



# Residential Greenspace Association with Childhood Behavioral Outcomes

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**Objective** To assess the relationship between greenspace exposure and childhood internalizing and externalizing behaviors.

**Study design** We analyzed data from the Cincinnati Childhood Allergy and Air Pollution Study, an ongoing prospective birth cohort. Greenspace exposure was estimated based on children's addresses using normalized difference vegetation index (NDVI) images. Neurobehavioral outcomes were assessed using the Behavioral Assessment System for Children, Second Edition. Regression models adjusted for neighborhood deprivation, maternal education, race, and sex assessed the risk for problematic internalizing and externalizing behaviors at residential greenspace buffers of 200, 400, and 800 m.

**Results** There were 562 and 313 children in our age 7- and 12-year analyses, respectively. At age 7 years, a 0.1-unit increase in NDVI was associated with decreased conduct scores ( $\beta = -1.10$ , 95% CI [-2.14, -0.06], 200 m). At age 12 years, a 0.1-unit increase in NDVI was associated with a decrease in anxiety scores ( $\beta = -1.83$ , 95% CI [-3.44, -0.22], 800 m), decreased depression scores ( $\beta = -1.36$ , 95% CI [-2.61, -0.12], 200 m), and decreased somatization scores ( $\beta = -1.83$ , 95% CI [-3.22, -0.44], 200 m).

**Conclusions** This study provides evidence that increased exposure to residential greenspace is associated with reduced youth's problematic internal and external behaviors, measured by Behavioral Assessment System for Children, Second Edition, at ages 7 and 12 years. Improved understanding of this mechanism could allow for implementation of neighborhood-level approaches for reducing the risk for childhood behavioral problems. (*J Pediatr* 2019;207:233-40).

**G**reenspace is generally defined as open land with some type of vegetative cover, including but not limited to city parks, domestic gardens, nature strips, green roofs, cemeteries, and grounds of institutions such as hospitals and universities.<sup>1,2</sup> Access to greenspace within urban areas can positively impact many aspects of health and well-being.<sup>3,4</sup> Incidence of anxiety and depression is generally lower among adults in urban areas that have more usable greenspace such as parks and gardens, and self-reported well-being is higher compared with urban areas with less greenspace.<sup>5,6</sup> Nutsford et al reported that both higher levels of greenspace and smaller distances from the home to usable greenspace were associated with fewer behavioral symptoms related to depression and anxiety in adults from deprived areas.<sup>7</sup> Carter and Horwitz found a positive association between adults' proximity to greenspace and their reported mental health, providing further support that accessing neighborhood greenspace can exert stronger positive effects on neurobehavioral health compared with physical health.<sup>4</sup> It has been suggested that the relationship between greenspace exposure and health may be even stronger for elderly people and children because they spend more time in the vicinity of their own home.<sup>8</sup>

Mechanisms by which greenspace may influence neurobehavioral problems are multifaceted and may include increasing physical activity, providing neighborhood meeting locations and facilitating social ties, alleviating stress and mental fatigue, preserving microbial diversity, reducing air pollution, and acting as a buffer for ambient noise.<sup>9-13</sup> Though the mechanisms through which greenspace provides health benefits have yet to be fully understood, clinicians have started prescribing exposure to greenspace as a natural treatment for behavioral symptoms related to both mental and physical illnesses.<sup>14</sup>

Given the functional and structural changes that occur in the brain during childhood and adolescence, exposure to greenspace during this critical period of development may influence neurodevelopment.<sup>15</sup> Hence, childhood represents an important target period for interventions.<sup>16</sup> Studies that have examined the relationship of greenspace with pediatric neurobehavioral disorders have primarily focused on externalizing behaviors such as aggression, hyperactivity, and attention deficit disorder.<sup>17-21</sup> Fewer have evaluated the impact of greenspace exposure on internalizing behaviors such as anxiety and depression in children.<sup>22</sup> With an estimated 31.9% of teenagers aged 13-18 years in the US suffering from a diagnosed anxiety disorder,<sup>23</sup>

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BASC-2 Behavioral Assessment System for Children, Parent Rating Scale, Second Edition  
CCAAPS Cincinnati Childhood Allergy and Air Pollution Study  
NDVI Normalized difference vegetation index

identifying population-level methods for prevention and treatment of all adolescent mental disorders through modifiable environmental factors deserves significant attention. Therefore, this study aims to explore the potential relationship between residential greenspace and both internalizing and externalizing behaviors at 2 time points for children residing in an urban environment.

