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Associations between Green Space Surrounding Kindergartens and Hyperactivity Behaviors among Chinese Preschool Children

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Abstract: Background: Attention deficit hyperactivity disorder (ADHD) affects approximately 2–7% of children worldwide and has become a global public health concern. The health effects of green space on ADHD in young children are unclear. We investigated associations between school-surrounding greenness and hyperactivity behaviors in preschool children. Methods: We performed a cross-sectional analysis using data of 66,678 preschool children (mean age: 3.53 years) from an on-going cohort in Shenzhen, China. The greenness surrounding kindergartens was measured using satellite-derived Normalized Difference Vegetation Index (NDVI) values at buffers of 250 m, 500 m, and 1000 m. Children's hyperactivity behaviors were measured using the validated Conners' Parent Rating Scale-Revised. We used generalized linear mixed models to assess the associations of greenness exposure with hyperactivity behaviors with adjustment for a variety of covariates. Results: Exposure to higher school-surrounding greenness was associated with lower prevalence of hyperactivity behaviors. In fully adjusted models, the odds ratio of hyperactivity behaviors in relation to an IQR (0.1) increase in NDVI at the 250 m buffer was 0.91 [confidence interval (CI): 0.84,0.98]. Consistent results were observed for greenness at the 500 m and 1000 m buffers. The negative association between greenness and hyperactivity behaviors was more pronounced in boys than in girls. Conclusions: Our findings suggest that higher levels of school-surrounding green spaces are associated with a lower risk of hyperactivity behaviors in preschool children.

Keywords: green space; hyperactivity behaviors; preschool children

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1. Introduction

Attention deficit hyperactivity disorder (ADHD) is among the most common neurobehavioral disorders, with a global prevalence of 2–7% in children, which is characterized by inattention, motor hyperactivity, and impulsivity [1–4]. China has also been facing the challenge of the rising prevalence of childhood ADHD. A recent meta-analysis indicates that the prevalence of ADHD in Chinese children rose from 5.5% in the 1980s to 6.7% in the early 2010s [5]. The main clinical diagnostic criterion of ADHD is hyperactivity behaviors [1]. Children with hyperactivity behaviors are at risk of having various persistent problems, including poor academic performance [6], difficulty interacting socially with peers [7], reduced lifetime earnings [8], increased suicide risk [9], and violent behavior [10], which often continues into adolescence and adulthood [11]. Identifying the risk factors of hyperactivity behaviors is imperative for early prevention.

The etiology of ADHD is still not fully understood, but both genetic and environmental factors are involved in its development [4,12]. One often-overlooked factor in the development of childhood behavioral disorders is green space in the living environment. It is hypothesized that exposure to greenness may improve behavioral and mental health [13–15] by advancing physical activity [16], promoting social activity [17], and decreasing harmful environmental exposures such as air pollution [18], heat [19], and noise [20]. In recent decades, a growing body of epidemiological studies has investigated the associations between green space and hyperactivity behaviors, but the results are inconsistent (listed in Table S1 in the Supplementary Materials). Particularly, exposure to higher levels of greenness has been associated with a lower risk of ADHD or hyperactivity behaviors in children in several studies [13,14,21,22], whereas some other studies reported null association [23] or even a reverse association [15]. In addition, in most previous studies, greenness exposure was assessed at the child's residential address only [13–15,23], neglecting the fact that children generally spend a considerable time at schools or kindergartens. Furthermore, most previous studies were conducted in Western countries and evidence from developing countries such as China is still scarce. To our knowledge, only one cross-sectional study of 59,754 school-aged (mostly older than 7 years) children in northeastern China found that school-surrounding NDVI was associated with lower odds of ADHD symptoms [21]. As hyperactivity disorders are commonly diagnosed in younger children (i.e., preschool children), investigations among such populations are more imperative for the early prevention of ADHD [24].

As the world's largest developing country, China has been experiencing a rapid urbanization since the late 1970s, which resulted in great pressure on the ecological environment [25]. Building a heathy living environment, in which green space is an important component, is a pressing issue in most countries, including China. We therefore conducted a large cross-sectional study to explore the associations between exposure to greenness surrounding schools and hyperactivity behaviors among Chinese preschool children. We hypothesized that a higher level of greenness surrounding kindergartens would be associated with a lower prevalence of hyperactivity behaviors.

