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ABSTRACT

This study used ZIP code level data on children's health (National Survey of Children's Health, 2012) and land cover (National Land Cover Database, 2011) from across the United States to investigate connections between proximity to green space (tree canopy), gray space (impervious surfaces), and expression of a critical co-morbid condition, anxiety, in three groups of youth: children diagnosed with autism spectrum disorder (ASD, n = 1501), non-ASD children with special healthcare needs (CSHCN, n = 15,776), and typically developing children (n = 53,650). Both impervious surface coverage and tree canopy coverage increased the risk of severe anxiety in youth with autism, but not CSHCN or typical children. Children with ASD might experience the stress-reducing benefits of nature differently than their typically developing peers. More research using objective diagnostic metrics at finer spatial scales would help to illuminate complex relationships between green space, anxiety, and other co-morbid conditions in youth with ASD.

1. Introduction

Exposure to nature and green space confers a wide array of physical, mental, and social health benefits (Hartig et al., 2014; Jennings et al., 2016; Shanahan et al., 2015b). Furthermore, exposure to natural environments is associated with improved mental health outcomes, lower stress and anxiety, and improved attentional states. However, most studies examining relationships between green space, health, and well-being focus on adults (Berman et al., 2008; Bratman et al., 2015; Kuo, 2015) or typically developing children (Bagot et al., 2015; Berto et al., 2015; Schutte et al., 2017; Taylor et al., 2002). Although some studies have focused on children with ADHD (Taylor and Kuo, 2009, 2011; Taylor et al., 2001; Wells, 2000), there remains a growing need to expand understanding of the impacts of nature and green space on the mental health of youth, who have much to gain from the restorative potential of nature (Dzhambov et al., 2018; Kaplan, 1995; Taylor and Kuo, 2006; Williams, 2017). This study investigates connections between proximity to green space (environments with high vegetation density), gray space (human-constructed environments), and expression of a critical co-morbid condition, anxiety, in youth with and without autism spectrum disorder (ASD).

1.1. Connections between Green Space & Children's Mental Health

The effects of nature exposure on children's mental health are often interpreted with respect to Attention Restoration Theory (ART), which posits that natural environments enhance attentional functioning (Berman et al., 2008; Bratman et al., 2012). Attention is a foundational

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executive function (EF), with strong associations with inhibitory control (i.e., the capacity to stop a naturally occurring response) and working memory (i.e., the capacity to maintain information within one's scope of attention in the face of distractions) (Miyake et al., 2000; Schutte et al., 2017). ART builds on William James's theory of attention and maintains that natural environments encourage the restoration of attentional capacity by capturing involuntary attention and relieving the burden of directed attention focused on omnipresent stimuli in non-natural settings (Kaplan, 1995). In urban areas, these non-natural settings are often defined by gray infrastructure, or “gray space,” comprised of roads, buildings, and other constructed features (Benedict and McMahon, 2006). To test the concepts of ART, researchers have relied on ratings scales designed to measure attention and/or attentional functioning, such as the Attention Deficit Disorders Evaluation Scale (Bagot, 2004; Wells, 2000), the Perceived Restorativeness Scale (Bagot et al., 2015; Ulrich, 1983), and a variety of in vivo executive and attentional functioning tasks (Berto et al., 2015; Schutte et al., 2017; Tennessen and Cimprich, 1995). Collectively, research indicates that exposure to more natural environments is associated with positive effects on typically developing children's attention and working memory (Bagot, 2004; Bagot et al., 2015; Dadvand et al., 2015; Kelz et al., 2013; Taylor et al., 2002; Tennessen and Cimprich, 1995; Wells, 2000).

Despite a historical focus on cognitive functioning, the influence of nature on affective dimensions of children's mental health might be equally important (Bratman et al., 2012). A complementary explanation of nature's effects on humans is stress reduction theory (SRT). SRT maintains that contact with nature or natural environments reduces stress through ameliorative physiological and psychological responses (Hartig et al., 2014; Ulrich, 1983). Assessment of these responses, often tracked through mood reports or physiological data (e.g., blood pressure, skin conductance, cortisol levels, neural activity), suggest that viewing natural scenes and vegetation (Kahn et al., 2009; Li and Sullivan, 2016; Ulrich, 1981, 1986) or experiencing nature directly (Bratman et al., 2015; Cole and Hall, 2010; Park et al., 2010) minimizes stress and stress-inducing processes such as cognitive rumination. Because stress and anxiety are strongly related, particularly in children (Mash and Barkley, 2003), these nature-based stress reduction strategies might help alleviate certain symptoms of anxiety-related disorders. However, there are few studies exploring the role of SRT in children's mental health, and most of these data focus on blood pressure and mood reports (Berto et al., 2015; Taylor et al., 2002; Ulrich, 1983). Some evidence suggests that nature exposure in typically developing youth positively impacts stress responses (Kelz et al., 2013; Li and Sullivan, 2016; Taylor et al., 2002; Wells and Evans, 2003), including mitigation of aggressive behaviors (Roe and Aspinall, 2011; Younan et al., 2016), but the stress inducing capacity of gray space and the stress recovery functions of green space (nature) in younger children, particularly children with disabilities, remains largely unexplored.

