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Effects of residential greenness on attention in a longitudinal study at 8 and 11–13 years

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ABSTRACT

In an urbanizing world, with 55% of the population living in cities, it is essential to design friendly and healthy ones. An emerging body of evidence has associated greenspace exposure with improved cognitive development, including attentional function; however, the longitudinal studies looking at the association with attentional function are still scarce. Therefore, the objective of this study was to analyze the association of the exposure to greenspace and attention in school children. This study was based on 751 participants at 8 years and 598 at 11–13 years of two sub-cohorts of the INMA cohort study in Gipuzkoa and Asturias, Spain. Greenspace exposure at home was characterized using four indicators: (i) average of Normalized Difference Vegetation Index (NDVI) and (ii) Vegetation Continuous Field (VCF) in buffers of 100 m, 300 m, and 500 m around the residential address, (ii) availability of a green space within 300 m from the residential address, and (iv) residential distance to green spaces. Participants' attention was characterized twice at ages of 8 and 11 years, using the computerized Attentional Network Test (ANT). General linear models were used for the cross-sectional analyses and linear mixed effects model for the longitudinal analyses. Our cross-sectional analyses showed a statistical significant protective association between average NDVI at 300 m and inattentiveness (−7.20, CI 95%: 13.74; −0.67). In our longitudinal analyses, although we generally observed beneficial associations between greenspace exposure and attention, none attained statistical significance. No statistically significant indirect effect were seen for NO_2. Our findings add to the emerging body of evidence on the role of green spaces in neurodevelopment, which can provide the evidence base for implementing intervention aimed at promoting neurodevelopment in urban children.

1. Introduction

The industrialization accelerated the process of rural exodus to the city in search of better living and working conditions (Delgado Viñas, 2019). This urbanization process has occurred mostly due to wealth creation and economic growth in cities (Bettencourt and West, 2010). Even so, this progressive increase of the population in cities had led the scientific community to evaluate whether current urban environments are healthy for people's well-being (WHO, 2010).

Current urban environments often promote an unhealthy lifestyle such as lack of physical activity and stress and higher exposures to environmental hazards such as air pollution, noise, and heat that are detrimental to health (Nieuwenhuijsen and Khreis, 2019). From a public health and urban planning perspective, in order to ensure people's

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wellbeing, it is necessary to design healthier and more resilient and sustainable cities (Duhl and Sanchez, 1999; WHO, 2008). Above all, greater emphasis needs to be placed on those vulnerable groups for whom the exposure to these environmental factors has the greatest effect on health. The older adult, people with chronic diseases and those with low socioeconomic status are more vulnerable to noise, extreme temperatures, and air pollution exposure than the general population (European Environment Agency, 2018). Children are also considered as a vulnerable group because they have higher respiratory frequency than adults and therefore a higher exposure to air pollutants. In addition, their immune system and organs are not yet mature as they are under development and therefore are more susceptible to the environmental hazards (European Environment Agency, 2018).

Urban greenspaces are defined as land that is partly or completely covered with grass, trees, shrubs, or other vegetation). Greenspace includes parks, community gardens, and cemeteries (United States Environmental Protection Agency, n.d.). According to a recent systematic review, urban greenspaces have potentially positive effects on physical, mental health and well-being of the population (Gianfredi et al., 2021). These health benefits could be in part explained through the ability of greenspaces to mitigate the exposure to the urban-related environmental hazards such as air pollution, heat, or noise and promote social interactions and physical activity (Dadvand et al., 2014; Dadvand et al., 2015a, 2015b; Dadvand et al., 2019; Diener and Mudu, 2021; Markevych et al., 2017; Nieuwenhuijsen and Khreis, 2019; World Health Organization, 2017).

Moreover, according to the Attention Restoration Theory (ART), greenspaces could restore directed attention. Based to this theory, when people enter a natural space, their attention is deactivated and instead, their effortless attention is activated, resulting in the restoration of directed attention capacity (Hartig et al., 2014; Kaplan, 1995; Markevych et al., 2017). It is during childhood and adolescence when cognitive functions such as attention, experience a higher development, the brain develops steadily during the prenatal and postnatal period, being these periods the most vulnerable to the possible effects of environmental pollutants. However it is during childhood and adolescence when cognitive functions such as attention, experience a higher development (Anderson, 2002; Grandjean and Landrigan, 2014).