2. Materials and Methods

2.1. Study Population

We conducted a cross-sectional analysis using the baseline survey data of an on-going prospective cohort study, the Longhua Child Cohort Study (LCCS), in Shenzhen, a city with rapid economic development in China [26]. This cohort has been documented in detail elsewhere [27,28]. Briefly, the LCCS was launched in September 2014 with yearly follow-up surveys being conducted since then. The primary objective of the LCCS was to assess the influence of family and school environments on children's neurobehavioral disorders, including hyperactivity behaviors. Preschool children were enrolled at their first admission into kindergartens. In particular, a total of 73,484 participants from 191 kindergartens were recruited between 2014 and 2019. Parents were invited to sign the informed consent form and then completed a self-administrated structured questionnaire containing information about the parents' socio-demographic characteristics and the children's general information.

In the present study, after excluding participants who provided incomplete information on the hyperactivity behaviors assessment (n = 1605) or the greenness exposure estimates (n = 448), as well as covariates (n = 4753), the remaining 66,678 children were included in data analysis. In general, the excluded subjects were not substantially different from those included in the data analysis in terms of distribution of general characteristics (Table S2 in the Supplementary Materials).

2.2. Ethical Consideration

This study was conducted in accordance with the Declaration of Helsinki and was approved by the local Women's and Children's Hospital, the Administration of Education, and the Human Research Ethics Committee of the School of Public Health at Sun Yat-sen

University in Guangzhou, China (No. 2015–2016). The parents or other guardians of all participants signed informed consents before entering the cohort.

2.3. Behavioral Assessment

Hyperactivity behaviors were measured using the hyperactivity index (HI) subscale in Conners' Parent Rating Scale-Revised (CPRS-48), an internationally disseminated and validated screening tool to assess behavioral difficulties in children aged between 3–16 years [29]. Children' parents completed the questionnaire, which includes 10 items (restless in the "squirmy" sense; disturbs other children; restless, always up and on the go; excitable, impulsive; mood changes quickly and drastically; cries easily or often; destructive; fails to finish things; distractibility or attention span a problem and easily frustrated in effort) by rating the frequency of each item in terms of 4 levels: 0 = never, 1 = sometimes, 2 = often, 3 = frequently. The average score was then calculated, with higher score indicating more severe hyperactivity behaviors. Children presenting a score of 1.5 or more were defined as having hyperactivity behaviors, which was consistent with our previous studies [27]. The CPRS-48 showed good validity and reliability in Chinese children, with a Cronbach α of 0.9 and a correlation of the Spearman–Brown split half of 0.9 [30].

2.4. Exposure Assessment

We used the satellite-image-based Normalized Difference Vegetation Index (NDVI) as a surrogate measure of greenness surrounding kindergartens. NDVI is a frequently used indicator of green space and its measurement is based on chlorophyll in plants, which absorbs the land surface reflectance of the visible (RED) and near-infrared (NIR) parts of the spectrum and is calculated as the difference between absorbed and reflected (near-infrared) light measured by satellites [NDVI = (NIR − RED)/(NIR + RED)] [31,32]. Additionally, we also used the Enhanced Vegetation Index (EVI), which is another indicator of greenness with additional controls for canopy background, aerosol resistance, and gain factor [33]. The values of both indices range from −1 to 1, with negative values corresponding to water bodies, values close to zero to barren areas, and positive values to green vegetation, where a higher NDVI or EVI represents more vegetation. The Moderate Resolution Imaging Spectroradiometer (MODIS) of the US National Aeronautics and Space Administration (NASA) provides 16-day NDVI and EVI data products (https://modis.gsfc.nasa.gov/data/dataprod/mod13.php (accessed on 21 January 2022)) that are publicly available. We calculated the mean NDVI/EVI of the year of the baseline survey (i.e., the year of admission) and the prior year at 250 m, 500 m, and 1000 m buffer radiuses around each kindergarten. We then used the mean NDVI/EVI levels of the two years as the exposure measures. As NDVI was more frequently used in previous studies, we used NDVI in our main analysis for easy comparison with the previous literature.