Currently, the literature examining connections between nature and the health and wellbeing of youth has primarily focused on one disability group: children with attention deficit hyperactivity disorder (ADHD). Research suggests that exposure to natural environments improves ADHD symptom expression (Kuo and Taylor, 2004; Taylor and Kuo, 2009, 2011; Taylor et al., 2001). For example, one experimental study reported that when children with ADHD took a 20 min walk in a city park, they had higher scores on a working memory task than after walking in downtown or residential areas (Taylor et al., 2009). This body of research highlights the value of natural environments for augmenting therapeutic interventions. However, much work is needed to detail how natural settings can be incorporated into interventions and what the appropriate “doses of nature” might be (Dzhambov et al., 2018; Shanahan et al., 2015a; Taylor and Kuo, 2011). Furthermore, there is a need to consider whether nature exposure might be beneficial for populations with developmental disabilities such as autism spectrum disorder (ASD) and stress-related co-morbidities like anxiety.

1.2. Autism, anxiety and potential benefits of stress reduction

The primary behavioral markers of ASD are atypical social-communication and restrictive and repetitive behaviors or interests (American Psychiatric Assocation, 2013; Bodfish et al., 2000; Lord et al., 2000; South et al., 2005). ASD affects 1 in 59 children and is associated with a number of cognitive and affective co-morbidities (Baio, 2018); a large body of evidence indicates that children with ASD have difficulties on a number of tasks related to problem solving and intellectual abilities (Hill, 2004; Pellicano, 2012). For example, many children with ASD have cognitive deficits and/or atypical information processing styles that may hamper their academic abilities, potentially affecting co-morbid learning disorders (Hill, 2004; Pellicano, 2012; Russell et al., 1996).

Children with ASD are also at greater risk for developing significant co-morbid anxiety conditions (e.g., generalized anxiety disorder) than typical peers and other clinical groups (Wood and Gadow, 2010); up to 39% of children with ASD have a co-morbid anxiety disorder and many others display sub-clinical anxiety traits (Van Steensel et al., 2012; White et al., 2009). Anxiety in ASD is associated with increased aggression, conduct problems, depression, self-injury, insistence on sameness, and irritability (Ambler et al., 2015; Lidstone et al., 2014; Mayes et al., 2011). Interestingly, some data supports the idea that anxiety in children with ASD is associated with *greater* cognitive, verbal, and/or developmental functioning (Hallett et al., 2013). Researchers theorize that children with ASD and greater social and cognitive capacity functioning may lead to increased awareness of their social differences, which could lead to increased levels of anxiety (Hallett et al., 2013, p., 2350; Wood and Gadow, 2010). However, other data indicates that anxiety disorders are more common in individuals with lower abilities (Van Steensel et al., 2012).

The heterogeneity in this literature likely relates to the variety of instruments used to assess anxiety symptoms (Wigham and McConachie, 2014), the particular sub-type of anxiety considered (e.g., separation, social, specific phobia) (Van Steensel et al., 2011), and difficulties related to accurately measuring anxiety in non-verbal children with ASD (Hallett et al., 2013). A recent meta-analysis supports the general view that increased anxiety is indeed positively correlated with cognitive abilities (Van Steensel and Heeman, 2017); however, previous work indicates that the relationship between anxiety and cognitive ability may vary according to anxiety subtypes (Van Steensel et al., 2011).

Overall, research indicates that anxiety symptoms are elevated in populations with ASD, and co-morbidities are high. Additionally, a study analyzing cross-sectional data from students in California suggests the prevalence of ASD in youth may be negatively linked to vegetation and tree canopy coverage and positively linked to road density (Wu and Jackson, 2017). Thus, individuals with ASD are an intuitive group in which to explore the relationship between nature exposure and anxiety, testing the general framework of SRT. According to SRT, the propensity for anxiety in youth with ASD might be exacerbated by exposure to urban development and positively impacted by time in nature.