Earlier quasi-experimental studies evaluated the improvement of attention across two exposure groups: either walking in a natural environment or walking in a non-natural environment in children aged 4–10 years (Anabitarte et al., 2021; Schutte et al., 2017; Stevenson et al., 2019). These studies, evaluating the short-term effect of natural environment on attention were generally supportive of a beneficial association (Kuo and Faber Taylor, 2004; Schutte et al., 2017; Stevenson et al., 2019). Later, epidemiological studies started to evaluate the association of the long-term greenspace exposure on attention in children. Amoly et al. (2015) objectively measured residential exposure to greenspace and assessed, cross-sectionally, its relationship with attention in children at age of 7–10 years concluding that higher residential exposure to greenspace was associated with better attention. Dadvand et al. (2015a, 2015b), evaluated short-term memory and inattention in a Spanish cohort of children aged 7–10 years and found that exposure to greenspace at school was associated with improvements in short-term memory and attention over a period of 12 months. On the other hand, Dadvand et al. (2017) analyzed the association of exposure to greenspace with attention over a longer period of time. These studies found that those children who had more exposure to greenspace had better attention and cognitive development.

There are few studies analyzing the relationship between exposure to greenspace and neurodevelopment during childhood, and few authors have studied this relationship longitudinally. Therefore, this study aimed to evaluate the association of long-term exposure to greenspace with attention using two different approaches: a longitudinal approach including two repeated measurements of attention (8 and 11–13 years old) and a cross-sectional approach taking into account only one measurement of attention (8 or 11–13 years old).

2. Methods

2.1. Study setting and population

The INMA cohort is a well-established population-based cohort aimed at evaluating the role of environmental factors during pregnancy and childhood on the growth and development of children (Guxens et al., 2012). The INMA cohort is conducted in seven centres across Spain, including Sabadell, Granada, Valencia, Asturias, Gipuzkoa, Menorca and Flix. This current study is based on data from Asturias and Gipuzkoa, both located in the north of Spain. They have a temperate climate with mild summers and water availability all over the year (Cfb according to Köppen's classification), so they have high levels of arboreal vegetation (Gobierno de España, 2011).

Pregnant women were informed about the project and recruited during the first trimesters of pregnancy in health centres and hospitals of the public health system. The inclusion criteria were the following: being older than 16 years, having a singleton pregnancy, not having used assisted reproduction techniques, intention to give birth in the reference hospital, and speaking and understanding Spanish or the local language (Basque, in the case of Gipuzkoa). Since recruitment, data have been collected in several follow-up phases: in the first and third trimester of pregnancy, at birth, and when the child was 14 months, 26 months, 4 years, 8 years and 11 years of age. At the beginning of the study (2004–2007 in Asturias and 2006–2008 in Gipuzkoa), 1132 pregnant women were recruited (494 from Asturias and 638 from Gipuzkoa), and 751 participants aged 8 years and 598 participants aged 11–13 years were included in this study (Fig. 1). The ethical committees of the hospitals involved in the regions approved the project and informed consent was obtained from all participants in each wave.

2.2. Exposure to greenspace

To characterize exposure to greenspaces at 8 and 11–13 years of age, four indicators were calculated around participants' home: two of them to characterize greenness surrounding home and the other two to characterize the access to urban greenspaces.

2.2.1. Residential surrounding greenness

Satellite-based Normalized Difference Vegetation Index (NDVI) and the Vegetation Continuous Fields (VCF) were applied to characterize residential surrounding greenspace. The NDVI is an index of the level of the photosynthetically active greenspace of a given area (Tucker, 1979). The index is calculated by the difference of the surface reflectance in the visible wavelength (0.4 μm–0.7 μm) and the near-infrared wavelength (0.7 μm–1.1 μm), the near infrared (NIR) and red band must be

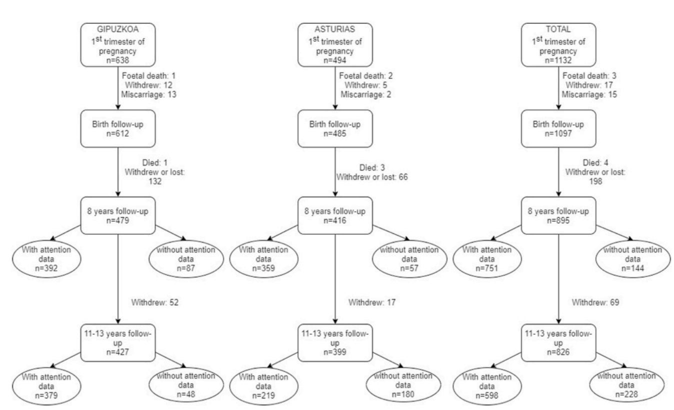

Fig. 1. Number of participants in each follow-up and available data in Asturias, Gipuzkoa and total.