As air pollution, another commonly assessed environmental factor, has been associated with the risk of hyperactivity behaviors, we consequently estimated it to control for its potential influence [34,35]. Contemporary exposure to nitrogen dioxide (NO_2) was estimated using the China High Air Pollutants (CHAP) datasets (https://weijing-rs.github.io/product.html (accessed on 21 January 2022)). The CHAP includes a mathematical model that calculate daily concentrations of NO_2 at a 10 km × 10 km resolution over China [36,37].

2.5. Covariates

Based on the previous literature, we initially identified a list of candidate confounders. We then developed a directed acyclic graph (DAGitty v3.0 software, supported by the Deutsche Forschungsgemeinschaft (DFG) grant, http://www.dagitty.net (accessed on 24 March 2022)) that visually represent the casual framework to select potential confounders (Figure S1 in the Supplementary Materials). Covariates identified included general demographic and socioeconomic characteristics and the health statuses of children and their mothers. In particular, for a child, we collected the child's sex (male vs. female), age (years), and birth-related conditions including natural birth (yes vs. no), preterm birth (yes vs. no), febrile convulsion (yes vs. no) and low birth weight (<2.5 kg, yes vs. no). The self-administered questionnaire also provided maternal information including highest level of maternal education (junior high school or lower vs. high school vs. college or higher), maternal employment (yes vs. no), maternal age at childbirth (>35 years vs. <35 years), maternal history of comorbidity during pregnancy (gestational diabetes mellitus or gestational hypertension), monthly family income (< RMB 5000 vs. 5001–10,000 vs. 10,001–20,000 vs. >20,000) and feeding patterns (breast feeding vs. mixed feeding vs. artificial feeding).

2.6. Statistical Analyses

We used generalized linear mixed models (GLMMs) to assess the associations of greenness exposure with hyperactivity behaviors, in which kindergartens were incorporated as a random intercept to account for possible within-kindergarten clustering effects, while NDVI and all covariates were fixed terms. For easy reference, the hierarchical level of each variable included in the GLMMs and the fit values to evaluate the model are shown in Tables S4 and S5 in the Supplementary Materials. We estimated the odds ratios (ORs) with the corresponding 95% confidence intervals (CIs) per interquartile range (IQR) increase in NDVI at the 250 m buffer in relation to the prevalence of hyperactivity behaviors. We also categorized the NDVI into quartiles, with the lowest quartile serving as the reference. Two models were fitted, including: (1) the unadjusted model and (2) the adjusted model incorporating all the confounders selected. Then we evaluated the associations between hyperactivity behaviors and NDVI within 500 m and 1000 m buffer radiuses using the same models. In addition to treating hyperactivity behaviors as a binary variable, we also used the original average score of hyperactivity behaviors and examined its association with greenness.

Next, we conducted stratified analyses to examine whether children's sex, maternal education, employment, history of comorbidity, and ETS could modify the associations between greenness and hyperactivity behaviors by adding a cross-product term in the adjusted regression models. A Bonferroni correction was used for the multiple comparisons.

To assess the robustness of our results, we performed a series of sensitivity analyses. First, we repeated the main analysis to explore the association between EVI, instead of NDVI, and hyperactivity behaviors. In addition, to investigate whether the association between green space and hyperactivity behaviors was influenced by air pollution [34,35], we additionally adjusted for NO_2.

All analyses were conducted using R (version 4.0.5) software (R Core Team, Vienna, Austria). Two-tailed *p* values of less than 0.05 were considered statistically significant.

3. Results

3.1. Characteristics of the Study Population

Table 1 shows the general characteristics of the study participants. The mean age of the participants was 3.53 (SD: 0.36) years, and 54.6% of them were boys. Among them, 3560 (5.3%) had low birth weight, 8214 (12.3%) had febrile convulsion and 5239 (7.9%) were born prematurely. As for the mothers, most of them were less than 35 years old at childbirth (91.4%), had high education levels (the percentage of junior high school or lower was 15.4%) and lower income (8.7% < RMB 5000/month), and reported no history of comorbidity (93.0%). A total of 1183 (1.77%) children had hyperactivity behaviors. Participants with hyperactivity behaviors were more likely to be boys and to have experienced preterm birth and febrile convulsion, while their mothers were more likely to be exposed to environmental tobacco smoke and to have a higher education level compared to those participants without hyperactivity behaviors. The median and interquartile range (IQR) values of NDVI 250 m were 0.28 and 0.10 (Table S3 in the Supplementary Materials).

