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Inverse relationship between urban green space and childhood autism in California elementary school districts

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A B S T R A C T

Green space has a variety of health benefits. However, little is known about its impact on autism, the fastest-growing neurodevelopmental disorder in children. This study examined the relationship between green space and childhood autism prevalence. Autism count data in 2010 were obtained for 543 of ~560 public elementary school districts in California. Multiple types of green space were measured in each school district, including percentages of forest, grassland, and average tree canopy and near-road tree canopy. Their associations with autism prevalence were evaluated with negative binomial regression models and spatial regression models. We observed inverse associations between several green space metrics and autism prevalence in school districts with high road density, the highly urbanized areas, but not in others. According to negative binomial regression models, adjusted rate ratios (RR) for the relationships in these school districts between autism prevalence and green space metrics in 10% increments were as follows: for forest, RR = 0.90 (95% confidence interval [CI]: 0.84–0.95); for grassland, RR = 0.90 (95% CI: 0.83–0.97); for average tree canopy, RR = 0.89 (95% CI: 0.83–0.95), and for near-road tree canopy, RR = 0.81 (95% CI: 0.73–0.91). These results suggest that increases of 10% in forest, grassland, average tree canopy and near-road tree canopy are associated with a decrease in autism prevalence of 10%, 10% 11% and 19%, respectively. In contrast, urban land and road density were positively associated with autism prevalence. The results of spatial regression models were consistent with those obtained by negative binomial models, except for grassland. Our study suggests that green space, specifically tree cover in areas with high road density, may influence autism prevalence in elementary school children beneficially. Further studies are needed to investigate a potential causal relationship, and the major mechanisms that may underlie the beneficial associations with green space, such as buffering traffic-related air pollution and noise.

1. Introduction

Autism spectrum disorders (ASD), commonly known as autism, are a group of complex neurodevelopmental abnormalities typically identified in early childhood (American Psychiatric Association, 2013). Children with ASD exhibit abnormal behaviors including deficits in social interaction and communication, and repetitive patterns of behavior (Geschwind, 2009; Newschaffer et al., 2007; Ozand et al., 2003). Over the past 3 decades, the rate of autism has increased dramatically. It was estimated to be approximately four to five cases per 10,000 children in the 1980s, to as high as 1 case per 68 children in 2014 (Christensen et al., 2016; Nevison, 2014). Currently, autism affects > 3 million people in the US and tens of millions in the world (Buescher et al., 2014). Since there is no cure, children with autism and their families can face a lifetime of adverse consequences related to impaired behavioral functioning (Newschaffer et al., 2007). The economic burden of autism in the US was estimated to be $268 billion in 2015 (Leigh and Du, 2015); the cost may exceed $2 million for individual lifelong care (Buescher et al., 2014).

It is believed that autism results from a combination of genetic and environmental factors (Chaste and Leboyer, 2012; Hallmayer et al., 2011; Newschaffer et al., 2007). Early studies focused on understanding genetic risk factors because high heritability was found in patients with autism (Bailey et al., 1995; Chaste and Leboyer, 2012). The rapid increase in autism prevalence has spurred researchers to explore environmental factors (Chaste and Leboyer, 2012; Dietert et al., 2011; Landrigan, 2010; London, 2000; McDonald and Paul, 2010; Nevison, 2014). Studies have linked autism to many of these, including pesticides, phthalates, polychlorinated biphenyls (PCBs), solvents, toxic waste, air pollutants and heavy metals (e.g., mercury, lead) (Becerra

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et al., 2013; Kalkbrenner et al., 2010; Kalkbrenner et al., 2014; Palmer et al., 2006; Raz et al., 2015; Roberts et al., 2007; Rossignol and Frye, 2014; Volk et al., 2013; Windham et al., 2006). However, no single environmental factor can explain the increased prevalence of autism (Dietert et al., 2011).

Green space is land partly or completely covered with grass, trees, shrubs or other vegetation (e.g., parks, forests, green roofs, and community gardens). It has positive influences on human health through direct and indirect pathways, such as encouraging physical activity and social contact (Maas et al., 2009; Mitchell and Popham, 2008; Wolch et al., 2014), and mitigating noise and traffic-related air pollution (Gidlof-Gunnarsson and Ohrstrom, 2007; Mitchell and Popham, 2008; Wolch et al., 2014). These influences promote physical fitness and maternal health (e.g., beneficial effects on pregnancy outcomes), and reduce the prevalence of some chronic illnesses such as obesity and cardiovascular disease (Coombes et al., 2010; Gidlof-Gunnarsson and Ohrstrom, 2007; Hystad et al., 2014; Lee and Maheswaran, 2011; van den Berg et al., 2015). Exposure to green space has been associated specifically with mental health (Beyer et al., 2014; Gascon et al., 2015). Access to gardens or other green space, and use of parks and playgrounds may reduce conduct and hyperactivity problems and improve attention and behavioral development in children, especially those with attention-deficit hyperactivity disorder (ADHD) (Amoly et al., 2014; Flouri et al., 2014; Kuo and Taylor, 2004; Li and Sullivan, 2016; Markevych et al., 2014; Taylor and Kuo, 2009). Additionally, exposure to green space may have a long-term influence on children's cognitive development (Dadvand et al., 2015; de Keijzer et al., 2016).