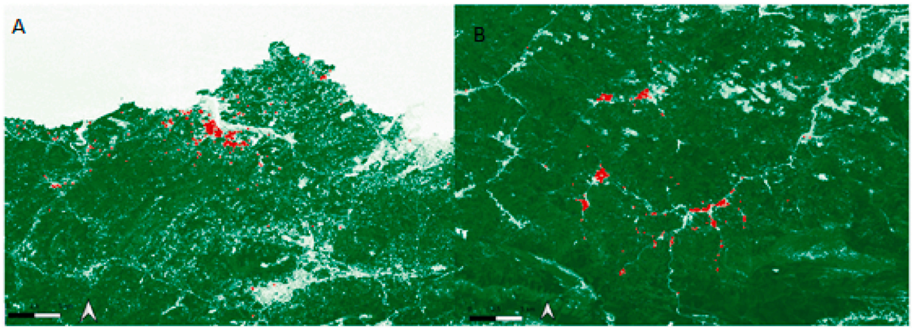

Fig. 2. Vegetation index, NDVI. Asturias (A) and Gipuzkoa (B) study area.

combined (Equation 1). This information was obtained through satellite images from Landsat 4–5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) with a resolution of 30 × 30 m in the maximum vegetation period (Supplementary Materials, Table S1). The index ranges from −1 to +1, with a value of 1 indicating the highest greenspace, negative values in the images have been reclassified to null values previously (James et al., 2015; Weier and Herring, 2000). The imagery had been selected according to the following criteria: i) cloud cover less than 10%, ii) Standard Terrain Correction (Level 1 T) and iii) greenest period of the year.

The VCF indicates the percentage of woody vegetation greater than 5 m in height in each 30 × 30 m pixel. This variable is a product derived from Landsat-5 Thematic Mapper (TM) and/or Landsat-7 Enhanced Thematic Mapper Plus (ETM+) bands (Sexton et al., 2013). To calculate VCF at both follow-ups satellite images of different dates were used in Asturias and Gipuzkoa (Supplementary Material Table S1).

We defined residential surrounding greenspace and tree cover as the average of NDVI and VCF, respectively, across buffers of 100 m, 300 m, and 500 m (Dadvand et al., 2017; Rammah et al., 2021) around the participant's residential address at each follow-up.

2.2.2. Residential access to greenspaces

The residential access to greenspaces was characterized by (i) the availability of an urban greenspace larger than 5000 m^2 (based on WHO recommendation) within, separately, 100, 200, and 300 m (WHO Regional Office for Europe, 2016) from the residential address (yes/no), and by (ii) the residential distance, in meters, to this large greenspace. This information was obtained from Urban Atlas 2012 and EUNIS 2009 (European Nature Information System) for Asturias and Gipuzkoa, respectively.

2.3. Attention

Attention was characterized using the Attention Network Test (ANT) (Fan et al., 2002; Rueda et al., 2004) at the 8 as well as 11-13y follow-ups. This computer test characterizes attention in children older than 6 years (Rueda et al., 2004). Participants have to press the left or right arrows on a keyboard depending on which way the central arrow of the five horizontal arrows on the screen is facing, in case of success participants will receive a positive auditory reinforcement (Woo hoo!) (Suades-González et al., 2017). All participants received the same instructions, which were agreed upon by all instructors. The first time-block was always for training and once the instructors checked that each child had understood how to do the test, the training ended and the test started, which consisted of four blocks of 32 trials each (128 trials in total). Median response time calculated from the response time collected in the 128 trials (Hit Rt median), which could indicate the speed of the participants in answering each test. The higher Hit Rt median hence suggestive of less attention. We also calculated the standard error of the response time (HRT-SE), which indicates the speed consistency in response time between the different tests of each participant. The higher HRT-SE could indicate more inconsistency in responding, hence more inattention (Dadvand et al., 2017; Pozuelos et al., 2014; Suades-González et al., 2017). The test was administered by a person prepared for this purpose in each cohort for each follow-up. The same computer was used for all participants in each cohort and all were given the same explanation.

