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RESEARCH

Increased urban greenspace in childhood associated with lower inattention deficit among adolescents

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Abstract

Purpose There is a growing interest in assessing the benefits of exposure to urban greenspace on mental health due to the increased urbanization of youth and concerns for their mental health. We investigated the prospective associations of residential greenspace in childhood and mental health in adolescence. Use of a well-characterized birth cohort permitted adjustment for a range of potential confounding factors including family and neighborhood characteristics in addition to prior mental health problems, and exploration of moderation effects by sex and family socioeconomic status.

Methods We analyzed longitudinal data collected from 742 urban-dwelling participants of the Quebec Longitudinal Study of Children Development. The Normalized Difference Vegetation Index (NDVI) within 250, 500, and 1000 m buffer zones surrounding the home residence was used to indicate childhood exposure to greenspace. Six self-reported mental health problems at 15/17 years were examined using the Mental Health and Social Inadaptation questionnaire: inattention, hyperactivity/impulsivity, conduct, depression, anxiety, and suicidal ideation.

Results Childhood urban greenspace was associated with lower inattention problems in both females and males. We observed a 0.14 reduced standard deviation (SD) ($\beta = -0.14$, SE = 0.05, $p < 0.01$) in relation to an interquartile range (IQR) increase of NDVI (0.15) at the 250 m buffer zone, and similar results were found in 500 m and 1000 m buffer zones. These associations only slightly attenuated after adjustment for individual (sex, childhood mental health), family (family SES, maternal age at birth, parental mental health, family composition), and neighborhood (material and social deprivation) characteristics ($\beta = -0.13$, SE = 0.06, $p = 0.03$). No association was found for other mental health problems, and no moderation associations of sex or family socioeconomic status were observed.

Conclusion These findings suggest that increasing residential greenspace in cities may be associated with modest benefits in attentional capacities in youth, necessitating further research to elucidate the underlying mechanisms.

Keywords Greenspace exposure · Residential · Mental health · Youth

Abbreviations

NDVI	Normalized difference vegetation index
IQR	Interquartile range
SD	Standard Deviation
ADHD	Attention-deficit hyperactivity disorder

Introduction

Approximately 1.2 million Canadian youth are affected by at least one mental health problem [1] with the prevalence of depression and anxiety on the rise [2]. These alarming

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numbers bring to light the importance of identifying modifiable protective factors that could aid in alleviating mental health problems.

In recent years, the potential benefits of exposure to greenspace (i.e., natural or semi-natural outdoor area completely or partially covered by vegetation, such as parks, forests, trees, and woodlands [3]) for mental health have gained significant attention [4–6], especially for urban dwellers who are more likely to benefit from greenspace (in comparison with those residing in rural areas) as evidenced in a recent review [7]. The promotion of greenspace in urban landscapes may hold the potential to improve health since greenspace offers opportunities to reduce exposure to harmful exposures (e.g., air and noise pollution), restore attentional capacities, and encourage physical activity [8].

Prospective population-based studies are imperative to assess the long-term associations between greenspace and mental health, especially as they allow for the examination of individuals exposed to settings differing in levels of surrounding greenspace (most commonly measured using the Normalized Difference Vegetation Index (NDVI) [9]) over long follow-up periods, and provide the ability to control for key confounding factors assessed prior to the exposure (e.g., childhood and parental mental health problems).

While some longitudinal population-based studies have found that increased greenspace exposure in childhood is associated with lower symptoms of depression [10, 11], anxiety [12], attention-deficit hyperactivity disorder (ADHD) [12–14], and conduct problems [12] in adolescence, other studies have not [15–17]. It is unclear whether or not the benefits of greenspace exposure on mental health affect all youth equally, and if some groups (such as female vs. male, or socioeconomically advantaged vs. disadvantaged youth) benefit more than others. With respect to sex, some studies indicate associations between increased greenspace exposure and lower mental health problems among male, but not female individuals [18], whereas other studies report inversed patterns of findings [14], or no differences [12, 19]. Although the mechanisms by which sex modifies the associations between greenspace and mental health remain unknown, previous systematic reviews have posited that physiological and psychological responses to greenness may differ across female and male individuals [20, 21]. At the same time, it has been suggested that individuals with mental health problems from disadvantaged socioeconomic backgrounds disproportionately benefit from higher greenspace exposure [22–25]; however, the few studies that investigated this question in youth have produced inconsistent results [13, 14, 26–29]. Additionally, several studies report associations between higher levels of residential greenspace and lower incidence of suicidal ideation and suicide mortality among adults [30–32]; however, evidence drawn from adolescent populations is scarce [33].