Table 1. Characteristics of the study sample according to hyperactivity behaviors.

Characteristics	Overall	Children without Hyperactivity Behaviors	Children with Hyperactivity Behaviors
	(*n* = 66,678)	(*n* = 65,495)	(*n* = 1183)
Child sex, *n* (%)			
Male	36,425 (54.6)	35,649 (54.4)	776 (65.6)
Female	30,253 (45.4)	29,846 (45.6)	407 (34.4)
Child age (years), mean (SD)	3.53 (0.36)	3.53 (0.36)	3.49 (0.37)
Maternal age at childbirth, *n* (%)			
≤35 years	60,923 (91.4)	59,793 (91.3)	1130 (95.5)
>35 years	5755 (8.6)	5702 (8.7)	53 (4.5)
Maternal education, *n* (%)			
Junior high school or lower	10,251 (15.4)	10,012 (15.3)	239 (20.2)
High school	36,774 (55.2)	36,107 (55.1)	667 (56.4)
College or higher	19,653 (29.5)	19,376 (29.6)	277 (23.4)
Maternal employment, *n* (%)			
No	29,670 (44.5)	29,209 (44.6)	461 (39.0)
Yes	37,008 (55.5)	36,286 (55.4)	722 (61.0)
Maternal history of comorbidity, *n* (%)			
No	62,000 (93.0)	60,891 (93.0)	1109 (93.7)
Yes	4678 (7.0)	4604 (7.0)	74 (6.3)
Family income (RMB/month), *n* (%)			
<5000	5831 (8.7)	5679 (8.7)	152 (12.8)
5001–10,000	14,492 (21.7)	14,141 (21.6)	351 (29.7)
10,001–20,000	23,791 (35.7)	23,389 (35.7)	402 (34.0)
>20,000	22,564 (33.8)	22,286 (34.0)	278 (23.5)
Natural birth, *n* (%)			
No	27,619 (41.4)	27,135 (41.4)	484 (40.9)
Yes	39,059 (58.6)	38,360 (58.6)	699 (59.1)
Feeding patterns, *n* (%)			
Breast feeding	28,952 (43.4)	28,552 (43.6)	400 (33.8)
Mixed feeding	30,755 (46.1)	30,130 (46.0)	625 (52.8)
Artificial feeding	6971 (10.5)	6813 (10.4)	158 (13.4)
Preterm birth, *n* (%)			
No	61,439 (92.1)	60,357 (92.2)	1082 (91.5)
Yes	5239 (7.9)	5138 (7.8)	101 (8.5)
Environmental tobacco smoke, *n* (%)			
No	48,914 (73.4)	48,213 (73.6)	701 (59.3)
Yes	17,764 (26.6)	17,282 (26.4)	482 (40.7)
Febrile convulsion, *n* (%)			
No	58,464 (87.7)	57,549 (87.9)	915 (77.3)
Yes	8214 (12.3)	7946 (12.1)	268 (22.7)
Low birth weight, *n* (%)			
No	63,118 (94.7)	62,000 (94.7)	1118 (94.5)
Yes	3560 (5.3)	3495 (5.3)	65 (5.5)
Greenness indices, median (Q3–Q1)			
$NDVI_{-250m}$	0.28 (0.33,0.24)	0.28 (0.33,0.24)	0.27 (0.33,0.23)
$NDVI_{-500m}$	0.28 (0.33,0.24)	0.28 (0.33,0.24)	0.27 (0.32,0.23)
$NDVI_{-1000m}$	0.28 (0.32,0.24)	0.28 (0.32,0.24)	0.27 (0.31,0.24)

3.2. Associations between Greenness Exposure and Hyperactivity Behaviors

Table 2 shows the results of the associations between greenness exposure and hyperactivity behaviors. Generally, the adjusted models had better-fitting performance than the crude models according to the Nagelkerke R square. After adjusting for covariates, school-surrounding greenness was negatively associated with hyperactivity behaviors, and a statistically significant random effect of kindergartens was identified (p-value < 0.05). For example, the OR for hyperactivity behaviors associated with one IQR increase in NDVI within 250 m was 0.91 (95% CI: 0.84,0.98). In quartile-based analysis, children living in areas with NDVI in higher quartiles reported lower odds of hyperactivity behaviors (compared to lowest quartile of NDVI within 250 m buffer: second quartile, OR = 1.01 [95% CI: 0.85,1.20]; third quartile, OR = 0.78 [95% CI: 0.65,0.94]; highest quartile, OR = 0.78 [95% CI: 0.65,0.94]; $p < 0.05$). Similar results were found for NDVIs within 500 m and 1000 m buffers. Consistently, a negative association was also found between greenness and the index score of hyperactivity behaviors (Table S6 in the Supplementary Materials).