## Methods

The study population is composed of children enrolled in the Cincinnati Childhood Allergy and Air Pollution Study (CCAAPS), an ongoing prospective birth cohort for which children were selected by age 6 months based on their residence at time of birth being either near (<400 m) or far (>1500 m) from a major highway or bus route in the Cincinnati, Ohio metropolitan area (born between October 2001 and July 2003).<sup>24</sup> At ages 1-4, 7, and 12 years, children enrolled in CCAAPS completed clinical examinations where a medical history, residential history, and physical examination were taken.<sup>25</sup> Parents provided informed consent before their children were enrolled, and this study was approved by the Institutional Review Boards of the University of Cincinnati and the Cincinnati Children's Hospital Medical Center.

### Greenspace Exposure Assessment

Greenspace exposure was estimated based on the children's residential addresses at ages 7 and 12 years using satellite-derived normalized difference vegetation index (NDVI) images. Residential addresses were geocoded using custom TIGER/Line software (US Census Bureau, Washington, DC).<sup>26</sup> A cloud-free composite NDVI raster at a resolution of 100 × 100 m was created by assembling individual images collected in June of 2010 that differed by no more than 15 calendar days. Imagery digital numbers were converted to top of atmosphere reflectance using the standard Landsat calibration process. Top of atmosphere reflectance was then converted to surface reflectance by using the 6S atmospheric correction procedure as described previously.<sup>27</sup> Residential greenspace was estimated by averaging NDVI values within 200, 400, and 800 m of each geocoded address. A 400 m buffer radius was selected a priori, and we followed up using 200 m and 800 m buffer radii to determine how variation in buffer radius might affect our results. A higher NDVI represents more surrounding greenspace, with values ranging from -1 to 1.

### Child Behavioral Assessment

Parents of enrolled children completed the Behavioral Assessment System for Children, Parent Rating Scale, Second Edition (BASC-2) at the 7- and 12-year visits. The BASC-2 is designed to assess a child's adaptive behaviors in both the community and home settings and has been validated for use on a US population.<sup>28</sup> Subscale scores for externalizing behaviors including hyperactivity, attention problems, aggression, and conduct problems, and internalizing behaviors, including depression, anxiety, and somatization, were selected for analysis a priori.

BASC-2 *t* scores were dichotomized into 2 categories: "at risk" or "not at risk" for developing behavioral problems on a given subscale using a cutoff *t* score of >59 and <59, respectively. The "at risk" category is a clinical designation used to indicate children who may be at higher risk for developing behavioral problems on a given subscale.<sup>28</sup> Observations were excluded from the analyses if the F-index score was <0 or >6, indicating a large number of missing items on the BASC-2, a C-index consistency score >17, or an R-index score >125 or <66 suggesting parental inattention to the questionnaire.

### Covariates and Statistical Analyses

Demographic information was collected at the first CCAAPS visit, as well as at follow-up visits. At the baseline visit, parents reported their child's sex (male/female) and race (African American/non-African American). At the age 7- and 12-year visits, current information on maternal education levels was collected and dichotomized into 3 categories (high school degree or less/trade school, some college, or college/graduate school).

A deprivation index, described in detail elsewhere,<sup>29</sup> was used to assess community level deprivation based on the census tract in which each child's geocoded residential address was located at the age 7- and 12-year time points. Briefly, a principal components analysis of 8 different socioeconomic census tract-level measures (fraction that graduated high school, fraction of households in poverty, median household income, fraction of population receiving public assisted income, fraction of houses that are vacant, median home value, fraction of population white, fraction of population black) from the 2010 American Community Survey was used to calculate an index that ranges from 0 to 1, with a higher value indicating more deprivation.

Potential confounders were identified using a causal inference framework based on previous work linking environmental exposures with behavioral outcomes,<sup>18,22</sup> and on established risk factors for childhood behavioral disorders within the CCAAPS cohort.<sup>25</sup> Colinearity among the covariates was assessed using Pearson correlation and variance inflation factors as appropriate. Because maternal education was highly correlated with household income, it was the sole variable selected to represent individual socioeconomic status in the final model. We carried out a sensitivity analysis using household income instead of maternal education. All regression models were adjusted for sex, race, maternal education, and neighborhood deprivation. We also carried out a sensitivity analysis to deal with possible confounding by stress or distress in the parent-child relationship by further adjusting our models for a *t* score representing relational frustration among children at age 12 years that completed a Parenting Relationship Questionnaire.<sup>30</sup>

