent group for all comparisons is the group of women in the lowest crime quartile, Q1, aged 30-34.

Table 5: Odds of preterm birth of women in medium, high, and very high spatially-smoothed tract crime quartiles compared to women in the lowest crime quartiles as calculated by three models

	Model 1	Model 2	Model 3
Q1	1.00 (ref)	1.00 (ref)	1.00 (ref)
Q2	1.13 (1.02, 1.26)*	1.14 (1.04, 1.26)*	1.14 (1.04, 1.26)*
Q3	1.19 (1.05, 1.33)*	1.20 (1.09, 1.33)*	1.18 (1.07, 1.30)*
Q4	1.14 (1.00, 1.30)	1.16 (1.04, 1.29)*	1.15 (1.03, 1.28)*

*Indicates a statistically significant comparison at the $\alpha=0.05$ level.
The referent group for each odds ratio is the group in the lowest crime quartile, Q1.
Model 1 is the model controlling for year and all possible individual and neighborhood-level confounders.
Model 2 is the model controlling for year and all possible individual-level confounders.
Model 3 is the model controlling for year and individual demographic confounders.

Figure 1: Violent crime rate in Atlanta, GA by type of crime: 1989-2009.

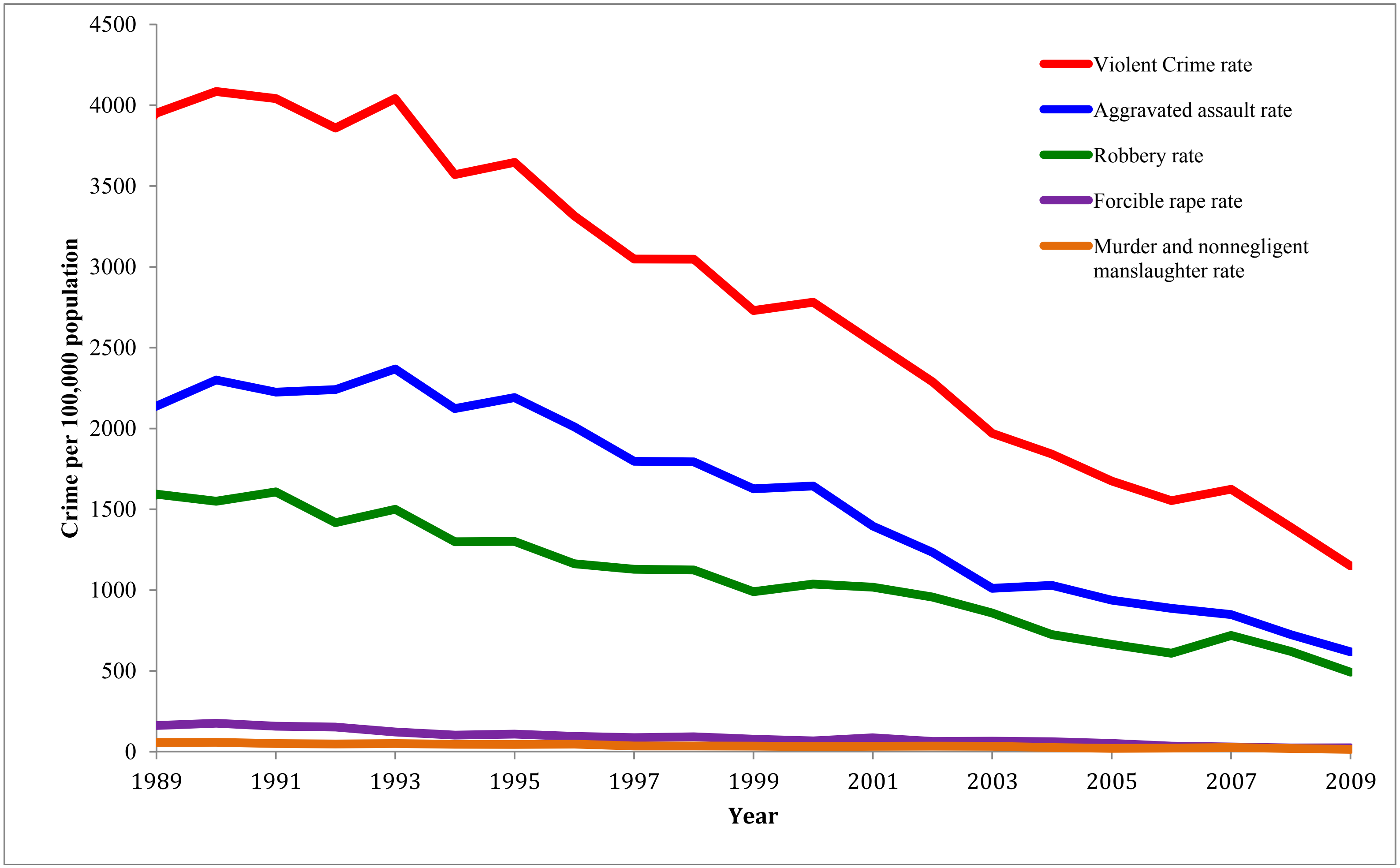
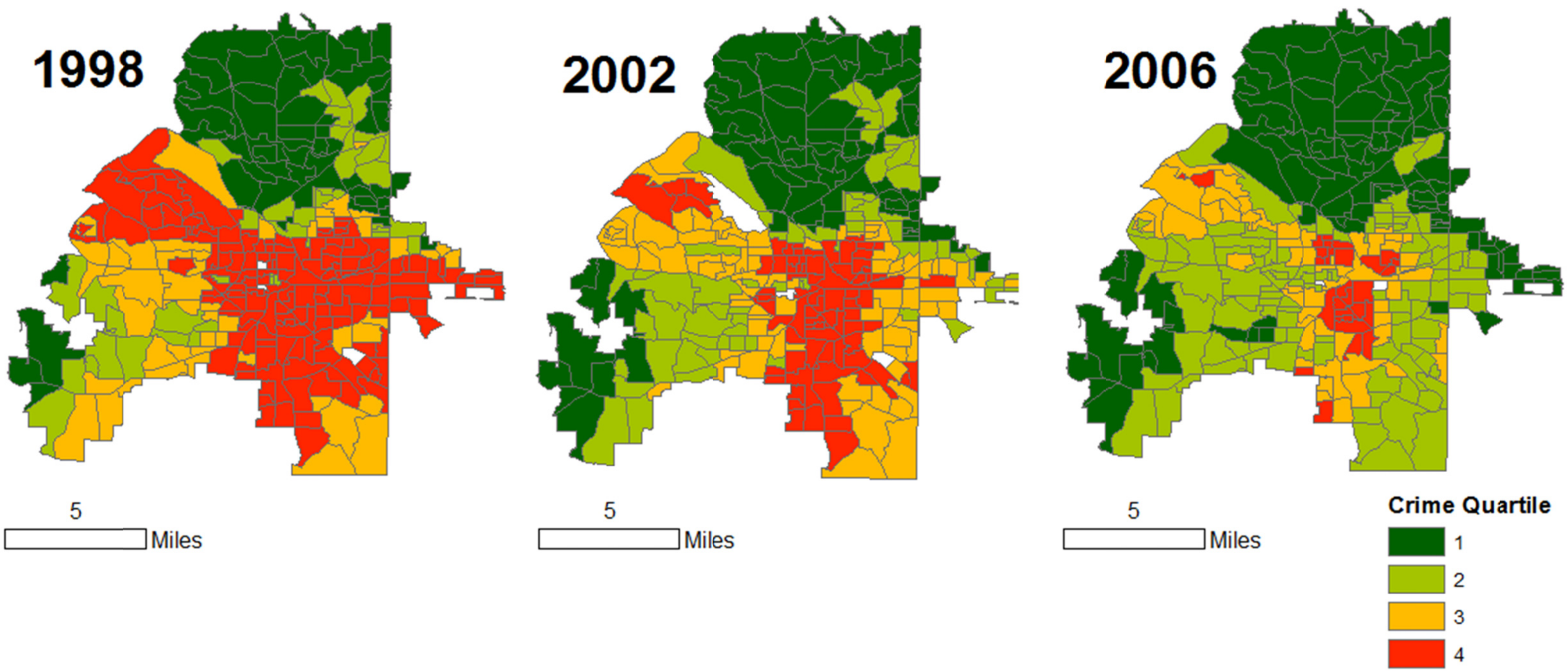
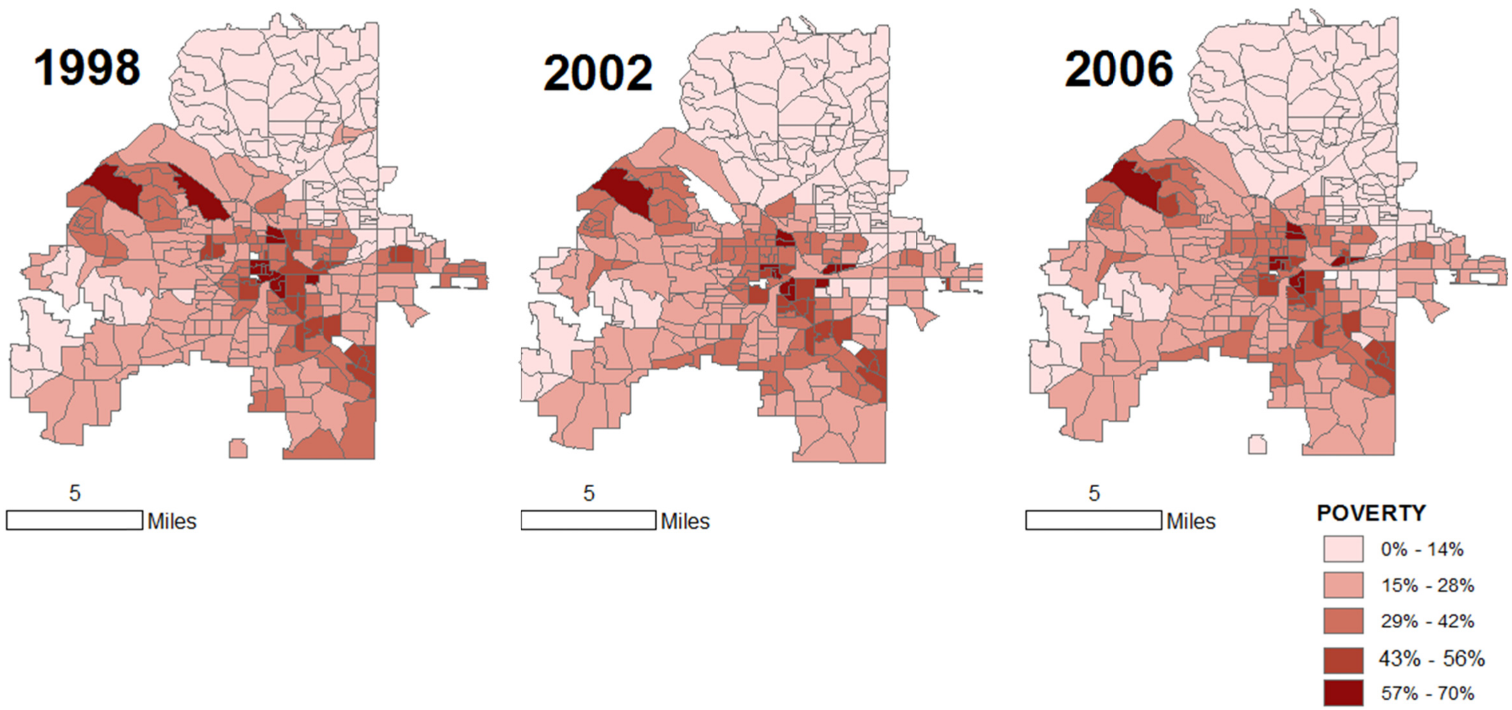