In this exploratory analysis, we hypothesized that neighborhoods with more green space would have lower autism prevalence. In California, autism prevalence has increased continuously in the past 20 years (Autism Society of California, 2012; Croen et al., 2002). Given its large population, California is expected to have a large number of autism cases (Autism Society of California, 2012). In recent years, urbanized area has also gradually increased and vegetation cover (e.g., farmland, forest) has decreased, according to studies on land cover change in South Coast areas in California (Chen et al., 2010; Fischer et al., 2007). This study examined the association of green space (e.g., forest, grassland, tree canopy and near-road tree canopy) and autism prevalence in California elementary school districts. It presumes that children were born and raised in the school districts where they matriculated at the time of the autism data collection. This work is the first attempt to examine whether green space could help mitigate childhood autism prevalence.

2. Methods

2.1. Study setting

This study was carried out in California—the most populous US state, with the largest number of public school students (Keaton, 2013). In California, there are about 560 public elementary school districts and 330 united school districts which include both elementary and high schools. According to statistics from the California Department of Education (http://www.cde.ca.gov/ds/sd/cb/cefenrollgradetype.asp), about 3 million children were enrolled in public elementary schools in the 2014–15 school year.

2.2. Childhood autism data

The number of children with autism in all public elementary school districts (kindergarten –grade 5, ages from 5 to 12 years) in 2010 was collected by the California special education management information system (CASEMIS) under the California Department of Education. The data are publicly accessible through the website of the Los Angeles Times (http://spreadsheets.latimes.com). The case definition of childhood autism is listed under the California Special Education Reference, Code of Federal regulations (CFR), 34 CFR Section 300.8(c)(1). Because the united school districts also include high schools, we excluded them from the analysis. We obtained autism count data and the number of students for 543 public elementary school districts, and matched these data with the location of each school district using ArcGIS 10.3 (ESRI, CA). Autism prevalence or prevalence rate was calculated using the number of autism cases divided by the number of students in these school districts.

2.3. Demographic and socioeconomic status data

Demographic and socioeconomic status (SES) data for the total population within each elementary school district were originally collected by the 2009 American Community Survey, US Census Bureau. From these datasets, we generated 10 indicators, including the percentages of males and females, the percentages of children (age ≤ 19) and older adults (age ≥ 65), the percentages of white, Asian, and black populations, the percentage of households without a vehicle, the percentage of unemployed population, and median annual household income. These variables were selected because many of them were considered in other studies (Becerra et al., 2013; Volk et al., 2013) as potentially associated with autism. The percentage of households without a vehicle was selected as a potential proxy for income; it also suggests a greater likelihood of local versus more distant environmental influences during non-work hours.

2.4. Exposure to green space

We assessed exposure to green space using publicly available remotely-sensed data on general land cover composition, and both average and near-road tree canopy in each school district. The first two types of measures estimate overall outdoor greenness that may support healthful lifestyles and buffer environmental hazards in the residential vicinity. Near-road tree canopy reflects the potential buffering effect of tree cover on exposure to traffic-related noise and air pollution; the latter in particular has been suggested as a possible maternal risk factor for autism (Volk et al., 2013).

2.4.1. Calculating land cover components

Land cover data were obtained from the National Land Cover Dataset (NLCD) 2011, created by classifying Landsat images to a spatial resolution of 30 m. Based on the NLCD classification system, land cover in each school district comprised 9 major categories: water, open land (developed open space, e.g., campus grounds, golf courses), urban land (≥ 20% impervious surface, e.g., moderate density residential, commercial), barren land, forest, shrubland, grassland, agriculture and wetland. We were particularly interested in forest, grassland, and urban land; the first two represent common green spaces in and around developed settings (Maas et al., 2006), and the last one may be an important promoting factor for autism, as studies have suggested increased autism risk from urbanicity (Becker, 2010; Lauritsen et al., 2014). The land cover image was first clipped by the 2010 school district boundary layer obtained from the US Census Bureau; then the percentages of these land cover classes in each school district were calculated using ArcGIS 10.3.

2.4.2. Calculating average tree canopy

The tree canopy data were obtained from the NLCD 2011 Cartographic Canopy dataset (http://www.mrlc.gov/nlcd11_data.php) created by the United States Forest Service (USFS). This dataset consists of a single raster layer of percent tree canopy, with a pixel size of 30 m. Each pixel has a value ranging from 0 to 100%, indicating the proportion of the pixel covered by tree canopy. These data are key to estimating tree cover in areas with ≥ 20% impervious surface, where no vegetation is captured by the NLCD classified land cover product. We clipped the tree canopy layer to each school district and averaged the