2.4. Covariates

The sociodemographic variables used in the models for this study were identified through a DAG model designed *a priori* based on the available literature (Supplementary Material Figure S1). The variables sex, prematurity (<37 weeks' gestation), birth weight (continuous), parity (continuous), maternal education (primary or without education, secondary or university), social class based on occupation (1: highest social class to 3: lowest social class) and smoking during pregnancy (yes or no) were collected in the pregnancy follow-up. Type of breastfeeding (maternal breastfeeding, mixed or formula feeding) and nursery (yes or no) were collected during the postnatal 24 months follow-ups. Time spent in sedentary activities (continuous) and maternal IQ were collected in the 4-year follow-up. Maternal scores on the Similarities subtest of the Wechsler Adult Intelligence-Third Edition (WAIS-III) (Wechsler and Kaufman, 2001) were assessed as a proxy for maternal IQ, given that this subtest has been shown to be a good predictor of global IQ (Wechsler, 1997). Time sleeping in hours (continuous) was collected in the 8-year follow-up and hours watching TV per week (continuous) was collected in the 8-year and 11-13-year follow-ups. Finally, the neighbourhood's socioeconomic status was collected through the deprivation index of the MEDEA2011 project for each follow-up, created by the following indicators: manual worker, unemployment, temporary workers and insufficient education overall and in young. This index has been created using the census section, the smallest administrative unit, as the administrative unit. (Domínguez-Berjón et al., 2008). Sex, prematurity and birth weight were collected through the clinical history. Parity, maternal education, social class, smoking during pregnancy, type of breastfeeding, nursery, time in sedentary activities, time sleeping and time watching TV were collected by questionnaire. Not all variables were used for the model adjustment.

2.5. Statistical analysis

First, with the aim of describing the sample, a descriptive analysis of both the characteristics of the sample, and the exposure and effect variables was carried out. The profile of the sample at 8 and 11–13 years of age was evaluated using nonparametric tests ($\chi 2$ for qualitative variables and Mann-Whitney for quantitative variables). In addition to between follow-ups, those who performed the test (included) were also compared to those who did not (excluded) at 8 and 11–13 years of age and in total.

2.5.1. Cross-sectional analyses

Once the variables of interest were identified through performing DAG model (supplementary material Figure S1), we used general linear models (Madsen and Thyregod, 2010) to test for the effect of either greenspace (NDVI/VCF), availability or distance of greenspaces on each of the Hit Rt median and HRT-SE for each follow-up. Date of measurements was introduced in the models as an offset variable. Residuals of each model were evaluated for validation purposes. For this purpose, we used the function lm() of package stats in R software (R Core Team, 2020). The objective of this analysis is to evaluate whether exposure to the green environment has better attentional results in those who are more exposed in comparison to those who are less exposed at home. Although green environment exposure is at 8 years and 11–13 years, it is assumed that most participants have been exposed since birth or at least 3 years ago, because according to the follow-up results, for every 10 participants only 2 changed residence between birth and 8 years and only 9% from 5 to 8 years. Therefore, we can assume that most of them have had a long-term exposure. Nevertheless, a sensitivity analysis was performed with only those who have not moved and with those who were not preterm to assess the consistency of the results obtained. We adjusted the aforementioned models for socioeconomic status, age at the time of attention test, sex, preterm, maternal IQ, maternal smoking during pregnancy and cohort (Table S3).