Exploratory analysis using splines suggested that the relationship between NDVI and BASC-2 scores was linear. Thus, associations between a 0.1-unit change in NDVI and BASC-2 scores were estimated using linear regression for continuous subscale scores and logistic regression for dichotomized (at-risk, not at risk) subscale scores. Continuous values are reported throughout as a mean and SD and dichotomous values

are reported as number and percentage of total study population. Population characteristics and BASC-2 scores were compared between age 7 and 12 years using a *t* test or  $\chi^2$  test as appropriate. Statistical analysis was carried out in RStudio, v 1.1.453 (J.J. Allaire, Boston, Massachusetts)<sup>31</sup> using the tidyverse,<sup>32</sup> ggplot2,<sup>33</sup> and pastecs<sup>34</sup> packages.

## Results

Of the 762 children enrolled in the CCAAPS cohort, 617 completed the follow-up visit at age 7 years, and 601 had a parent complete the BASC-2. In total, 22 individuals were excluded at age 7 years because of missing data or suggested parental inattention to the BASC-2 questionnaire. After also excluding those with incomplete residential address history or demographic data (*n* = 17), 562 children remained for the age 7-year analysis. At the age 12-year visit, 344 parents completed the BASC-2 and 8 individuals were excluded based on invalid BASC-2 scores. Those with incomplete residential address history or demographic data (*n* = 23) were also excluded for a final sample size of 313 individuals. Population characteristics are described in the **Table** and overall, these did not differ between ages 7 and 12 years. Neighborhood deprivation was negatively associated with NDVI with a Pearson correlation coefficient of -0.5 (*P* < .001) and maternal education was positively associated with NDVI in a  $\chi^2$  analysis (*P* < .001).

Correlation between NDVI values for 200, 400, and 800 m buffer radii at ages 7 and 12 years was assessed. When excluding participants whose residential address changed between the 2 time points, the correlation coefficient was 0.99 for every buffer size. An assessment of the correlation between NDVI at all buffer radii for both ages, including children whose address changed, can be found in **Figure 1**.

Mean *t* scores ( $\pm$ SD) and the percentage of children considered to be “at risk” for selected BASC-2 subscales are reported for both ages in the **Table**. Anxiety *t* scores were significantly higher at age 12 vs 7 years (52.05 vs 49.69, *P* < .001). *t* scores for conduct were significantly lower at age 12 vs 7 years (49.57 vs 51.08, *P* = .04). There were significantly more children in the “at risk” category for anxiety at age 12 vs 7 (25% vs 15%, respectively *P* < .001). For anxiety problems, 36 (11.5%) children were considered “at risk” at both ages, 70 (22.4%) children changed from “not at risk” at age 7 years to “at risk” at age 12 years, and 35 (11.2%) changed in the opposite direction.

### NDVI and Continuous BASC-2 Scores

We assessed the relationship between NDVI and BASC-2 scores using regression models adjusted for mother’s education, neighborhood deprivation, race, and sex (**Figure 2**). At age 7 years, a 0.1-unit increase in NDVI was associated with decreased conduct scores at a 200 m buffer radius only ( $\beta$  = -1.10, 95% CI [-2.14, -0.06]). We did not observe any significant associations between age 7 years NDVI and continuous BASC-2 scores for hyperactivity, anxiety, somatization, depression, or aggression at any buffer radii.

At age 12 years, a 0.1-unit increase in NDVI was associated with a decrease in anxiety scores at an 800 m buffer radius only ( $\beta$  = -1.83, 95% CI [-3.44, -0.22]). Increased NDVI was also associated with decreased depression scores at both 200 m ( $\beta$  = -1.36, 95% CI [-2.61, -0.12]) and 800 m ( $\beta$  = -1.63, 95% CI [-3.00, -0.26]) buffer radii and with decreased somatization scores at 200 m ( $\beta$  = -1.83, 95% CI [-3.22, -0.44]) and 400 m ( $\beta$  = -1.69, 95% CI [-3.08, -0.30]) buffer radii. There were no significant associations between age 12 NDVI and continuous BASC-2 scores for hyperactivity, aggression, or conduct problems at any buffer radii.