Drawing from a representative sample of adolescents residing in urban regions of the province of Québec (Canada), this study had two aims. First, we aimed to investigate the associations of childhood residential greenspace with a range of mental health problems (i.e., inattention, hyperactivity/impulsivity, conduct problems, depression, anxiety, and suicidal ideation) with adjustment for factors at the individual, family, and neighborhood levels. Second, we examined whether these associations were moderated by sex and by disparities in levels of family socioeconomic status (SES).

Methods

Participants

Participants were from the Québec Longitudinal Study of Child Development (QLSCD; conducted by Institut de la Statistique du Québec, ISQ), a population-based birth cohort of 2120 children born in Québec, Canada, in 1997–1998 and followed up annually or biannually since [34]. The Québec Master Birth Registry of the Minister of Health and Social Services was used to create a stratified random sample based on living area and birth rates [35]. At its inception, the QLSCD represented the Québec population of singleton births, including all ranges of socioeconomic status (SES). More information regarding the QLSCD can be found on https://www.iamillbe.stat.gouv.qc.ca/default_an.htm. The QLSCD protocol was approved by the Institut de la statistique du Québec and the St-Justine Hospital Research Centre ethics committees, and informed consent, assent, or both were obtained at each data collection.

Procedure

We used information on childhood residential greenspace at 10 years of age (2008) and mental health outcomes reported by the adolescents via an online questionnaire at 15 and 17 years of age (2013/2015) [36–38]. We selected children who were residing in urban regions of Québec (i.e., Montreal, Sherbrooke, Trois-Rivières, Gatineau, and Saguenay; population size > 100,000 habitants per region, except Montreal with > 3 million habitants) in 2006/2008, accounting for 65% of all children participating in the QLSCD.

Adolescent mental health problems

Mental health symptoms in the past year were assessed using the Mental Health and Social Inadaptation Assessment for Adolescents [39] (never = 1; sometimes = 2; often = 3). Adolescents self-reported externalizing problems, namely inattention, hyperactivity/impulsivity, and conduct problems,

and internalizing problems, namely depression, generalized anxiety, and serious suicidal ideation ("did you ever seriously think of attempting suicide?"; yes = 1, no = 0). The six scales were z-standardized (Mean = 0, SD = 1) and averaged across the two assessments to obtain a summary score for each problem during adolescence (i.e., 15 and 17 years). The items comprised in these scales, their internal consistencies, and their correlation matrix are presented in Supplementary Tables S1 and S2.

Childhood residential greenspace

We retrieved the residential greenspace measure from the Canadian Urban Environment Health Research Consortium which was characterized using the Normalized Difference Vegetation Index (NDVI). NDVI quantifies vegetation by measuring the ratio between near-infrared light, which vegetation reflects, and red light, which vegetation absorbs [40]. Values from this index range between − 1 and 1, with negative values representing water and/or cloud covering and/or inorganic objects, values around zero representing sparse and brown vegetation, and higher positive values representing dense and green vegetation. We used NDVI data from 2007 provided by the United States Geological Survey Landsat 8 satellite, with a spatial resolution of 30 m accessed via Google Earth Engine [41–44]. Given substantial snow covering during the winter months in Québec, pixels with more than 20% cloud or snow were not included in the NDVI calculation and all bodies of water were masked.

NDVI values were available for 2007, and six-digit postal code information for QLSCD participants was available in 2006 and 2008. As such, we geocoded the NDVI values in 2007 with the children's six-digit postal codes in 2008 or 2006 for the 71 participants with missing postal code information in 2008 (correlation between NDVI values from postal code information in 2008 and 2006 was 0.89, $p < 0.001$; Fig. 1), resulting in a cross-sectional NDVI assessment. The six-digit postal code is the most precise unit in Canada that allows for the identification of where individuals reside [45]; in urban regions, this is equivalent to one side of a city block (e.g., single apartment building) [46]. In the current study, there was no clustering of participants within six-digit postal codes (i.e., more than 98% of postal codes had a single participant allocated to it). Greenspace data were abstracted to produce measures corresponding to circular buffers of 250 m, 500 m, and 1000 m around the centroid of each child's residential postal code. Our main analysis relied on the 250 m buffer, and we modeled the maximum annual mean value obtained from across a series of pixels each having their own annual mean within this buffer. We also conducted sensitivity analyses using similarly derived maximum annual mean values with 500 m and 1000 m buffers.