2.5.2. Longitudinal analyses

Likewise, we used general linear mixed-effects models (Madsen and Thyregod, 2010) to test for the effect of both age and either greenspace (NDVI/VCF), availability or distance of greenspaces on each of the responses Hit Rt median and HRT-SE, once the effect of adjusting variables had been accounted for. Since responses were measured in the same subjects at two different ages (8- and 11-13-year-old), subject (nested within cohort) was fitted as a random factor. The response variables is expressed by the difference between attention measured at 8 and at 11–13 years (Hit Rt median at 8 years – hit rt median at 11–13 years and HRT-SE at 8 years – HRT-SE at 11–13years). To correct the observed within-group heteroscedasticity, a constant variance structure was introduced in the models to allow for different variances according to the levels of cohort and age. These models we adjusted for age at the time of attention test, socioeconomic status, sex, preterm, maternal IQ, maternal smoking during pregnancy and cohort. For this purpose, we used the function lme() of package nlme (Pinheiro et al., 2018) in R software (R Core Team, 2020).

When models were statistically significant, mediation models using NO_2 as mediator were fitted. More information about these mediation models is given in supplementary material.

3. Results

In the first trimester of pregnancy 1132 woman were recruited (494 from Asturias and 638 from Gipuzkoa) in INMA. Longitudinal data up to the 8-year follow-up was available for 66% of the recruited families, being 61% for those from Gipuzkoa and 73% from Asturias. At the 11–13 years follow-up, we collected information from 53% of the recruited families, being 59% for those from Gipuzkoa and 37% from Asturias. In the case of Asturias, the notable decrease in the sample of the last follow-up was due to lockdown measures taken due to the COVID-19 pandemic.

Table 1 shows the characteristics of the study samples at both follow-ups. Women made up 49% of the sample, under 5% of children had the history of preterm delivery, and around 12–13% of the mothers were smoker during pregnancy. The median of mother's IQ was 9.76 of the possible range of 0–14. The neighbourhood socioeconomic status of the participants changed significantly between the two follow-ups. At 8 years follow-up 64% of the had a high socioeconomic level (indexes 1 and 2) while at 11–13 years 72% of the families had these socioeconomic levels. Moreover, children's sleeping time was significantly higher at the 11-13-years follow-up. For the rest of characteristics we did not observe any notable difference between the follow-ups.

Table 1
Description[a] of characteristics of the study participants at 8 and 11–13 years follow-up.

Characteristics	8 years follow-up (n = 751)	11–13 years follow-up (n = 598)	p-value[b]
Sex (female)	0.489	0.507	0.547
Preterm birth(yes)	0.049	0.046	0.965
Age (mean (min-max))	8.10 (7.7–9.7)	11.4 (10.3–13.1)	–
Maternal IQ[c] (0–14)	9.76(3.67)	9.76(3.67)	0.704
Maternal smoking during pregnancy (yes)	0.132	0.121	0.495
Neighbourhood socioeconomic status			0.005
1 Better	0.309	0.370	
2	0.326	0.362	
3	0.186	0.137	
4	0.137	0.102	
5 Lower	0.041	0.029	
Parity			0.978
0	0.590	0.599	
1	0.364	0.350	
2	0.040	0.044	
3	0.005	0.007	
4	0.001	0.002	
Birth weight (gr.)	3290 (545)	3290 (558.75)	0.976
Time watching TV 8y(min.)	60 (60)	60 (75)	0.989
Time watching TV 11-13y (min.)	60 (30)	60 (30)	0.873
Time sleeping (hrs.)	10.29 (0.93)	10.36 (0.68)	0.016
Time spent in sedentary (hrs.)	90.5 (13)	90.5 (12.28)	0.908
Maternal education			0.967
Primary or without education	0.118	0.114	
Secondary	0.401	0.395	
University	0.482	0.490	
Social class			0.802
I- More rich	0.420	0.443	
II	0.227	0.226	
III-Less rich	0.353	0.319	
Type of breastfeeding			0.645
Maternal breastfeeding	0.273	0.283	
Mixed	0.547	0.563	
Formula feeding	0.181	0.153	
Nursery at 24 months(yes)	0.722	0.741	0.487

[a] Categorical variables were described through percentages and for continuous variables, with median and IQR.
[b] p-value of difference between the two follow-ups using chi-squared test for the categorical variables and Mann-Whitney *U* test for the continuous variables.
[c] Similarities subtest.

The characteristics of children and their mothers participating and non-participating at each wave, 8 and 11–13 years of age, are shown in the supplementary material (Table S2), being the main difference that of the mother's IQ.