Table 2. Odds ratios (ORs) and 95% CI for the associations of NDVI exposure with hyperactivity behaviors in young children.

Exposure	Case (N, %)	Crude Model OR (95% CI)	*p*-Value	Adjusted Model [a] OR (95% CI)	*p*-Value
NDVI 250 m					
Continuous (per IQR)	1183 (1.77)	0.87 (0.79,0.95)	<0.05	0.91 (0.84,0.98)	<0.05
Q1	327 (1.97)				
Q2	324 (1.94)	0.86 (0.71,1.04)		1.01 (0.85,1.20)	
Q3	262 (1.57)	0.64 (0.52,0.79)		0.78 (0.65,0.94)	
Q4	270 (1.62)	0.65 (0.52, 0.82)		0.78 (0.65,0.94)	
p for trend		<0.05		<0.05	
NDVI 500 m					
Continuous (per IQR)	1183 (1.77)	0.86 (0.78,0.94)	<0.001	0.89 (0.83,0.96)	<0.001
Q1	333 (2.02)				
Q2	295 (1.76)	0.74 (0.61,0.89)		0.89 (0.74,1.06)	
Q3	295 (1.77)	0.69 (0.56,0.86)		0.83 (0.69,1.00)	
Q4	260 (1.56)	0.60 (0.48,0.75)		0.71 (0.58,0.86)	
p for trend		<0.05		<0.05	
NDVI 1000 m			<0.001		<0.001
Continuous (per IQR)	1183 (1.77)	0.83 (0.75,0.91)		0.87 (0.81,0.94)	
Q1	324 (1.95)				
Q2	317 (1.90)	0.85 (0.7,1.03)		0.96 (0.81,1.14)	
Q3	272 (1.64)	0.65 (0.51,0.81)		0.81 (0.67,0.98)	
Q4	270 (1.61)	0.63 (0.5,0.80)		0.71 (0.59,0.86)	
p for trend		<0.05		<0.05	

[a]: Adjusting for child's sex, age, highest level of maternal education, maternal employment, age at childbirth, history of comorbidity, monthly family income, natural birth, feeding patterns, preterm birth, febrile convulsion, low birth weight, and ETS.

3.3. Stratified Analyses

In the sex-stratified analysis, the negative associations of greenness with hyperactivity behaviors were only statistically significant in boys (OR = 0.85 [95% CI: 0.77,0.94]), but not in girls (OR = 1.02 [95% CI: 0.90,1.15]) (Figure 1), and the between-sex difference was statistically significant (p for interaction = 0.01). For monthly family income, the pattern was less clear. No significant effect modification was observed for other factors.