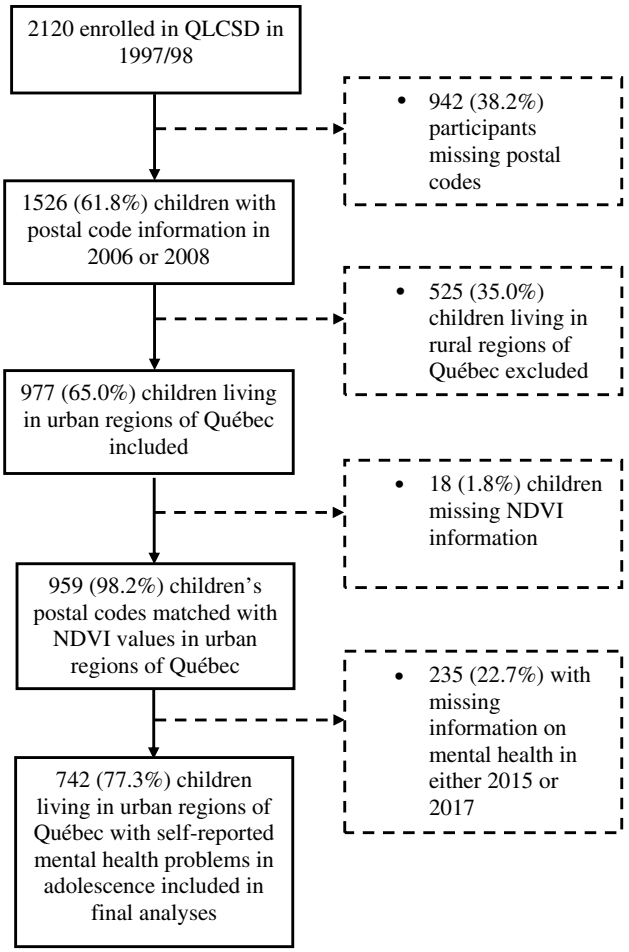

Fig. 1 Flowchart of participants in the QLSCD cohort used in the study. Note: Data were compiled from the final master file of the Québec Longitudinal Study of Child Development (1998–2017), ©Gouvernement du Québec, Institut de la statistique du Québec. Geographical region classification was calculated with Canadian census data in 2006 [47] based on all six-digit postal codes in Québec which were then matched to the six-digit postal codes of participants in the QLCSD. Participants residing in rural regions of Québec (i.e., regions with 10 000 to 100 000 residents) accounted for 35.0% of the cohort and were excluded from this study. QLSCD = Québec Longitudinal Study of Child Development

Confounding factors

Confounding factors were selected based on their associations with mental health and/or greenspace exposure (Supplement Table S3) and were measured at 8 and 10 years of age with scores averaged across assessments (to maximize the total sample size), unless otherwise indicated.

Individual characteristics

Child sex (male/female) was reported by parents. Childhood mental health problems were reported by school teachers using the Social Behavior Questionnaire [48]: oppositional

and defiant behavior (four items; e.g., defiant or refused to comply), inattention and hyperactivity (nine items; e.g., "could not sit still"), and depressive and anxious symptoms (five items, e.g., fearful or sad). The items were derived from the Canadian National Longitudinal Study of Children and Youth [49], which incorporates items from the Child Behavior Checklist [50], with responses rated on a three-point scale.

Family characteristics

Maternal age at childbirth was recorded in years. Parental depressive symptoms in past week were assessed at 5 months using 12 items from the short form of the Centre for Epidemiological Study Depression Scale (12 items; e.g., "I felt depressed") [51]. Parental antisocial behaviors during adolescence were assessed using five retrospective conduct items (e.g., having been in > 1 fight that they started; having stolen > 1 time) [52]. For all parental mental health problems, a mean score was derived based on the availability of data from at least one parent. SES was measured using a standardized aggregate index of five items relating to parents' education level, occupational prestige, and gross annual household income [53]. The scale ranged from -3 to 3, centered at 0, with higher scores indicating higher SES. Family composition was categorized as intact (biological parents) or non-intact (single, separated, divorced, or widowed).

