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Associations between residential greenness and birth outcomes across Texas

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ABSTRACT

Background: The amount of greenness around mothers' residences has been associated with positive birth outcomes; however, findings are inconclusive. Here we examine residential greenness and birth outcomes in a population-based birth cohort in Texas, a state with large regional variation in greenness levels, several distinct cities, and a diverse population.

Methods: We used Vital Statistics data to create a birth cohort (n=3,026,603) in Texas from 2000 to 2009. Greenness exposure measures were estimated from full residential addresses across nine months of pregnancy, and each trimester specifically, using the mean of corresponding MODIS satellite 16-day normalized difference vegetation index (NDVI) surfaces at a 250 m resolution, which have not been previously used. Logistic and linear mixed models were used to determine associations with preterm birth, small for gestational age (SGA) and term birth weight, controlling for individual and neighborhood factors.

Results: Unadjusted results demonstrated consistent protective effects of residential greenness on adverse birth outcomes for all of Texas and the four largest cities (Houston, San Antonio, Dallas, and Austin). However, in fully adjusted models these effects almost completely disappeared. For example, mothers with the highest (> 0.52) compared to the lowest (< 0.37) NDVI quartiles had a 24.4 g (95% CI: 22.7, 26.1) increase in term birth weight in unadjusted models, which was attenuated to 1.9 g (95% CI: 0.1, 3.7) in fully adjusted models. Maternal and paternal race, ethnicity and education had the largest impact on reducing associations. Trimester-specific greenness exposures showed similar results to nine-month average exposures. Some evidence was seen for protective effects of greenness for Hispanics, mothers with low education and mothers living in low income neighborhoods.

Conclusions: In this large population-based study, across multiple urban areas in Texas and diverse populations, we did not observe consistent associations between residential greenness and birth outcomes.

1. Introduction

A rapidly growing body of evidence suggests residential greenness (also referred to as green space, or natural environments) is associated with a range of positive health outcomes, including improved mental health (Sugiyama et al., 2008; Thompson et al., 2012; Van den Berg et al., 2010), decreased mortality (Donovan et al., 2013; Mitchell and Popham, 2008; Takano et al., 2002; Villeneuve et al., 2012) and positive birth outcomes (Dadvand et al., 2012a, 2012b, 2012c, 2014; Donovan et al., 2011; Hystad et al., 2014). Pregnancy represents a susceptible time-period for environmental exposures (Fedulov et al., 2008; Jirtle and Skinner, 2007; Merlo et al., 2009) and birth outcomes are important population health indicators as they have substantial impacts immediately as well as over the life-course (Gray et al., 2014). Given the defined exposure period during pregnancy, birth outcomes may be particularly useful for determining potential influences of residential greenness on health.

A limited number of studies have examined associations between residential greenness and birth outcomes (Casey et al., 2016; Dadvand et al., 2012a, 2012c, 2014; Donovan et al., 2011; Ebisu et al., 2016; Hystad et al., 2014; Laurent et al., 2013; Markevych et al., 2014). A meta-analysis summarizing the literature showed that residential greenness was positively associated with birth weight within approximately 100 m buffers (Dzhambov et al., 2014), but other studies observed associations for different buffer sizes (Donovan et al., 2011; Markevych et al., 2014). Overall conclusions for preterm birth and small for gestational age vary and are less consistent than birth weight (Agay-Shay et al., 2014; Casey et al., 2016; Dadvand et al., 2012c; Ebisu et al., 2016; Grazuleviciene et al., 2015). Importantly, most studies used a static measure of greenness (typically from summer

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months) and none include trimester-specific exposure estimates, which have been essential for examining other environmental exposures, such as air pollution (Lee et al., 2013). In addition, only two studies (Dadvand et al., 2012c; Ebisu et al., 2016) have examined multiple urban areas and it is unknown if residential greenness has a similar effect across multiple urban areas or if associations reflects city-specific urban form characteristics and population dynamics. Finally, while there is evidence that exposure to greenness may have a larger impact on minority and low socio-economic status (SES) populations (Dadvand et al., 2012a, 2012b, 2014), the existing literature lacks the diversity to fully examine populations that may benefit the most from greenness exposures.

Here we examine associations between residential greenness and birth outcomes, including preterm birth, SGA and term birth weight, for more than three million births occurring in all urban areas of Texas from 2000 to 2009. We assess the effects of greenness throughout pregnancy by looking at trimester specific models, and examine associations for the four largest cities of Texas separately and by individual and neighborhood SES and race/ethnicity. Texas has substantial regional variation in greenness levels, several large and distinct cities, and diverse populations based on SES, race and ethnicity that allow us to fully explore how residential greenness may be associated with birth outcomes and how individual, neighborhood and city-level factors may modify potential associations.