As shown in Table 2, at the age of 8 years NDVI was higher in Gipuzkoa than in Asturias for the three buffers ($p < 0.05$) and, at the age of 11–13 years, the difference was also observed with NDVI 500 m ($p < 0.05$), but not for the buffers of 100 and 300 m. Regarding the differences between follow-ups, there were statistically significant differences in all NDVI buffers, being greenspace scores higher at 11–13 years. For VCF, significant differences were found between cohorts at both waves, 8 and 11–13 years, at the 100 m and 300 m buffers; differences were also seen between waves at 8 and 11–13, although VCF 300 m difference was marginally significant. Unlike NDVI, the average VCF value was higher in the Asturias than in the Gipuzkoa cohort. No differences in VCF were observed for 500 m, neither between cohorts nor between follow-ups.

Almost all families (97%) lived within 300 m of a greenspace larger than 5000 m^2. The availability a greenspace larger than 5000 m^2 only differed statistically for the 100-m buffer between cohorts at both follow-ups. No differences in the availability of large greenspaces were

Table 2
Description of measures of green exposure measurements (measured at home) at age of 8 and 11–13 years.

Variables	8-y follow-up				11-13-y follow-up				
	Total (n = 751)	Asturias (n = 359)	Gipuzkoa (n = 392)	p-value[a]	Total (n = 598)	Asturias (n = 219)	Gipuzkoa (n = 379)	p-value[a]	p-value[b]
Residential Surrounding greenspace (NDVI) (median(IQR))									
100	0.312 (0.177)	0.298(0.202)	0.319(0.158)	0.027	0.379 (0.185)	0.382(0.221)	0.378(0.159)	0.850	0.000
300	0.389 (0.172)	0.377(0.209)	0.405(0.155)	0.000	0.461 (0.165)	0.457(0.226)	0.462(0.143)	0.504	0.000
500	0.454 (0.148)	0.424(0.175)	0.477(0.137)	0.000	0.514 (0.133)	0.507(0.214)	0.519(0.121)	0.012	0.000
Residential surrounding tree cover (VCF) (%)									
100	9.31 (7.1)	11.44 (5.35)	6.89 (4.89)	0.000	8.59 (6.35)	11.2 (4.93)	6.67 (4.82)	0.000	0.035
300	12.07 (7.48)	13.01 (6.58)	10.97 (7.9)	0.000	11.75 (7.25)	13.01 (6.1)	10.68 (7.89)	0.000	0.087
500	15.62 (8.3)	15.28 (7.6)	16.11 (10.17)	0.300	15.32 (8.71)	14.98 (6.45)	15.76 (10.2)	0.368	0.252
Green availability (>5.000m^2) (%)									
100	62.55	69.16	57.14	0.001	61.990	69.95	57.94	0.007	0.884
200	89.48	89.41	89.54	1	89.14	90.16	88.62	0.679	0.917
300	97.33	97.51	97.19	0.979	96.85	96.89	96.83	1.000	0.726
Distance to a green area >5.000m^2 (m)	73.17 (99.7)	57.42 (84.17)	83.9 (103.04)	0.003	75.62 (102.74)	58.46 (81.74)	83.9 (107.47)	0.004	0.539

Note: p-values are reported for chi-squared test for categorical variables and Mann-Whitney *U* test for continuous variables. For continuous variables, median (IQR) and for categorical variables count (percentage) of each category has been reported. p-value[a] for the difference between children in each cohort. p-value[b] for the difference between children with attention availability data at the 8-year follow-up and at 11-13-y follow-up.

seen between the two follow-ups. The distance to greenspaces of larger than 5000 m^2 was statistically longer between the two cohorts and between waves, being the distance in Asturias smaller than in Gipuzkoa.

3.1. *Cross-sectional association between exposure to greenspace and attention*

As presented in Table 3, for the 8-year follow-up we only observed a marginally significant inverse (i.e. protective) relationship between VCF at 500 m buffer and HRT-SE. Although no other significant relationship was found, NDVI and VCF distance to a greenspace showed an inverse relationship with HRT-SE response and a positive relationship with distance to greenspace. Hit Rt median was not associated with any of the greenspace indicators at this wave.

At 11–13 years follow-up we found an inverse relationship between NDVI (300 m buffer) and Hit Rt median and HRT-SE, being statistically marginally and statistically significant, respectively. Also, a marginal inverse relationship was seen between NDVI (500 m buffer) and HRT-SE. The rest of the residential greenspace indicators did not show any significant association with any of attention measurements.