### NDVI and Dichotomous BASC-2 Scores

In the clinical setting, children with a score of greater than or equal to 60 in a particular subsection of the BASC-2 are considered to be “at-risk” for that disorder. For this reason, we also examined the relationship between NDVI and dichotomized BASC-2 scores (**Figure 3**). At age 7 years, increased NDVI was significantly associated with decreased risk of conduct problems at 200 m (OR 0.73, 95% CI [0.57, 0.94]) and 800 m (OR 0.74, 95% CI [0.57, 0.96]) buffer radii. At age 12 years, an increase in NDVI was significantly associated with decreased risk of anxiety problems at buffer radii of 200 m (OR 0.69, 95% CI [0.51, 0.94]), 400 m (OR 0.72, 95% CI [0.53, 0.98]), and 800 m (OR 0.61, 95% CI [0.43, 0.84]).

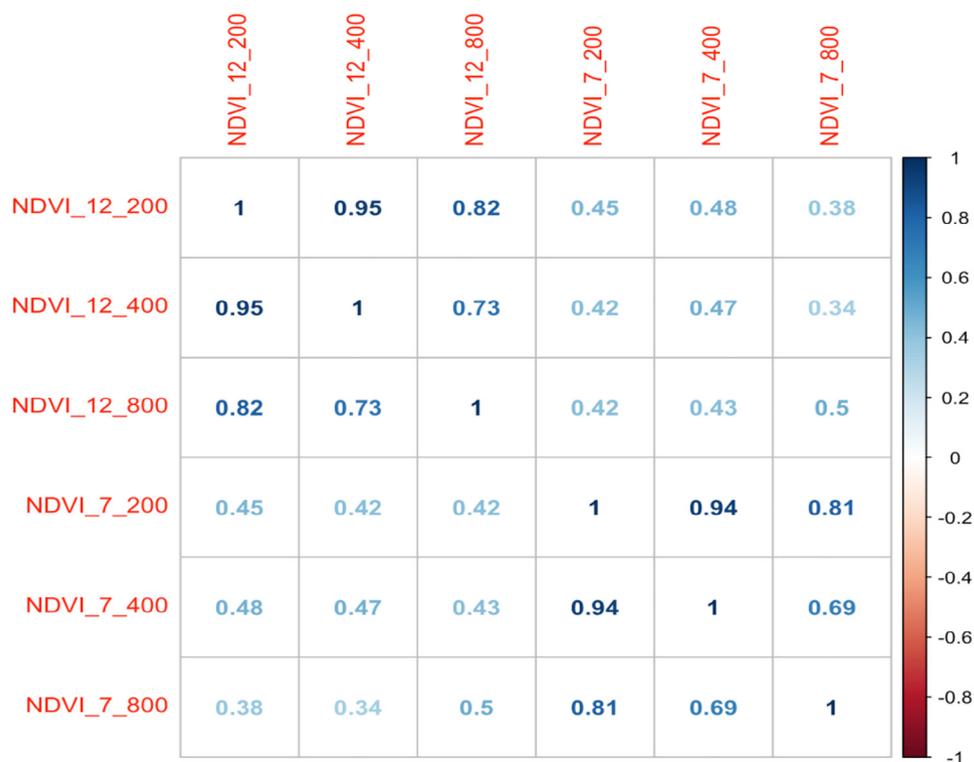
### Age 7-Year NDVI and Age 12-Year BASC-2 Scores

Because nearly all of the changes in NDVI from age 7 to 12 years in our study population were driven by residential mobility, rather than by changes in the underlying NDVI surface, we were unable to use a longitudinal study design. However, we did examine the relationship between NDVI at age 7 years and BASC-2 scores at age 12 years (**Figure 4** and **5**). There were no significant associations in BASC-2 scores in either the continuous or dichotomous model.

**Table.** Study population characteristics at age 7 and age 12 years

Population characteristics	Age 7 y	Age 12 y	<i>P</i> value
Sample size	562	313	
Male	309 (55%)	176 (56%)	.73
Black	117 (21%)	69 (22%)	.67
Mother graduated high school	560 (98%)	306 (98%)	.92
Deprivation index	0.38 (0.15)	0.38 (0.15)	.85
NDVI with 400 m buffer	0.55 (0.10)	0.56 (0.10)	.16
BASC-2 subscore scores			
Aggression	50.37 (9.66)	49.51 (8.87)	.19
Conduct	51.08 (10.74)	49.57 (9.44)	.04
Hyperactivity	50.94 (10.57)	51.07 (10.04)	.86
Somatization	48.76 (10.48)	49.58 (11.61)	.28
Depression	49.27 (9.31)	49.90 (10.22)	.35
Anxiety	49.69 (10.77)	52.05 (11.95)	<.001
Number at-risk per subscale			
Aggression	89 (16%)	38 (12%)	.14
Conduct	79 (14%)	31 (10%)	.07
Hyperactivity	105 (19%)	59 (19%)	.95
Somatization	74 (13%)	50 (16%)	.26
Depression	62 (11%)	44 (14%)	.19
Anxiety	86 (15%)	79 (25%)	<.001

Continuous values are reported as a mean and SD, and dichotomous values are reported as number and percentage of total study population. *P* values are for either a *t* test or  $\chi^2$  test of the characteristics between age 7 and 12 years.