1.3. Operationalizing “Nature”

Before the impacts of nature on anxiety can be assessed, “nature” must be defined. Natural environments are perceived and experienced by humans in a variety of ways (Hartig et al., 2014; Kaplan and Kaplan, 1989). Collectively, these social conceptualizations and objective realities often result in a definition of nature that encompasses easily perceived natural features (e.g., trees and forests, animals, water bodies) and process (e.g., wind, clouds and rain, sunlight) (Bratman et al., 2012; Hartig et al., 2011). Therefore, the task of converting the complex concept of nature into measurable variables impacting human health is inherently difficult. Some studies have focused on psychological responses to natural attributes such as vegetation, wildlife, and landscapes (Kahn et al., 2009; Li and Sullivan, 2016; Ulrich, 1986). Others have focused on ecological features such as species diversity (Dallimer et al., 2011; Hanski et al., 2012) or ecosystem services (Jennings et al., 2016; Smith et al., 2013) as indicators of health promoting natural environments.

Perhaps the most frequent approximations of nature in health research feature spatial assessments of green space, a common category of land use that describes land partly or completely covered by grass, trees, or other vegetation (often including parks, gardens, etc.) and may be located in urban, agricultural, or rural settings (Lee and Maheswaran, 2010). In this context, spatially-derived proxy measures of nature include public park land (Larson et al., 2016), general green space (Alcock et al., 2014; Maas et al., 2006; Mitchell and Popham, 2008; Richardson et al., 2012), and more precise measures of variability in vegetation cover such as the normalized difference vegetation index (Cohen-Cline et al., 2015; James et al., 2016; Wolfe and Mennis, 2012).

Our study utilized a similar spatial approach, focusing on two categories of land cover that help define the naturalness of a landscape: green space (measured as tree canopy coverage) and gray space (measured as impervious surface coverage). Trees are critical components of green space with established links to physiological and psychological aspects of human health (Hartig et al., 2011; Sanesi et al., 2011; Ulmer et al., 2016). By improving air quality (Dadvand et al., 2015; Donovan et al., 2013; Lovasi et al., 2013), mitigating urban heat effects (Jesdale et al., 2013), and performing a number of other important ecosystem services (Nowak et al., 2014), trees create health promoting environments. By increasing the aesthetic, recreational, restorative, and socio-cultural value of landscapes, trees can also facilitate active lifestyles and enhance mental and social health (Holtan et al., 2015; Schwarz et al., 2015; Smardon, 1988; Ulmer et al., 2016). Forest canopy coverage therefore represents a useful proxy for nature, particularly in urban areas (Nowak et al., 1996).

Towards the other end of the urban-natural spectrum lies impervious surface, including all land areas where man-made materials (e.g., buildings, roads) exist, commonly referred to as “gray space” (Benedict and McMahon, 2006). Research shows that impervious surfaces compromise watershed functioning and ecological processes (Arnold and Gibbons, 1996; Jackson, 2003; Jim, 2004) and may precipitate a number of human health problems (Frazer, 2005). In fact many of the health promoting physical (e.g., ecosystem services) and psychological (e.g., differing degrees of cognitive and affective stimulation) elements of nature exposure are absent in settings dominated by impervious surfaces (Bratman et al., 2012). As urbanization progresses and impervious surface coverage continues to grow at the expense of green space (Nowak and Greenfield, 2012), these health impacts could become more pronounced. Impervious surface therefore represents an effective proxy for anthropogenic impacts and human ecological footprints (Sutton et al., 2009).

Using these two spatial metrics as a proxy for nature, we sought to determine whether exposure to nature is associated with decreases in the severity of co-morbid anxiety symptoms in children with and without ASD. We hypothesized that, for youth with ASD as with their typically developing peers, anxiety symptoms would be more severe in settings dominated by impervious surfaces or gray space (H_1) and less severe for youth in settings characterized by higher tree canopy coverage or green space (H_2).

2. Methods

2.1. Autism & anxiety data sources

Autism data came from the Maternal and Child Health Bureau of the Health Resources and Services Administration funded National Survey of Children's Health (NSCH; Child and Adolescent Health Measurement Initiative, 2017). The 2011–2012 version of the NSCH includes 95,677 parent or guardian-reported surveys collected on typical and atypically developing U.S. children (aged 0–17 years) across the entire United States. ZIP code level data is available at the Research Data Center housed at the Center for Disease Control in Atlanta, GA (CDC-RDC).

All analyses were conducted with subsets of data from three diagnostic groups: 53,609 typically developing children (typical youth), 1501 children with ASD (youth with ASD), and 15,723 children without ASD who had other special healthcare needs (CSHCN). All youth were between the ages of 6 and 17; six was selected as the lower threshold age for identification because the majority of children with ASD are identified by the age of six (Maenner et al., 2013). Extant research supports the validity of the NSCH autism data, which comports with data from the CDC's Autism Developmental Disability Monitoring Network (CDC-ADDM; the 14 site ASD epidemiology and tracking network) and National Health Interview Survey (Blumberg et al., 2013).