2. Materials and methods

2.1. Birth cohort

Data for all births among Texas residents between 2000 and 2009 (3,899,627 birth records) were provided by the Texas Vital Statistics program. A total of 3,413,787 (88%) birth records could be geocoded to full residential address. We restricted our analysis to mothers (n=3,233,236) living in metropolitan areas of Texas (population ≥50,000) by using the Core-Based Statistical Areas classification system. We further excluded any infants whose birth weight was not between 500 and 5000 g (n=11,994), non-singleton births (n=126,818), and those with missing covariates (n=67,821). Our final sample for the analysis of residential greenness included 3,026,603 births.

2.2. Residential greenness exposure assessment

Estimates of residential greenness were derived from MODIS satellite NDVI imagery and maternal residence at the time of birth. NDVI is an indicator of greenness based on land surface reflectance of visible and near infrared parts of spectrum (Weier and Herring, 2000). Values range from −1 to1 with the higher numbers indicating more greenness. This measure does not discern types of vegetation but represents all green vegetation. We used 16-day, 250 m resolution composite images derived from MODIS (https://lpdaac.usgs.gov/) to estimate trimester-specific and entire pregnancy length greenness exposures based on maternal residences reported at time of birth. Estimates are based on averaging composite images over the time interval of interest (e.g. trimester 1, 2, 3, and entire pregnancy) with each image weighted based on the number of estimated pregnancy days covered by the image (Eq. (1)).

$$NDVI_{residence_i} = \frac{\sum_{j=1}^{n} NDVI\ for\ month_i\ *time\ Range_j}{number\ of\ days\ in\ time\ interval\ of\ inteerst} \quad (1)$$

where time Rangej=number of estimated gestational days within MODIS NDVI composite j and time interval of interest (e.g. trimester 1, pregnancy, etc).

We chose 250 m to measure greenness as we are interested in capturing local residential greenness levels outside the mother's home and not regional (e.g. > 1 km buffer) greenness levels that may capture larger-scale influences of greenness (e.g. urban core versus suburb influences). Due too computational, time and manuscript length constraints we did not examine NDVI in multiple buffer distances.

2.3. Additional spatial exposures and neighborhood measures

Additional spatial exposure measures were derived to examine traffic air pollution as a potential causal pathway and to control for potential neighborhood contextual confounding factors. To derive a spatial measure of traffic air pollution, we applied a previously developed national land use regression (LUR) model for NO_2 which includes satellite NO_2 estimates and eight land use variables (Novotny et al., 2001). The LUR estimates were fused with monthly ground-based monitoring data to estimate average NO_2 exposures during each trimester and the entire pregnancy period (Bechle et al., 2015). We chose to include NO_2 air pollution since this pollutant demonstrates fine-scale spatial variability (e.g. (Brauer et al., 2007) that is most likely influenced by residential greenness levels (Hystad et al., 2014). Neighborhood SES variables and population density were downloaded at the census tract level from the American Fact Finder website (http://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml) for 2000 and 2010 census and linked to each birth within the census tract. For example, we accessed the percent of the population that was "white alone, not Hispanic or Latino" in order to derive out percent white variable. Variables included percent Hispanic; percent White; percent adult population without a high school diploma; and median household income; percentage of the population below the poverty line; and percent unemployment. Population density was used to control for potential confounding factors associated with urban form, such as inner city cores or suburban areas.

2.4. Individual covariates

Individual covariates were captured from the birth certificate data provided by the Texas Vital Statistics program. Covariates were determined a-priori. Maternal as well as paternal (if available) covariates included: age; smoking (yes/no during pregnancy); education (less than high school diploma, high school diploma, some college, college degree and post graduate degree); and race/ethnicity (White, Black, Asian, Hispanic, Other). Pregnancy-related variables included method of delivery; parity (first birth or not); prenatal care received; gestational age; baby's sex; and month and year of birth. When available, maternal and paternal characteristics were both included in subsequent analyses to better capture household SES influences.

2.5. Analysis

We investigated the association between NDVI and three birth outcomes of interest: 1) birth weight for full term babies (≥37 weeks of gestation); 2) odds of preterm birth (< 37 weeks of gestation); and 3) odds of being SGA (defined as the bottom decile in birth weight, stratified by gestational age, gender, and year of birth) (Groom et al., 2007; Kliegman, 2011). Logistic and linear mixed regression models were developed to examine NDVI and birth outcomes associations. Random intercepts based on metropolitan statistical areas (MSAs) were included in the statistical models to adjust for between MSA differences in birth outcomes and potential residual confounding. Fully adjusted models included all individual covariates described previously as well as neighborhood variables, NO_2 air pollution concentrations and population density. Term birth weight analyses also included a categorical variable for the estimated gestational age at birth. Associations between greenness exposures and birth outcomes are presented corresponding to quartiles (defined by the distribution of NDVI across Texas, with the lowest NDVI quartile as the reference) as we observed non-linearity in most models. We first present models for