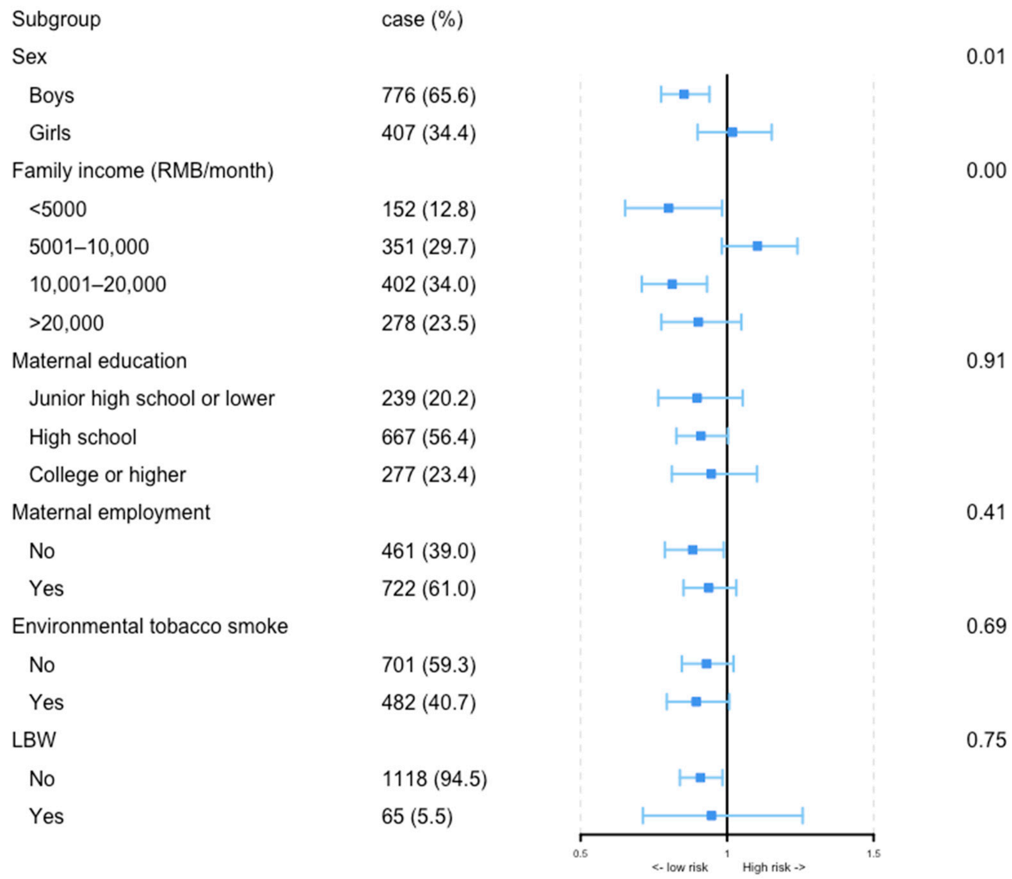

Figure 1. Associations of school-surrounding greenness (NDVI 250 m) with the hyperactivity behaviors in stratified analyses.

3.4. Sensitive Analyses

In general, similar results were found when EVI was used as a measure of greenness surrounding kindergartens instead of NDVI (Table S7 in the Supplementary Materials). For example, the fully-adjusted OR per IQR increment in EVI at the 250 m buffer associated with hyperactive behaviors was 0.90 (95% CI: 0.83,0.98). Adding NO_2 into the adjusted models did not change the results materially either (Table S8 in the Supplementary Materials).

4. Discussion

In this large cross-sectional study among Chinese preschool children, we found that exposure to higher levels of greenness surrounding kindergartens was associated with lower odds of having hyperactivity behaviors. These associations were robust in a number of sensitivity analyses. Our study adds robust evidence on the potential health effects of green space on hyperactivity disorders in young children in a developing country that has been experiencing great transformations in the ecological environment in urban settings due to rapid urbanization.

Our results are consistent with a cross-sectional study [21] of 59,754 school-aged (mostly more than 7 years) children in northeastern China, which found that a 0.1-unit increase in school-based NDVI was associated with a lower odds of ADHD symptoms (OR = 0.87; 95% CI, 0.83–0.91) within the 500 m buffer. Similarly, a German cohort and a Danish cohort reported that children exposed to greater degrees of green space had a decreased risk of developing ADHD, compared with their counterparts with a lower exposure level [13,14]. A recent analysis of 28,797 Canadian children also suggested that greenspace was associated with lower incidence of ADHD [22]. However, inconsistency still exists. A study from Barcelona, Spain demonstrated null association [23]. Particularly, this cross-sectional study observed that school-based greenness was not significantly associated with ADHD measured using DSM-IV scores. Such results are in accordance with a longitudinal study in New Zealand, which reported that neither minimum NDVI in early life (age < 2 years) nor any measures of mean NDVI were significantly associated with ADHD [15]. It should be noted that most of the previous studies were conducted in Western countries. Additionally, the majority of these studies measured greenness levels at the children's residences, but not at schools. The inconsistent findings about green space and hyperactivity behaviors in children from current studies including ours, could be attributed to multiple factors such as heterogeneity in the study population and methodological differences in greenness assessment. Notably, we recruited preschool children, while most previous studies targeted school-aged children and adolescents. As for the assessment of green space, the exposure site (school vs. residence) and time window varied across different studies. Additionally, the methods used to measure hyperactivity behaviors varied across different studies. We used CPRS-48 to identify hyperactivity behaviors, whereas other studies used different questionnaires (e.g., Strengths and Difficulties Questionnaires [SDQ] [23]) or hospital diagnoses [15]. Studies with more comparable methods are needed to better investigate the health effects of green space on children's hyperactivity disorders in the future.