For regression analyses, children were split into two anxiety groups based on responses to the following two questions: (a) “Does [Child] currently have anxiety problems?”; (b) “Would you describe [his/her] anxiety problems as mild, moderate, or severe?” Children whose caretakers stated that they either had no or mild anxiety problems were classified as “No/Low” severity ($n = 69,267$; typical = 53,528, ASD = 1125, CSHCN-no ASD = 14,614), and children whose caretakers stated they had moderate or severe anxiety were classified as “Moderate/Severe” ($n = 1651$; typical = 1157, ASD = 373, CSHCN-no ASD = 121).

2.2. Green space data sources

Green space data came from the National Land Cover Database (NLCD) (http://www.mrlc.gov/nlcd2011.php); a publicly available dataset of land cover classifications across all 50 United States (Homer et al., 2015), including spatial layers for canopy cover and impervious surface. We used the 2011 NLCD data to develop ZIP code level measures of tree canopy and impervious surface coverage for the entire United States. ZIP code level values were calculated with zonal statistics in ArcGIS. Pixels were considered in a ZIP code if their center fell within the boundary based on ZIP code tabulation areas determined by the US Census Bureau (https://www2.census.gov/geo/pdfs/education/brochures/ZCTAs.pdf). These are the closest approximation to USPS ZIP codes available. The land cover classes found in NLCD are created through classification of multispectral satellite imagery. Using training data of verified land cover types, different measures of reflectance are categorized by way of machine learning models (Homer et al., 2015). The NLCD is a best estimate of actual land cover.

Impervious surface coverage (gray space) was operationalized as the percentage of a ZIP code area that has been covered by constructed (non-natural) surfaces (e.g., paved street surfaces, buildings/rooftops). Impervious surface data in the NLCD is derived from satellite imagery classification, topography, and nighttime light imagery.

Tree canopy coverage (green space) was operationalized as the percentage of a ZIP code area covered by tree canopy, with values potentially ranging from 0% to 100%. Tree canopy data in the NLCD is derived from a process involving derivation of canopy density from high resolution aerial images and models calibrated using reference data and Landsat satellite imagery (Huang et al., 2001). Regression tree algorithms are used to map a per-pixel percent tree canopy value for the United States. Resulting estimates are then compared to sample sites for validation (Homer et al., 2015). The final product is at a spatial resolution of 30-meter pixels (Yang et al., 2003).

We provided the CDC-RDC with the NLCD data file, and the CDC-RDC merged the NSCH (2011/2012) with the NCLD files at the ZIP code level. In June 2018, we analyzed the data at the CDC-RDC. The CDC-RDC then checked all statistical files and masked data when identification could be of concern.

Table 1
Distribution of typically performing children (typical youth), children with special health care needs without autism (CSHCN), and children with autism spectrum disorder (youth with ASD) among anxiety categories and across model covariates (Co-morbid conditions and socio-demographic attributes).

Variables	Typical Youth	CSHCN	Youth with ASD
Total Sample	53,650	15,776	1501
Anxiety			
None	53,216	13,601	929
Mild	312	1013	196
Moderate	112	906	258
Severe	9	251	115
ASD			
None	53,639	15,723	0
Mild	0	0	832
Moderate	0	0	491
Severe	0	0	178
Depression			
None	53,454	14,408	1303
Mild	135	695	87
Moderate	52	520	78
Severe	9	145	32
Conduct Problems			
None	53,481	14,078	1066
Mild	81	500	128
Moderate	78	831	193
Severe	9	364	112
IQ Problems			
None	53,613	15,185	1183
Mild	22	215	98
Moderate	^	^	^
Severe	^	^	^
Learning Problems			
None	52,200	12,159	458
Mild	1050	1749	336
Moderate	355	1418	456
Severe	37	434	244
ADD/ADHD			
None	52,741	10,693	851
Mild	674	2081	161
Moderate	217	2321	322
Severe	15	655	166
Age			
Early Childhood	21,260	6996	551
Middle Childhood	16,403	3851	413
Adolescence	15,987	4929	537
Race/Ethnicity			
White	34,723	10,578	1070
Black	4929	1671	110
Hispanic	7116	1623	131
Other-Unspecified	6882	1904	190
SES			
< =100 of poverty	7155	2652	246
100–199%	9234	2917	314
200–299%	8826	2473	282
300–399%	7984	2134	195
400%+	20,451	5600	464
Maternal Education			
High School	8973	2626	256
Less than High School	3734	923	77
More than High School	36,044	10,482	1022

Note: ASD = Autism Spectrum Disorder; CSHCN = Children with Special Healthcare Needs; All data derived from National Survey for Children's Health (NSCH 2011–12; Child and Adolescent Health Measurement Initiative, 2017).