**Figure 1.** Correlation matrix displaying Pearson correlation coefficients between each NDVI buffer (200, 400, 800 m) at ages 7 and 12 years.

### Sensitivity Analyses

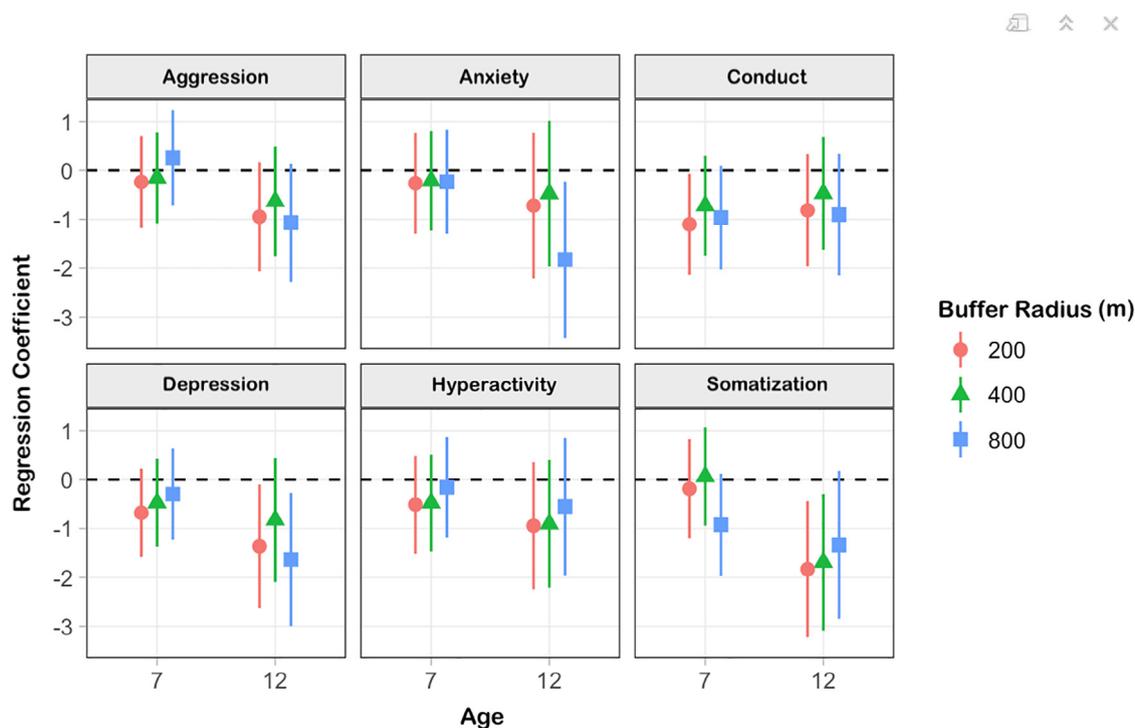
Using household income instead of maternal education to adjust for confounding by family socioeconomic status did not meaningfully change our results. In addition, we repeated our analyses for the portion of 12-year-old children that had information available on parent-child relational frustration to account for possible confounding by parental behavior and we saw no meaningful changes to our results.

## Discussion

In our assessment of BASC-2 scores as a continuous variable with NDVI at age 7 years, increased greenspace within 200 m was associated with decreased risk of conduct-related behavior problems. At age 12 years, increased greenspace within 200 m was associated with decreased risk of depression- and somatization-related behavioral problems. Increased greenspace within a 400 m radius was associated only with decreased somatization scores. Increased greenspace within 800 m was associated with decreased risk of anxiety and depression problems. When dichotomizing BASC-2 scores using clinically relevant thresholds, increased age 7-year greenspace within both 200 and 800 m was associated with decreased risk of conduct-related behavioral problems. An increase in age 12-year greenspace within 200, 400, and 800 m was associated with decreased risk of anxiety-related behavioral problems. Taken together, these findings indicate that more residential greenspace

is associated with lower risk of conduct problems at age 7 years and anxiety problems at age 12 years, as well as a lower risk for depression and somatization problems at age 12 years.