When repeating the analyses only with those participants who did not change their residence (Supplementary material Table S4-5), and with those that were not preterm, we did not observe any notable change in the aforementioned findings (Data not shown).

3.2. *Longitudinal association between greenspace exposure and attention*

In total, there were 555 children with attention test measurements in the two follow-ups (206 from Asturias and 349 from Gipuzkoa). No significant relationships were observed in the longitudinal analyses between greenspace indicators and attention measurements (Table 4).

No indirect effect between NDVI 300 and NO_2-mediated HTR-SE was found. The results can be found in supplementary material (Figure S3).

4. Discussion

The objective of this study was to analyze the association between exposure to greenspace and attention at the age of 8 and 11–13 years. Our study was based on two well-established and well-characterized

Table 3
Coefficients (together with 95%CI) of the regression models estimating the association between several versions of exposure measurements (NDVI, VCF, green availability, green distance) and two measurements of attention score (Hit Rt median/HRT-SE), once that the effect of the covariates have been accounted for.

	8 years n = 751		11–13 years n = 598	
	Hit Rt median	HRT-SE	Hit Rt median	HRT-SE
NDVI - 100 m buffers	9.69 (−6.24; 25.62)	−0.47 (−7.23; 6.30)	−8.15 (−19.49; 3.19)	−4.18 (−10.83; 2.48)
300m buffers	2.57 (−13.43; 18.57)	−1.03 (−7.82; 5.75)	−10.33 (−21.49; 0.83)	−7.20 (−13.74; −0.67)*
500m buffers	0.69 (−15.59; 16.98)	−2.81 (−9.71; 4.09)	−8.11 (−19.29; 3.08)	−6.56 (−13.10; 0.01)
VCF - 100m buffers	3.49 (−13.26; 20.24)	−0.01 (−7.12; 7.09)	2.13 (−10.00; 14.26)	4.31 (−2.79; 11.41)
300m buffers	−8.08 (−23.79; 7.63)	−4.59 (−11.25; 2.06)	−6.62 (−18.02; 4.78)	−3.48 (−10.17; 3.21)
500m buffers	−10.74 (−26.28; 4.79)	−6.48 (−13.06; 0.09)	−3.66 (−14.85; 7.53)	−3.18 (−9.74; 3.38)
Green availability 100	8.60 (−24.39; 41.59)	5.27 (−8.87; 19.42)	0.04 (−23.44; 23.53)	−1.29 (−14.96; 12.36)
Green availability 200	7.59 (−44.29; 59.46)	−3.57 (−25.81; 18.68)	−6.59 (−44.16; 30.97)	−14.69 (−36.51; 7.12)
Green availability 300	−15.97 (−123.67; 91.74)	7.89 (−38.29; 54.08)	−20.31 (−87.81; 47.19)	−22.48 (−61.71; 16.75)
Green distance	−1.79 (−17.81; 14.22)	−0.49 (−7.36; 6.37)	3.62 (−8.06; 15.29)	3.58 (−3.21; 10.36)

*$p < 0.05$. Adjusted for socioeconomic status, age at the time of attention test, sex, preterm, maternal IQ, maternal smoking during pregnancy and cohort.

Table 4
Coefficients (together with 95%CI) of the regression mixed effect models estimating the association between several versions of exposure measurements (NDVI, VCF, green availability, green distance) and two measurements of attention score (Hit Rt median/HRT-SE), once the effect of the covariates have been accounted for.

	Hit Rt median		HRT-SE	
	Value	p-value	Value	p-value
NDVI – 100m buffers	72.817 (−207.211; 352.846)	0.610	−9.052 (−131.197; 113.093)	0.884
300m buffers	−58.803 (−338.487; 220.880)	0.680	3.585 (−119.127; 126.297)	0.954
500m buffers	−93.634 (−391.159; 203.890)	0.537	−25.755 (−156.792; 105.283)	0.700
VCF – 100m buffers	0.847 (−5.529; 7.223)	0.794	−1.000 (−3.787; 1.786)	0.481
300m buffers	−2.814 (−7.553; 1.924)	0.244	−0.065 (−2.718; 1.428)	0.541
500m buffers	−3.900 (−8.302; 0.504)	0.083	0.949 (−2.880; 0.982)	0.335
Green availability 100	−17.401 (−97.394; 62.593)	0.669	3.909 (−30.770; 38.587)	0.825
Green availability 200	10.606 (−116.171; 137.383)	0.870	22.623 (−32.822; 78.068)	0.423
Green availability 300	−18.206 (−256.378; 219.965)	0.881	80.267 (−22.953; 183.486)	0.127
Green distance	0.087 (−0.399; 0.574)	0.725	−0.049 (−0.262; 0.164)	0.654