In the present study, stronger associations between greenness exposure and hyperactivity behaviors were found among boys than in girls. Several previous studies also reported a sex difference in the associations between green space and hyperactivity behaviors. For example, a longitudinal study in New Zealand found that the protective effects of NDVI were only evident in boys, but not in girls [15]. However, controversial results have also been found in some other studies, including the Seven Northeastern Cities Study [21], which reported no clear modifying effect by child sex. Despite the mixed findings, the underlying mechanisms for any sex difference are unclear. A possible reason could be that boys generally spend more time engaging in physical activities in green space than girls [16], and a higher level of physical activity might improve neurodevelopment in children and reduce the risk of behavioral disorders, including hyperactivity [38]. Nevertheless, it is still inconclusive whether green space shows greater protective effects in males than in females [39]. More studies are required to better address this issue.

The mechanisms by which greenness reduces behavioral disorders including hyperactivity are not fully understood. Recent studies found that surrounding greenness was associated with blood DNA methylation, which is mapped to genes related to mental health disorders, neoplasms, and other diseases [40]. This offers a potential biological pathway to underlie this association, as a high level of green space could reduce the methylation of genes related to hyperactivity behaviors. In addition, greenness could affect hyperactivity behaviors indirectly. For example, green space might mitigate air pollution and noise levels [41,42], consequently reducing the adverse health effects of these exposures. In addition, children living in green spaces have more opportunities for physical activity and subsequent social activities, which could improve their mental and behavioral health [16,17].

A major strength of this study is its large population-based sample with a rich set of covariates including both individual and household covariates. In addition, we used two different green space metrics (NDVI and EVI) at three different buffer radiuses (250 m, 500 m, and 1000 m), and consistent results were found.

This study also has some limitations. First, the cross-sectional nature of our study cannot ensure the temporal sequence of greenness exposure and hyperactivity behaviors, which limits the capacity for causal inference. Second, greenness exposure was defined as the average of NDVI/EVI values at each school's location, whereas exposure at the children's residence was not measured. Third, the NDVI (or EVI) that we used was only an objective measure of the amount of greenness around kindergartens, while the accessibility or proximity to greenness was not directly measured. Fourth, information on hyperactivity behaviors and some other covariates was attained retrospectively by a questionnaire, which was subject to recall bias. Finally, given the cross-sectional nature of our study, we did not perform more in-depth analyses such as mediation analysis to explore the potential mechanisms underlying the greenness–hyperactivity associations. We will perform these analyses in the future when longitudinal data are available.

5. Conclusions

Our study demonstrated a negative association between school-surrounding green space and hyperactivity behaviors among Chinese preschool children, especially among boys, suggesting that green space might have protective effects against childhood hyperactivity disorders. Increasing green space in urban settings could be a preventive measure to reduce behavioral problems in children. Nonetheless, more studies are warranted to replicate our findings and to shed light on the underlying mechanisms.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/future1010005/s1. Figure S1: Directed acyclic graph for the association between greenness and hyperactivity behaviors; Table S1: Summary of epidemiological studies of associations between school-based greenness and ADHD/hyperactivity behaviors; Table S2: Characteristics of the study samples; Table S3: Summary of greenness indices and correlations between NDVI and EVI; Table S4: Factors at each hierarchical level in regression analysis; Table S5: Odds ratios (OR) and 95% CI for the effect of baseline NDVI on hyperactivity behaviors in young children; Table S6: β and 95% CI for the effect of baseline NDVI on hyperactivity index; Table S7: Odds ratios (OR) and 95% CI for the effect of baseline EVI on hyperactivity behaviors; Table S8: Odds ratios (OR) and 95% CI for the effect of baseline NDVI on hyperactivity behaviors additionally adjusted NO_2.

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Informed Consent Statement: This study was approved by the Human Research Ethics Committee of the School of Public Health at Sun Yat-sen University in Guangzhou, China (No. 2015-2016), and all participants gave informed consent.

Data Availability Statement: Due to privacy and ethical considerations, data sharing is not applicable to this article.

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