2.3. Model covariates

When assessing relationships between autism, anxiety, and green space our statistical models accounted for several important covariates related to anxiety and ASD. First, participants were subdivided based on whether they had ASD or not (e.g., typical youth, CSHCN, youth with ASD). Severity of symptoms related to the following co-morbid conditions associated with ASD and/or anxiety were also considered: depression (Strang et al., 2012), behavioral or conduct problems (Hill et al., 2014), intellectual disability or mental retardation (Baio, 2018), learning disability (Nelson and Harwood, 2011), and ADHD (Simonoff et al., 2008). These were all considered as ordinal variables indicating expression of symptoms at the following levels: none, mild, moderate, or severe (see Table 1 for details).

Because ASD and anxiety are often associated with a variety of socio-demographic attributes, many of which (e.g., income, education) also co-vary with proximity to green and gray space, these variables were considered in our analysis as well (Anderson and Mayes, 2010; Bal et al., 2013; Crespi, 2016; Van Wijngaarden-Cremers et al., 2014). We assessed gender, and age grouped by early (6 – 7 years), middle (8 – 12 years), and adolescent (13 − 17) years. Race/ethnicity was divided into non-Hispanic White, non-Hispanic Black, non-Hispanic Other/Unspecified, and Hispanic. Socio-economic status was assessed with respect to poverty level and divided into Less than 100% (i.e., below poverty line), 100–199%, 200–299%, 300–399%, 400–499%, and 400+% above poverty line. Maternal education included Less than High School, High School, and greater than High School. Table 1 highlights the distribution of youth in all three diagnostic groups for each of these covariates.

2.4. Data analysis

We used weighted and stratified binary logistic regression models using the R 'survey' package (Lumley, 2004, 2011) to evaluate the relationship between nature (canopy coverage and impervious surface) and anxiety severity in children at the ZIP code level, including interaction terms to test H_1 and H_2. We also controlled for the covariates specified above, including ZIP Code size. NSCH results are weighted by the probability of survey selection with adjustments based on state demographic factors and whether the interview took place via cellphone or landlines; analyses reflect adjustments based on weights and stratifications per NSCH recommendations. To determine the predictive value of key environmental variables and covariates, we used the Rao-Scott test with appropriate adjustments based on survey weights and stratifications. Odds ratios (and corresponding confidence intervals) were assessed to compare the relative effects of predictor variables on anxiety severity.

3. Results

Descriptive statistics indicated slight differences between the low and high anxiety groups of youth across all ASD diagnostic groups with respect to ZIP code size, impervious surface and tree canopy coverage (Table 2). Results of the logistic regression model supported the existence of a relationship between the predictor and outcome variables, though much of the variance in anxiety severity was unaccounted for in the final model (Nagelkerke's $R^2 = 0.38$). When considered altogether, we did not observe a relationship between canopy coverage or impervious space and anxiety severity. However, when investigating planned interactions with gray space and green space based on ASD categorization, we found that proximity to gray space and green space appeared to affect youth with ASD differently than their typically developing peers (Table 3). In youth with ASD, both impervious surface ($OR = 1.03$, 95%CI = 1.01–1.05, $p < .05$) and tree canopy coverage ($OR = 1.03$, 95%CI = 1.01–1.05, $p < 0.05$) were significantly associated with higher odds of moderate to high levels of anxiety problems, supporting H_1 but refuting H_2. Contrary to our hypotheses, similar relationships were not observed for typically developing youth or those with other special health care needs.

Most of the other significant relationships in the model were expected. Youth with ASD and other special health care needs had higher levels of anxiety compared to typical children (Table 3). Across groups, conditions comorbid with anxiety were associated with increased odds of moderate to high levels of anxiety, including depression, behavioral or conduct problems, learning disability, and ADHD (Table 3).

Table 2
Description of ZIP code size and land cover characteristics for typically performing children (typical youth), children with special health care needs without autism (CSHCN), and children with autism spectrum disorder (youth with ASD) with different levels of anxiety in NSCH (2011–12).