Similar to Nutsford et al, we found evidence that there is a significant relationship between increased exposure to greenspace and decreased risk of anxiety-related behaviors.<sup>7</sup> Notably, the relationship that Nutsford et al found between greenspace and reduction of anxiety-related behaviors was seen at 3000 m but not at 300 m, and we found this relationship to be significant at smaller buffer sizes of 200 and 800 m. A key difference between the 2 studies is that Nutsford et al included participants ages 15–65 years, which somewhat limits comparison with our study because of the inclusion of adults. We did not find evidence for a relationship between greenspace and depression-related behaviors, as has been reported by others.<sup>9</sup> Recently, a relationship between access to greenspace and aggression in youth aged 9–18 years was reported.<sup>18</sup> We did find an association between increased greenspace and decreased aggression-related behavior problems at age 12 years, though this relationship was not significant. A possible explanation for this difference is the use of a different behavioral assessments in the 2 studies. It has been documented that the BASC-2 and the Child Behavior Checklist, used by Younan et al, resulted in large mean differences in the subscales for aggression, anxiety, and somatization between the 2 assessments.<sup>18,35</sup> In addition, Younan et al carried out their study with children and adolescents aged 9–18 years, and our study was restricted to children at age 7 and 12 years. The differences seen



**Figure 2.** Coefficients (with accompanying 95% CIs) from the linear regression models between BASC-2 subscale *t* scores and a 0.1-unit change in NDVI, showing the adjusted results at various buffer radii. Adjustments were included for mother's education, neighborhood deprivation, race, and sex.

between our study and others with similar experimental designs highlight the concept that the impact of greenspace exposure differs by developmental stage.

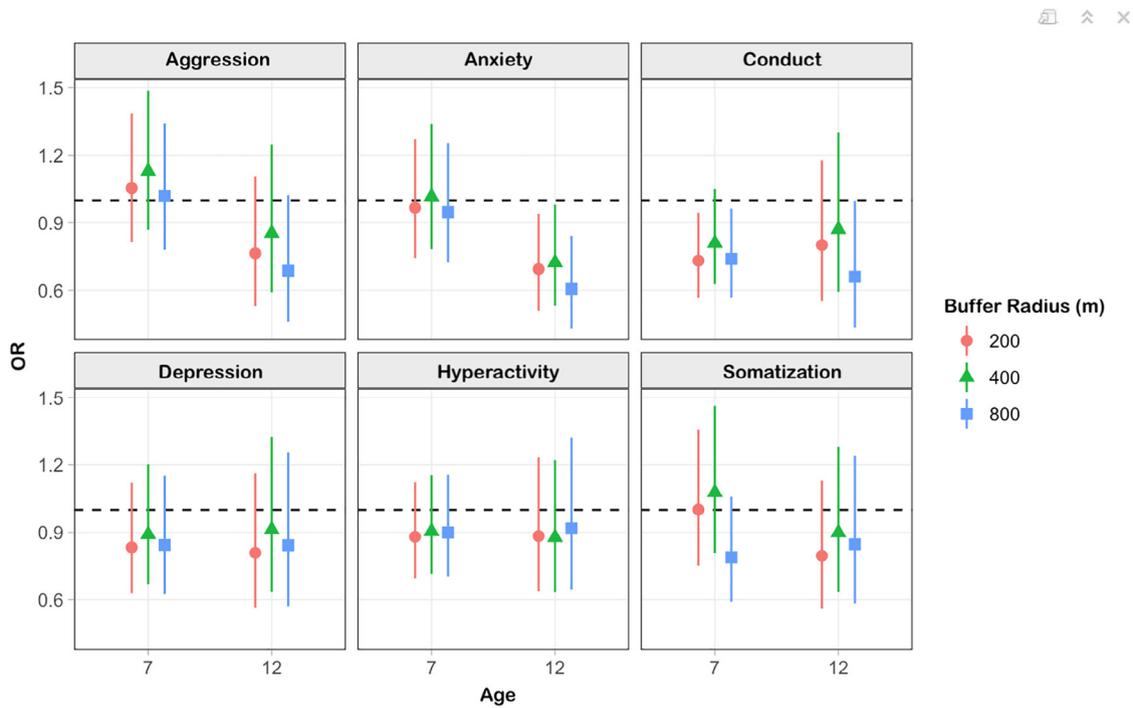
An advantage of our study was the ability to compare residential greenspace and BASC-2 scores at both age 7 and 12 years. Our results suggest that the cross-sectional relationship between greenspace and mental health in children differs depending on age. A recent study that assessed internalizing and externalizing behaviors every 2 years throughout childhood reported an increasing benefit of greenspace as children aged.<sup>22</sup> Similar to our results, this benefit was limited to internalizing behaviors.