Figure 2: Distribution of spatially smoothed block-group level violent crime rate quartiles in Atlanta, GA: 1998, 2002, and 2006.



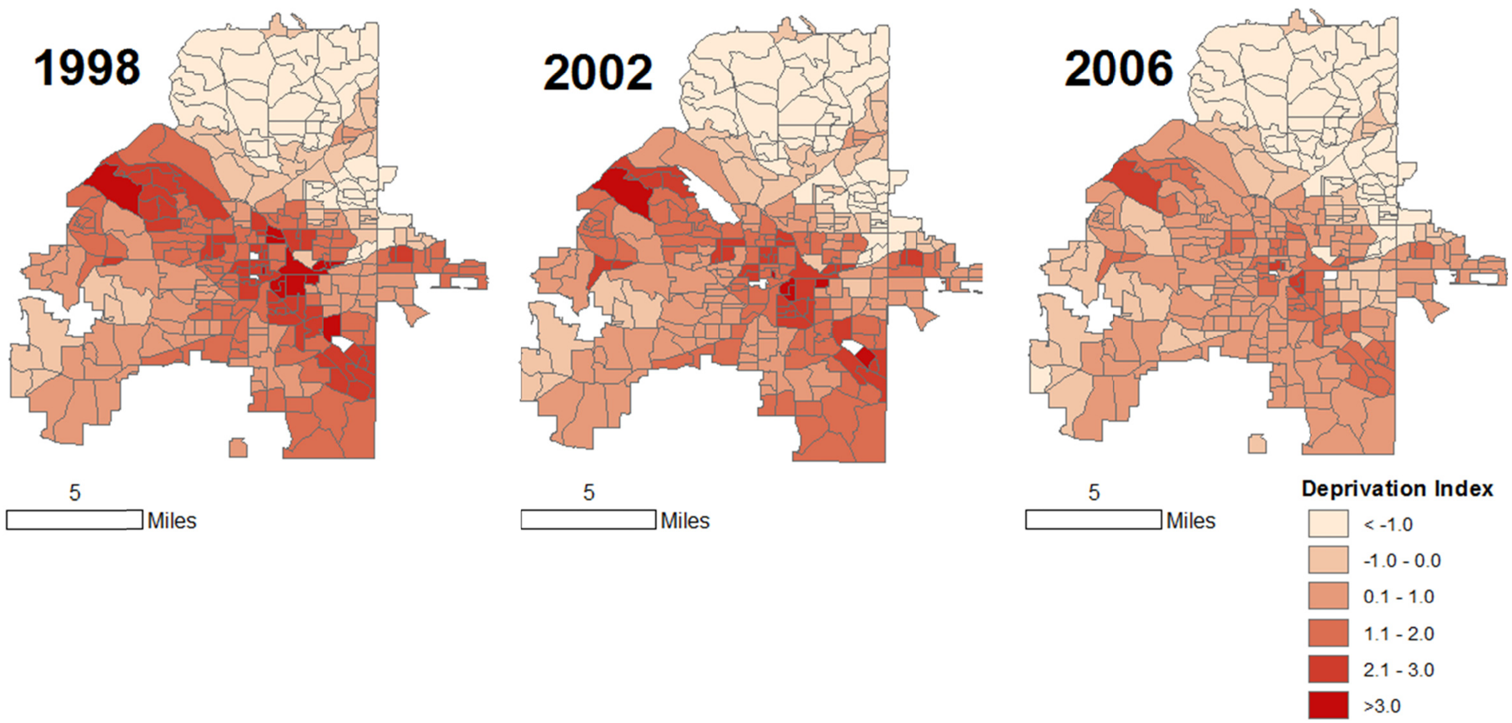
Violent crime in this analysis is any instance of homicide, rape, assault, or robbery reported within the city of Atlanta, Georgia between the years of 1997 and 2007. Crime data was provided by the Atlanta Police Department as a count of crime events which occurred within each block group during each year. Crimes were converted to overlapping 2-year crime rates (e.g. 1997-1998, 1998-1999, 1999-2000, etc.) by dividing the sum of the crimes in a block group over a given two year period by the population of that block group as determined from the 2000 U.S. Census. In order to stabilize rates which may be extreme due to small event numbers we applied a spatial smoothing algorithm using GeoDa software. The smoothing process was applied separately to each 2-year rate. Each mother was assigned the 2-year smoothed crime rate of the block group in which she resided that corresponded with the period of time that covered the calendar year of the birth of her infant and the year preceding that. Crime rates were then divided into quartiles of the distribution of exposed women across all years.