Variable	Typical Youth		CSHCN		Youth with ASD	
	No Anxiety	Anxiety	No Anxiety	Anxiety	No Anxiety	Anxiety
ZIP code size (km^2)						
Mean	209.24	208.14	201.61	173.31	209.77	132.17
SD	381.65	397.31	370.85	260.44	399.41	225.20
Range	8164.98	8164.92	8164.83	2419.25	8164.92	1173.32
% Impervious Surface						
Mean	15.50	13.43	15.65	14.91	16.13	21.16
SD	18.18	16.41	18.39	17.66	19.01	21.16
Range	94.69	74.88	91.54	75.08	89.52	72.06
% Canopy Coverage						
Mean	31.85	33.39	32.52	36.14	33.17	31.01
SD	22.58	22.84	22.58	22.84	22.47	23.16
Range	94.33	83.54	94.33	83.54	87.50	68.52

Note: ASD = Autism Spectrum Disorder; CSHCN = Children with Special Healthcare Needs; Mental health data derived from National Survey for Children's Health (2011–12; Child and Adolescent Health Measurement Initiative, 2017); Land Cover data derived from National Land Cover Database (2011; Homer et al., 2015).

Regarding socio-demographic variables, associations with moderate to severe anxiety were observed for age (lower odds for early childhood), sex (lower odds for males), race (lower odds for non-White groups), SES (higher odds for 200–299% poverty range), and maternal education (higher odds for youth with more educated mothers; Table 3).

4. Discussion

Our study, the first of its kind to explicitly examine the relationship between nature exposure and anxiety in youth with ASD relative to their peers, indicates positive but relatively weak statistically significant relationships between children's anxiety and ZIP code level data for both impervious surface and tree canopy coverage across the United States. The observed link between impervious surface and anxiety in youth with ASD supported our initial hypothesis (H_1). Attention restoration theory (ART) suggests that neurocognitive over-stimulation and the directed attention fatigue associated with life in urban (impervious) environments can exacerbate mental health problems; these issues can be mitigated by restorative time in nature (Kaplan, 1995). Stress reduction theory (SRT) holds that exposure to natural areas and features can increase distance to common stressors, decrease their perceptual salience, and exert a calming influence via physiological regulation (Hartig et al., 2014). In many cases, these stressors emerge in human-built environments dominated by impervious or gray space. As a result, people often seek escape from physical and social stressors by visiting and recreating in natural areas (Home et al., 2012; More and Payne, 1978). Contact with nature evokes positive affect, which in turn blocks negative or stressful thoughts and feelings (Ulrich, 1983, 1986). Literature reviews confirm these findings, revealing reliable evidence of reductions in self-reported anger, fatigue, anxiety, and sadness following contact with natural environments (Bowler et al., 2010; Hartig et al., 2014). Although very few studies explore the relationship between nature and mental health in children with disabilities, limited research focused on youth with ADHD (Taylor and Kuo, 2009, 2011) and ASD (Wu and Jackson, 2017) suggest similar trends. Our findings related to impervious surfaces and anxiety severity in youth with ASD also seems to support the conclusion that increased exposure to gray space and diminishing opportunities for contact with nature may negatively impact children's mental health.

Unexpectedly, however, our model revealed a similar positive relationship between anxiety and green space for youth with autism, refuting H_2. Based on SRT, ART, and existing literature, we anticipated an inverse relationship between anxiety and tree canopy coverage; instead, youth with ASD generally expressed higher levels of anxiety in areas with greater tree canopy coverage. There are several potential explanations. First, although statistically significant, the reported odds for both impervious surface and canopy coverage were small and the full model did not account for much of the variance in reported anxiety severity. In other words, the practical significance of these relationships in youth with ASD may be minimal.

The observed relationships, and the absence of similar results for typically developing youth and youth with other special health care needs, may also be confounded by our scale of analysis. Many researchers note the constrained inferential capacity of studies that examine health impacts of highly variable environmental attributes (e.g., impervious surface, tree canopy coverage) at broad spatial scales (e.g., ZIP codes). In many cases, exposure to neighborhood green space is assessed in very local contexts, often less than 1 km from individuals' place of residence (James et al., 2016; Ulmer et al., 2016; Van den Berg et al., 2015) or school (Dadvand et al., 2015). These studies are based on the assumption that most individuals spend a vast majority of time within close proximity of their home. Under this assumption, green or gray space slightly farther from the home (but within the same ZIP code) that is rarely viewed or experienced might have little influence on mental or physical health. Evidence suggests this assumption may be accurate for urban youth, a group that typically does not travel far from their home neighborhood environment (Villanueva et al., 2012). But other studies highlight the importance of considering broader neighborhood context when evaluating the health of urban environments for youth, considering a wide range of amenities and features that extend well beyond the immediate vicinity of the home (Audrey and Batista-Ferrer, 2015; Wu and Jackson, 2017). Some researchers have even argued that entire cities or metropolitan areas represent an appropriate unit of analysis for evaluating relationships between green space and health, citing their role as larger social-ecological systems and the mobility that many residents enjoy within urban boundaries (Larson et al., 2016; Richardson et al., 2012). Such diverse perspectives span a wide spatial spectrum, suggesting that ZIP code is indeed a viable unit of analysis. However, it is important to reiterate that our approach did not account for restorative attributes of neighborhoods at the street level or other potential mediators (e.g., leisure time physical activity, social cohesion), which may have more nuanced (and perhaps more significant) impacts on the anxiety and mental health of youth including those with ASD (Dzhambov et al., 2018). Similarly, it did not account for distinctions in the quality and structure of green space, which have been shown to influence mental health outcomes in both children (Feng and Astell-Burt, 2017; Richardson et al., 2017) and adults (Wood et al., 2017). On-the-ground, site-based research incorporating both environmental attributes and exposure frequency, intensity, and duration (i.e., nature dose) would yield additional