Neighborhood characteristics

Neighborhood socioeconomic disadvantage was estimated using material and social deprivation indices based on census data [54], consistent with approaches used in previous studies [55–58]. These deprivation indices are based on data aggregated at the dissemination area level, which represents the smallest spatial unit available from census data in 2006 (in urban areas this is equivalent to an average of 400–700 individuals residing in one or more neighboring blocks of houses). They were constructed using a principal component analysis that integrated six census variables into two components (material and social). The material deprivation index is computed based on the proportion of individuals without a high-school diploma, their average personal earnings, and the employment–population ratio at the dissemination area level. The social deprivation index is computed from the proportions of individuals, respectively, living alone, heading a single-parent family, and being separated, divorced, or widowed. Both material and social deprivation indices were categorized into quintiles of equal population size, ranging from the most privileged (first quintile) to the most deprived (fifth quintile). We linked the children's six-digit postal code data with the corresponding dissemination area which allowed us to identify participants' socioeconomic characteristics based on their neighborhood area.

Statistical analyses

Analyses were conducted using SPSS (version 27). First, we examined the sample characteristics using means or frequencies. Second, we examined the association between greenspace and mental health problems using linear regression for continuous outcomes and logistic regression for suicidal ideation adjusting for identified individual, family, and neighborhood characteristics. Associations were expressed in relation to one interquartile range (IQR) increase in the 250 m buffer of childhood residential greenspace. The IQR for the childhood residential greenspace metric (maximum of surrounding annual mean NDVI values within the 250 m buffer) was 0.15. Mental health problems outcomes were standardized (mean, 0; SD, 1) so that the regression coefficient (β) represents the standard deviation (SD) increase in symptoms associated with each IQR increase in greenspace. Third, to test whether sex and/or SES moderated the associations between greenspace exposure and mental health problems, interaction terms for these variables were examined separately in the fully adjusted models. Statistical significance was set at $p < 0.05$, and all tests were two-tailed.

Results

Sample characteristics

Of the 2120 participants recruited at baseline, 1526 children participated in data collection in 2006 or 2008 and provided information on their postal code, of whom 959 were living in urban regions. Of them, 742 participants (77.3%) provided information pertaining to mental health problems (Fig. 1). Key characteristics of the 742 participants are shown in Table 1. Participants residing in urban areas but who were not included in the study sample ($n = 235$) were more likely to be male (131/235 [55.7%] for those excluded from analyses vs. 336/742 [45.2%] for those included in analyses, $\chi^2 = 7.83$, $p = 0.005$); their mothers had more depressive symptoms at birth (1.52 vs. 1.30 [on a scale from 0 to 10], $t_{971} = 2.23$, $p = 0.026$); and their parents had lower socioeconomic status at 5 months (z scores − 0.22 vs. 0.07, $t_{970} = -3.95$, $p < 0.001$; Supplement Table S4).

Associations of childhood greenspace with mental health problems and moderations by sex and family SES

In the unadjusted model, an interquartile range increase in childhood greenspace exposure (0.15; 250 m buffer) was

Table 1 Key characteristics of 742 participants from the QLSCD surveyed at ages 15 to 17 years in 2013 or 2015 and greenspace exposure at age 10 years in 2006 and 2008

Variables	Study sample	
	M (SD)	*N* (%)
Adolescent mental health problems		
Conduct problems	0.74 (0.86)	
Inattention	3.37 (1.81)	
Hyperactivity/impulsivity	2.61 (1.57)	
Depression	3.62 (2.01)	
Anxiety	4.31 (1.97)	
Suicidal ideation		
Yes		73 (9.8)
No		669 (90.2)
Childhood NDVI (250 m)	3.24 (0.66)	
Individual level		
Female		406 (54.7)
Male		336 (45.3)
Childhood conduct problems	1.53 (0.77)	
Childhood ADHD	2.67 (2.39)	
Childhood depression/anxiety	2.12 (1.96)	
Adolescent ritalin use[a]		
Yes		95 (13.2)
No		627 (86.8)
Family level		
Maternal age	30.19 (4.94)	
Parental depression	1.18 (0.91)	
Parental antisociality		
Parental socioeconomic status	0.20 (0.96)	
Family composition	0.41 (0.54)	
Intact		521 (70.2)
Not intact		221 (29.8)
Neighborhood level		
Material deprivation[a]		
Most privileged		253 (34.1)
Most deprived		74 (10.0)
Social deprivation[b]		
Most privileged		191 (25.7)
Most deprived		108 (14.6)