There is considerable variability (ranging from 30 to 5000 m) in the buffer radii selected in different studies to calculate individuals' greenspace exposure using NDVI and other similar greenspace estimates.<sup>36</sup> Little evidence is available regarding which buffer size and shape are most suitable for this type of study. A strength of our assessment is the evaluation of the relationship between greenspace and neurobehavioral outcomes at 3 different buffer radii. Although buffers of certain sizes are often highly correlated,<sup>36</sup> we found significant differences between the associations of buffer radii of 200, 400, and 800 m with BASC-2 outcomes. This finding is important in that it indicates that greenspace affects neurobehavioral outcomes differently depending on its proximity to an individual's residential address, and that selecting only 1 buffer radius may have caused significant mental health outcomes to be missed in other studies using NDVI as a proxy for greenspace exposure.

Markevych et al have provided a theory that may explain why our findings differ between 200, 400, and 800 m buffer radii.<sup>36</sup> It is suggested that greenspace within small buffer sizes (<100 m) is relevant to reductions of traffic air pollution and noise, as this small area is most representative of vegetation directly outside of one's residence. Medium-sized buffer radii representing the space that is visible around the home may be more representative of greenspace's restorative influence, and the largest buffer radii may reflect the opportunity to engage in recreational physical activity.<sup>36</sup>

One limitation of our study is that the parental-reported BASC-2 may predict children's risk for internalizing behavioral problems differently at age 12 than it does at age 7 years. During the transition from childhood to adolescence, increases in parent-child negativity and conflict have been documented<sup>37</sup> and this can lead to parents reporting their child's symptoms as less severe than the child themselves would report.<sup>38</sup> If parental under-reporting at age 12 years exists in our study, this difference would bias our results toward the null and, therefore, would not affect the validity of our conclusions.

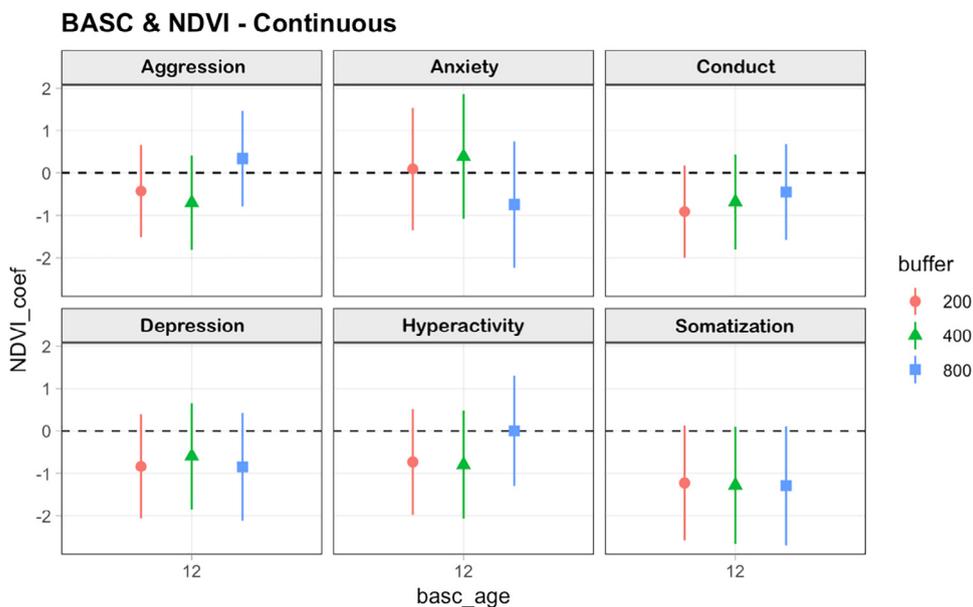
Another important limitation of our study is that we were only able to carry out separate cross-sectional analyses at age 7 and age 12 years, rather than a longitudinal assessment, because of a lack of power. To mitigate this issue, we analyzed the relationship between greenspace at age 7 years and neurobehavioral problems at age 12 years, and found no significant relationship. This finding implies that it is the current greenspace exposure that influences risk of neurobehavioral problems, not prior greenspace exposure.