Table 3
Parameter estimation from the binary logistic regression model predicting anxiety severity (0 = No/Low vs. 1 = Moderate/High) in youth with and without ASD.

Variables	B	SE	Odds	2.5%CI	97.5%CI	Sig.
(Intercept)	− 4.91	0.05	0.01	0.00	0.02	
Impervious Space	0.00	0.01	1.00	0.99	1.02	
Canopy Coverage	− 0.03	0.00	1.00	0.99	1.01	
ZIP Code Area km^2	0.00	0.00	1.00	1.00	1.00	
Diagnostic Groups						
Typical Youth (Ref)						
CSHCN	2.06	0.30	7.87	4.38	14.14	***
Youth with ASD	2.41	0.65	11.60	3.32	40.52	***
ASD Severity						
Mild (Ref)						
Moderate	− 0.37	0.45	0.67	0.28	1.59	
Severe	− 0.17	0.52	0.83	0.29	2.33	
Depression						
None (Ref)						
Mild	2.57	0.27	13.14	7.76	22.27	***
Moderate	2.64	0.34	13.92	7.13	27.18	***
Severe	3.49	0.45	33.17	14.33	76.75	***
Conduct Problems						
None (Ref)						
Mild	1.30	0.28	3.67	2.13	6.34	***
Moderate	1.04	0.24	2.82	1.76	4.53	***
Severe	1.34	0.26	3.90	2.32	6.55	***
IQ Problems						
None (Ref)						
Mild	− 0.10	0.12	1.06	0.59	1.93	
Moderate	− 0.10	0.12	0.87	0.44	1.70	
Severe	− 0.10	0.12	0.64	0.27	1.53	
Learning Problems						
None (Ref)						
Mild	4.03	0.14	1.49	1.12	1.97	**
Moderate	0.59	0.20	1.78	1.19	2.68	**
Severe	0.22	0.34	1.24	0.62	2.47	
ADD/ADHD						
None (Ref)						
Mild	− 0.33	0.17	0.98	0.70	1.36	
Moderate	0.34	0.16	1.41	1.03	1.93	*
Severe	0.29	0.24	1.35	0.84	2.15	
Child Age						
Early Childhood	− 0.28	0.13	0.75	0.59	0.96	*
Middle Childhood	0.16	0.13	1.17	0.91	1.50	
Adolescence (Ref)						
Sex						
Female (Ref)						
Male	− 0.43	0.11	0.65	0.53	0.80	***
Race/Ethnicity						
White(Ref)						
Black	− 0.96	0.20	0.38	0.26	0.57	***
Hispanic	− 0.66	0.30	0.51	0.29	0.92	*
Other	− 0.50	0.16	0.61	0.45	0.82	**
SES						
< =100 of poverty (Ref)						
100–199%	− 0.07	0.18	0.93	0.65	1.33	
200–299%	− 0.56	0.24	0.57	0.35	0.91	*
300–399%	− 0.33	0.25	0.71	0.43	1.18	
400%+	− 0.24	0.22	0.77	0.50	1.19	
Maternal Education						
High School (Ref)						
Less than High School	− 0.01	0.21	1.01	0.67	1.52	
More than High School	− 0.64	0.16	1.90	1.40	2.57	***
ImperviousMean*Group Interaction						
ImperviousMean*Typical (Ref)						
ImperviousMean*CSHCN	− 0.01	0.01	1.00	0.98	1.01	
ImperviousMean*ASD	− 0.03	0.01	1.03	1.01	1.05	*
CanopyMean*Group Interaction						
CanopyMean*Typical (Ref)						
CanopyMean*CSHCN	− 0.01	0.01	1.01	1.00	1.02	
CanopyMean*ASD	− 0.03	0.01	1.03	1.01	1.05	*

Model Fit Statistics: Nagelkerke Pseudo R^2 = 0.38; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

insights regarding the specific relationships between green space, gray space, and wellbeing that can inform urban design and public health promotion (Shanahan et al., 2015a), particularly for youth with disabilities (Taylor and Kuo, 2011).