Data are *n*(%) or mean (SD). NDVI = Normalized Difference Vegetation Index. The Mental Health and Social Inadaptation Scale [39] was used to assess mental health problems; however, these measures did not provide clinical diagnoses, but rather assessed severity of symptoms. Data were compiled from the final master file of the Québec Longitudinal Study of Child Development (1998–2017), ©Gouvernement du Québec, Institut de la statistique du Québec. NDVI metrics, indexed to DMTI Spatial Inc. postal codes, were provided by CANUE (Canadian Urban Environmental Health Research Consortium)

[a]Maximum available data were $N = 722$

[b]Only data in the extreme categories are reported (first quintile = most privileged; fifth quintile = most deprived)

associated with 0.14 SD decrease in adolescent inattention ($\beta = -0.144$, SE = 0.055, $p < 0.01$). This association persisted in the fully adjusted model with control for individual, family, and neighborhood characteristics, wherein an interquartile range increase in childhood greenspace exposure (0.15; 250 m buffer) was associated with 0.13 SD decrease in adolescent inattention ($\beta = -0.126$, SE = 0.059, $p = 0.032$; Fig. 2A; Supplement Table S5). To verify the robustness of the results, sensitivity analyses were conducted to examine the (1) extent to which prescribed adolescent Ritalin use at 15/17 years of age may impact the association between greenspace exposure and ADHD and (2) whether or not important variations in the strength of association between greenspace exposure and mental health varies across different distance buffers (500 m and 1000 m). First, additional adjustment for adolescent past-year use of Ritalin (13.2% of sample) did not attenuate the association between childhood greenspace exposure and inattention ($\beta = -0.128$, SE = 0.060, $p = 0.032$). Second, similar pattern of results were observed across the three buffers for the association between greenspace exposure and inattention (see Supplement Tables S6 and S7).

No significant associations between childhood greenspace exposure and externalizing (conduct; $\beta = -0.021$, SE = 0.058, $p = 0.715$, hyperactivity/impulsivity; $\beta = -0.044$, SE = 0.058, $p = 0.447$) and internalizing (depression; $\beta = 0.021$, SE = 0.055, $p = 0.704$, anxiety; $\beta = -0.017$, SE = 0.056, $p = 0.761$, and suicidal ideation; odds ratio [OR] = 1.25, 95%CI [0.83,1.89]); Fig. 2B–F; Supplement Table S5) mental health problems were observed in adolescence, for both sexes combined.

Overall, associations between greenspace exposure and mental health problems were not moderated by child's sex ($ps > 0.05$), except for a significant greenspace-by-sex interaction for conduct problems ($\beta = -0.167$, SE = 0.075, $p = 0.025$) at the 250 m buffer, suggesting associations between higher greenspace and lower conduct problems in female ($\beta = -0.130$, SE = 0.076, $p = 0.088$), but not in male ($\beta = 0.107$, SE = 0.082, $p = 0.193$) participants. However, this greenspace-by-sex interaction for conduct problems was not replicated at the 500 m and 1000 m buffers (Supplement Tables S6 and S7). There were no significant interactions between childhood greenspace exposure and SES for any mental health problems ($ps > 0.05$).

Discussion

This study examined associations between childhood urban greenspace exposure and a range of mental health problems in adolescence. After adjustment for characteristics at the individual, family, and neighborhood levels, including prior childhood mental health problems and socioeconomic