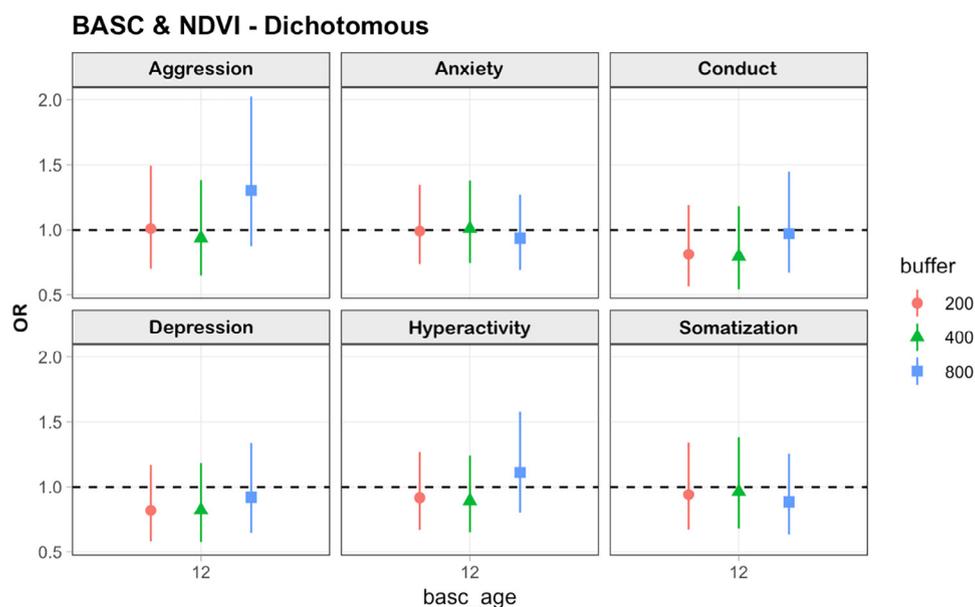
**Figure 3.** ORs (and accompanying 95% CIs) from the logistic regression models for being “at risk” as defined by BASC-2 because of a 0.1-unit change in NDVI, showing the adjusted results at various buffer radii. Adjustments were included for mother’s education, neighborhood deprivation, race, and sex.

Using NDVI as a measure for greenspace does not provide information about the quality and characteristics of the greenspace that may impact children’s likelihood of utilizing it. For example, Jones et al found that the accessibility of

greenspace is often greater in more deprived areas, but residents of these areas have more negative perceptions and are less likely to use the greenspaces.<sup>39</sup> If proximal greenspace is unusable or otherwise unappealing, it is unclear if and how



**Figure 4.** Coefficients (with accompanying 95% CIs) from the linear regression models between a 0.1-unit change in NDVI at age 7 years and BASC-2 subscale *t* scores at age 12 years, showing the adjusted results at various buffer radii. Adjustments were included for mother’s education, neighborhood deprivation, race, and sex.



**Figure 5.** ORs (and accompanying 95% CIs) from the logistic regression models for being “at risk” at age 12 years as defined by BASC-2 because of a 0.1-unit change in NDVI at age 7 years, showing the adjusted results at various buffer radii. Adjustments were included for mother’s education, neighborhood deprivation, race, and sex.

it might mediate children’s risk for mental health disorders. Future research in this area should evaluate how perceptions of greenspace quality, safety, and usability impact mental health and well-being. In this study, we only considered greenspace, but other spatially-varying environmental exposures such as air pollution and community characteristics such as neighborhood crime have also been shown to be associated with neurobehavioral outcomes in children and could act in combination with greenspace as part of a complex mixture.<sup>40-42</sup> Future studies should work to quantify the role of greenspace as one of many determinants of adolescent neurobehavior in an “exposome” framework. As with all cross-sectional studies, another limitation is the presence of unmeasured confounding which might influence our results.

In summary, this study contributes evidence that increased residential greenspace puts youth at lower risk for behaviors associated with conduct disorders at age 7 years and lower risk for behaviors associated with anxiety, depression, and somatization at age 12 years. Future studies are needed to elucidate why the relationship between greenspace and neurobehavioral outcomes differs between the 2 ages and at different buffer radii. An improved understanding of the mechanism by which proximity to greenspace mediates risk of these behaviors is also needed to best implement neighborhood-level approaches to reduce the risk for child and adolescent neurobehavioral problems. ■

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