Results may also have been influenced by the measurement and operationalization of the anxiety variable. On the NSCH, anxiety is reported by the children's caretaker on a subjective scale. Different individuals may therefore have different interpretations of anxiety severity. Our dichotomized version of the NSCH variable provided even fewer details about the inherent variability and complexity associated with anxiety – particularly in youth with ASD. Research suggests that anxiety is a multi-faceted construct with social (e.g. separation anxiety) and asocial dimensions (e.g., physiological arousal). Anxiety is typically viewed as a negative condition associated with higher levels of stress and mental health disorders (Mash and Barkley, 2003). However, some research indicates that increased anxiety is associated with better functioning in social/communication domains in children with ASD (Van Steensel and Heeman, 2017). Future research could therefore dissect the complex relationship between anxiety and nature in youth with ASD in more detail, perhaps using in-depth clinical anxiety measures with sub-scales for social and non-social anxiety facets as well as language/communication outcome variables (Grills and Ollendick, 2003). Self-reported scales for assessing different dimensions of anxiety, mood or other mental health outcomes might enhance validity (Van den Berg et al., 2010; Wells and Evans, 2003). Future research could also employ more objective physiological measures of anxiety or anxiety-induced stress such as blood pressure and heart rate variability (Berto et al., 2015; Kelz et al., 2013; Park et al., 2010; Ulrich, 1981), cortisol levels (Roe et al., 2013; Van den Berg and Custers, 2011; Ward Thompson et al., 2012), or neural activity (Bratman et al., 2015).

The previous explanations highlight potential limitations associated with the scale of analysis and the measurement of key variables. However, it is also possible that youth with ASD represent a unique group whose anxiety is differentially affected by exposure to nature. Some research indicates that, to many youth and adults unaccustomed to spending time outdoors in natural settings, nature is a “wild” or “scary” place that induces anxiety and fear (Gatersleben and Andrews, 2013; Milligan and Bingley, 2007; Stodolska et al., 2013). Negative (or positive) perceptions of natural environments are also influenced by family beliefs and values, leading to very different types of anxiety-inducing experiences for youth experiences depending on familial or cultural context (Bixler and Floyd, 1997). Research also suggests that different structural and spatial dimensions of green space might generate different restorative outcomes (Stigsdotter et al., 2017). For example, in one of the only studies focused on the nature-related health benefits on youth with disabilities (in this case, ADHD), Taylor and Kuo (2011) found that hyperactive children who played in green play settings displayed milder symptoms than those who played in built outdoor or indoor settings, but only if those settings were open grass (i.e., tree-less). By offering higher levels of prospect (field of vision) and lower levels of refuge (places to hide) (Gatersleben and Andrews, 2013), these open, green play spaces may have been perceived as less threatening than those covered by dense tree canopies for both youth with ADHD and youth with ASD. Typically developing youth (Chawla et al., 2014; Younan et al., 2016) and adults (Fan et al., 2011; Holtan et al., 2015; Maas et al., 2009) experience a range of social benefits associated with time in nature that help to enhance mental health. Youth with autism, who tend to be more socially disconnected, may not experience these benefits. Rather than functioning as a restorative force or a stress buffer, it is possible that anxiety and stress for youth with ASD may be exacerbated in settings with dense tree cover. If similar trends are observed in areas dominated by impervious surfaces, then one might conclude that open green space is the optimal natural environment for reducing anxiety in youth with ASD. Future studies that integrate experimental research designs and more precise measures of vegetative cover are needed to test this hypothesis.

5. Conclusion

The cross-sectional data reported here represents a first attempt to examine the relationship between nature exposure and anxiety in youth with and without ASD across the entire United States. Although this ZIP code level spatial assessment precluded fine-scale testing of specific environmental attributes and their causal impacts on different aspects of children's mental health, our models enabled us to test two hypotheses regarding pathways to nature-based health promotion. Results revealed mixed support for stress reduction theory (SRT), showing that both gray space (impervious surfaces) and green space (tree canopy) increased the risk of severe anxiety in youth with autism. More work is needed to investigate and understand the unexpected association between tree canopy coverage and anxiety. Is this relationship unique to youth with ASD, who might experience the stress-reducing benefits of nature differently than their typically developing peers? Would the observed relationship hold if a similar study was conducted at finer spatial scales using more refined and objective diagnostic metrics? What other environmental and social factors influence associations between anxiety and green space? Future research should explore these possibilities by systematically evaluating the restorative potential of nature exposure for children and adolescents, especially those with developmental disabilities.

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