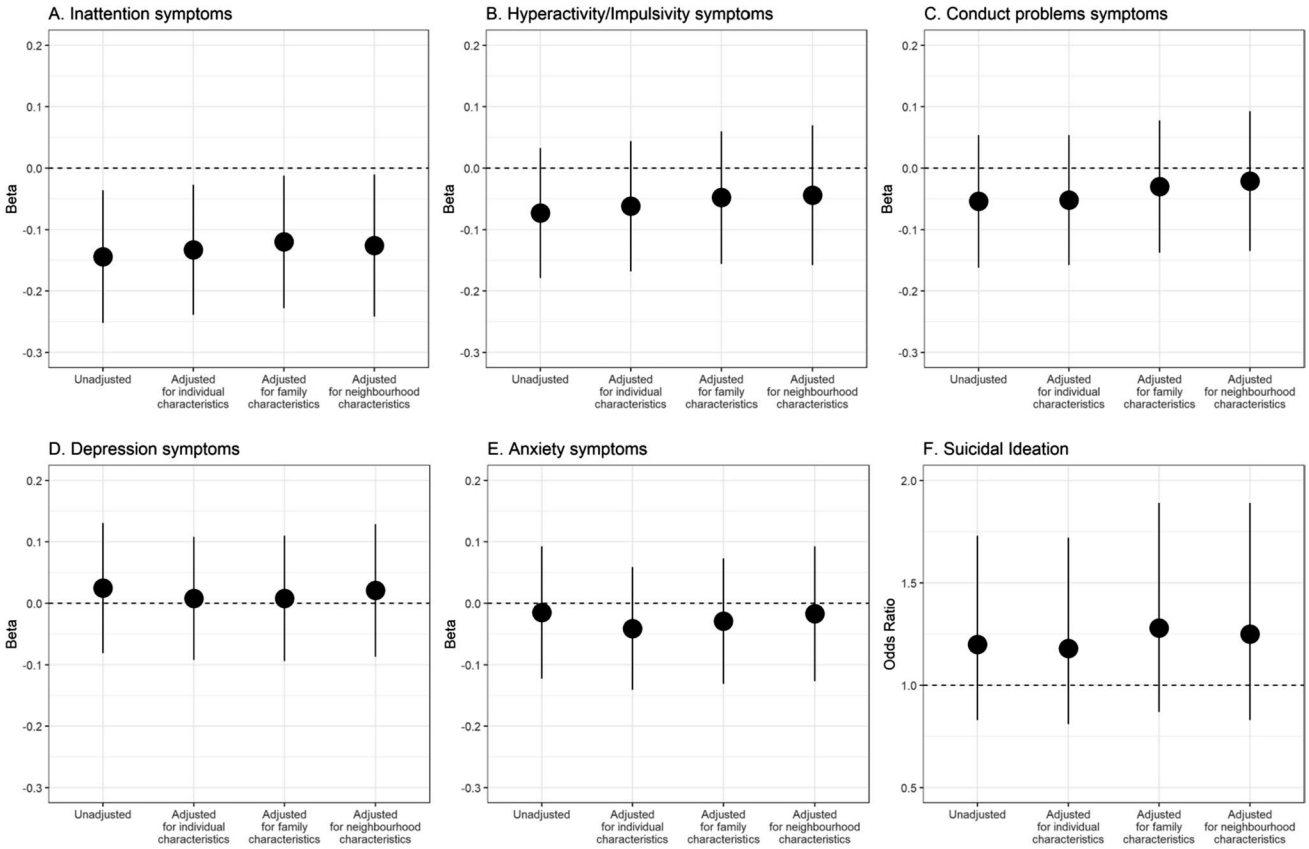

Fig. 2 Associations between residential greenspace exposure (250 m) at age 10 years with adolescent mental health problems at either 15 to 17 years among 742 participants from the QLSCD[a,b]. Note: Analyses for inattention, impulsivity/hyperactivity, conduct, depression, anxiety, and suicidal ideation problems were conducted on the full sample as there was non-significant greenspace-by-sex interactions ($ps > 0.05$). Across all mental health problems, there were no significant greenspace-by-SES interactions ($ps > 0.05$). Note: Individual characteristics included sex and childhood mental health problems. Family characteristics included maternal age, parental mental health, socioeconomic status, and family composition. Neighborhood characteristics included material and social deprivation [54]. [a]Data were compiled from the final master file of the Québec Longitudinal Study of Child Development (1998–2017), ©Gouvernement du Québec, Institut de la statistique du Québec. [b]NDVI metrics, indexed to DMTI Spatial Inc. Postal codes were provided by CANUE (Canadian Urban Environmental Health Research Consortium)

characteristics, we found an association between greenspace exposure and reduced inattention problems in both males and females. We found no evidence of an association between greenspace exposure and adolescent hyperactivity/impulsivity, conduct, depression, anxiety, and suicidal ideation problems, and sex and family SES did not consistently moderate any of the associations.

Greenspace and ADHD

Our findings showing associations between childhood greenspace and lower inattention problems are in line with current knowledge summarized in systematic reviews [59, 60] including a few longitudinal studies [13, 14, 61, 62]. Consistent with the findings from our study, two longitudinal studies based on prospective cohorts from Germany and Denmark [14, 61] showed that increasing levels of residential greenspace were associated with fewer symptoms of ADHD throughout childhood and adolescence in both females and males. Moreover, in another sample of 57,450 New Zealand youth followed from ages 2–18 years, those exposed to increasing levels of neighborhood greenspace throughout their lives had a lower incidence of being diagnosed with ADHD before 18 years of age [13]. Conversely, in a sample of youth from England, increasing levels of residential greenspace was associated with lower levels of inattention, although these associations were better explained by socioeconomic status [62].