Figure 3: Distribution of poverty in Atlanta, GA, represented as the percent of people in each census tract below the poverty line: 1998, 2002, and 2006.



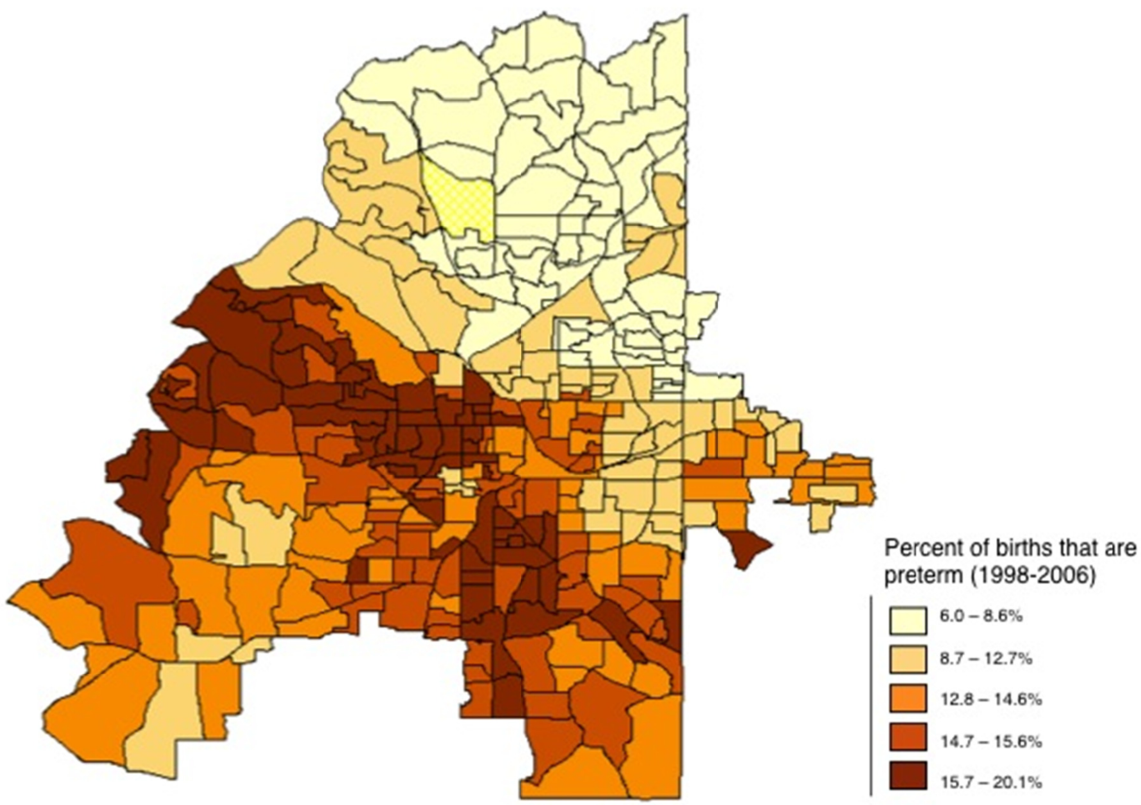
Data from the 1990 and 2000 US Census and the 2005-2009 American Community Survey, model-interpolated to give yearly estimates.

Figure 4: Distribution of tract-level deprivation indices in Atlanta, GA: 1998, 2002, and 2006.



Data from the 1990 and 2000 US Census and the 2005-2009 American Community Survey, model-interpolated to give yearly estimates. The deprivation index combines measures of income, employment, household structure, and education. The index is standardized the average for the state of Georgia; this average gets a score of "0". A change of one unit in the index corresponds to a difference of one standard deviation from the state mean deprivation. Positive numbers indicate census tracts more deprived than average, and negative numbers indicate census tracts less deprived than average.

Figure 5: Distribution of spatially-smoothed block group preterm birth rates in Atlanta, GA: 1998-2006.



Births in each block group were aggregated over the nine-year period to calculate overall measures. We applied a spatial smoothing algorithm using GeoDa to stabilize unstable proportions due to small numbers.

Figure 6: Number of births per spatially-smoothed block group violent crime quartile in Atlanta, GA: 1998-2006.