To the best of our knowledge, our study was the first to examine the strength of associations for the full spectrum of ADHD-specific problems (inattention vs hyperactivity/impulsivity) which builds on prior research by showing that childhood greenspace exposure was associated with lower levels of inattention in females and males, but not

hyperactivity–impulsivity problems. There are brain mechanism differences demonstrated in youth presenting with profiles of combined ADHD vs profiles of inattentive or hyperactive–impulsive problems only [63]. In the present study, the potential restorative qualities of greenspace exposure were observed for inattention problems across a variety of buffer zones (250 m, 500 m, 1000 m). These results are in line with one robust randomized control study which demonstrated that youth diagnosed with ADHD ($n = 17$) had better attention (assessed with the digit span backwards, a standardized measure of concentration) after walking in a park, in comparison with when they walked in an urban neighborhood, and the benefits of walking in a park in improving attention were large (Cohen's $d = 0.77$) [64]. These results echo those from a large observational study of children (7–10 years of age) residing in Spain that illustrated how over a 12-month period, children residing in the greenest neighborhoods improved their attentional capacities assessed via a computerized attentional task [29].

Greenspace and other mental health problems

Our study showed no significant associations between childhood greenspace exposure and depression and anxiety in adolescence. These results are consistent with another longitudinal study of American adolescents that indicated that childhood greenspace exposure was not associated with self-reported symptoms of anxiety and depression in adolescence [65]. Conversely, other longitudinal studies have shown that increased childhood greenspace exposure was associated with fewer symptoms of depression [66] and anxiety [12] in adolescence, although these studies used other greenspace metrics than NDVI as was utilized in our study. It has been illustrated that different greenspace metrics yield differing associations between greenspace exposure and mental health outcomes [67, 68].

Our finding that childhood greenspace was not associated with suicidal ideation in adolescence is in line with a previous study that evaluated associations between school surrounding greenspace and suicidal ideation in youth [33]. However, other studies based on adult populations [30, 31] have demonstrated that increased level of residential greenspace is linked to decreased risk of suicide mortality. It may be that greenspace exposure affects suicidal ideation and suicide mortality differently.

For conduct problems, our findings suggesting reduced symptoms among females (not males) exposed to higher levels of greenspace at the 250 m buffer should be interpreted with caution, as this result was not replicated within the 500 m and 1000 m buffer zones. Additionally, longitudinal studies have yielded mixed results [16, 26, 28]. On the one hand, a study of 1287 American adolescents indicated that more residential greenspace was associated with fewer aggressive symptoms in late adolescence [26]. On the other hand, a study of 715 Dutch adolescents reported no significant associations between surrounding residential greenspace and conduct problems when adolescents reached young adulthood [16]. In contrast to our findings that higher levels of surrounding greenspace were associated with fewer conduct problems in females, a study of 2909 Scottish children indicated that closer proximity to parks was associated with fewer conduct symptoms in boys, but not in girls [28]. However, this study measured greenspace in terms of the proximity to parks, rather than the level of surrounding residential greenspace, as measured in our study.

Socioeconomic inequalities in the distribution of greenspace

In line with studies from other countries, our results revealed socioeconomic inequalities in the distribution of greenspace, with children growing up in socioeconomically disadvantaged families being more likely to live in areas with lower levels of greenspace. Nevertheless, we did not find that greenspace was more beneficial for mental health problems of the most socioeconomically disadvantaged youth, as shown elsewhere [13, 14, 27].

Potential mechanisms

Greenspace exposure may protect youth's mental health due to three major reasons. First, increased greenspace can reduce stress (e.g., cortisol) and increase attention, self-control, and problem-solving capacities, ultimately promoting the restoration of psychological well-being [4]. The "Attention Restoration Theory" posits that natural green environments diminish mental fatigue thus increasing attentional capacities [69]. Second, urban environments are notorious for emitting air and noise pollutants which can have adverse consequences for mental health [70, 71]. Increased greenspace in urban settings provides the potential to mitigate major pollutants, as natural environments are not generally pollutant emission sites. Third, contact with greenspace strengthens psychosocial adaptation by encouraging physical activity and social connection, both of which are protective factors for mental health [72, 73].

Methodological considerations

This study has several strengths, including its prospective design with greenspace exposure assessed in childhood and a wide range of mental health outcomes in adolescence. The use of a well-characterized cohort permitted the inclusion of several confounding factors at differing levels, including adjustment for prior mental health problems assessed in childhood. We also evaluated our associations between

mental health and greenspace exposure across three circular buffer zones (250 m, 500 m, 1000 m). However, some limitations should also be highlighted. First, although NDVI objectively quantifies the level of surrounding greenspace in a given area, it does not capture the quality, access, and use of greenspace, which has been previously associated with improved mental health in youth [74, 75]. Additionally, the present study examined residential greenspace only, while other greenspace exposure contexts, such as the school environment, may also impact mental health [33]. Second, surrounding greenspace was estimated at one time point in childhood and did not allow for an evaluation of the cumulative effects of greenspace exposure throughout childhood which may have underestimated the total greenspace exposure for a given participant over time [76, 77]. Future studies could examine the extent to which change in greenspace exposure overtime is associated with change in mental health symptom severity. Third, mental health problems were self-reported by adolescents which does not provide a clinical diagnosis for mental health problems, although the measure used [39] does cover a large spectrum of mental health symptoms based on DSM-5 criteria. Fourth, the presence of potential unmeasured confounding factors is a limitation of this work, although we did adjust our analyses for individual, family, and neighborhood characteristics, consistent with previous studies [62, 78] and extending prior knowledge by adjusting for childhood mental health problems and parental depressive symptoms and antisocial behaviors. Of note, ethnicity and racism have been shown to intersect with environmental exposures and health [79], but there were insufficient data on these factors to adequately adjust for them in the QLSCD. Fifth, while psychometric properties are acceptable, the internal consistency for inattention problems (15 years $\alpha = 0.66$, 17 years $\alpha = 0.68$) was close but below the conventional 0.70 threshold [80], suggesting that these results may need to be interpreted cautiously. While the present study did not find differences in the associations by sex, future studies could examine whether sex/gender potentially modify associations between greenspace exposure and mental health. Sixth, attrition occurred among potentially at-risk individuals, such as those from lower SES backgrounds, children of mothers with more depressive symptoms at birth, and male participants; which may have resulted in a selection bias and an underestimation of associations for these individuals.

Conclusion

Our longitudinal study revealed that higher levels of urban residential greenspace were associated with lower levels of inattention problems in male and female youth from all socioeconomic backgrounds. This finding along with other studies [14, 61] further highlights the importance of promoting the development of urban greenspace infrastructures to protect youth mental health. Although more studies are needed to elucidate the pathways by which greenspace benefits attentional abilities in youth, results from this study underscore the importance of promoting urban greenspace such as parks, gardens, street trees, or private backyards. Nevertheless, urban planning decisions may also consider other aspects of greenspace such as quality, quantity, and accessibility, which are also known to bring health benefits [74, 75].

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00127-023-02575-0.

Author contributions Ms. Bolanis and Dr. Geoffroy conceptualized and designed the study, conducted the analyses, drafted the initial manuscript, reviewed and revised the manuscript, had full access to the data used in this study, and took responsibility for the integrity and accuracy of the data analysis; Drs. Orri, Vergunst, Philippe, Ouellet-Morin, Paquin, Ms. Bouchard, and Mr. Girard participated in the analysis and interpretation of data, drafted the initial manuscript, and reviewed and revised the manuscript for important intellectual content; Drs Robitaille, Gauvin, and Côté reviewed and revised the manuscript for important intellectual content; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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Data availability Data have been obtained from a third party. The data analyzed in this study were obtained from the Institut de la statistique du Québec, and as stipulated in clauses 10 and 11 of the Institut de la statistique's du Québec Act (Canada), the access to the data is restricted to the parties identified in the partnership agreement signed to ensure the conduct of the study and which describes the author's right. In the QLSCD cohort, the participants only consented to share their data to the study's financial partners and affiliated researchers and their collaborators. Those partners and researchers only have access after signing a data sharing agreement. Requests to access these data can be directed to the Institut de la statistique du Québec's Research Data Access Services – Home (www.quebec.ca).

Declarations

Conflict of interest There are no conflicts of interest to disclose.

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