*$p < 0.05$. Mixed effects models with random cohort effect adjusted for socio-economic status, age at the time of attention test, sex, preterm, maternal IQ, maternal smoking during pregnancy and cohort, cohort x age and exposure x age.

birth cohorts with repeated assessment of attention using objective computerized tests and a prospectively-collected covariate data since pregnancy. In our cross-sectional analyses we observed a protective association between average NDVI at 300 m buffer around the residential address and HRT-SE (an indicator of inattentiveness) at 11–13 years, which was not seen at 8 years. For the rest of the cross-sectional associations and all longitudinal associations, we generally observed beneficial associations between residential surrounding greenspace and Hit Rt mean and HRT-SE; however, none of these associations attained statistical significance. In general, the cross-sectional and the longitudinal studies within this research work led to similar, consistent, results (in general terms, no significant effects were found). Nonetheless, in the cross-sectional study, and only for the response HRT-SE at 11–13 years of age and exposure NDVI at 300 m buffers, we found one significant effect [−7.20 with 95% C.I. (−13.74, −0.67)]. In the longitudinal study, a nearly significant effect ($p = 0.083$) was found for only for the response Hit Rt median and VCF 500 m buffers [estimate of the effect: 3.900 with 95% C.I. (−8.30, 0.50)]. These findings stayed unchanged after we limited participants to those who did not change their address since 4-year follow-up. Conducted mediation analysis did not revealed NO_2-mediated effects of NDVI 300 m on HTR-SE at 11 years.

Regarding residential greenspace, different levels of greenspace measured by NDVI have shown an association on attention; for example, studies conducted in Mediterranean areas with lower NDVI levels than ours have also observed a relationship between greenspace exposure and attention in children of the similar age (Amoly et al., 2015; Asta et al., 2021; Dadvand et al., 2017). In contrast, we did not observe any association between greenspace measured by VCF and attention, and neither did the only other study that analyzed the relationship between VCF and attention (Dadvand et al., 2017). To our knowledge, only one study besides this one has analyzed the improvement of attention at different ages related to exposure to residential greenspace (Dadvand et al., 2017), this study was also carried out in the INMA project, but in this case in the cohorts of Sabadell and Valencia. Attention data were collected at the 4–5 and 7–8 year follow-ups and the analyses were carried out cross-sectionally. Previous longitudinal studies have found a relationship between greenspace and attention from age 4–10 years, therefore, this study extends the positive results previously observed (Asta et al., 2021; Dadvand et al., 2017; Dadvand et al., 2015a, 2015b; Liao et al., 2020). In our case, no associations were observed at 8 years of age, although the trend was toward reduced inattention.

It should be noted that there are also other studies in which association between exposure to greenspace and Attention-Deficit/Hyperactivity Disorder (ADHD) is investigated. There are studies that have studied the relationship between NDVI and ADHD (Donovan et al., 2019; Markevych et al., 2018; Thygesen et al., 2020; Yang et al., 2019), and also with access to green spaces (Markevych et al., 2014). Some studies have seen an association between NDVI and ADHD diagnosis (Donovan et al., 2019; Markevych et al., 2018; Thygesen et al., 2020) and another, in contrast, with ADHD symptomatology (Yang et al., 2019). Another study saw a relationship between access to urban green spaces and ADHD symptomatology (Markevych et al., 2014). These studies have generally reported that higher greenspace exposure is associated with lower risk of ADHD and its symptomatology. Therefore, this study provides evidence on the effect of residential greenspace exposure on attention.

In our current study, no association was seen between residential surrounding tree cover and attention, except for a marginal association at age 8 with HRT-SE. No effect with higher tree cover was seen in this study either. Unlike the study above mentioned, which was mainly located in a Mediterranean climate and therefore does not have much tree cover higher than 5 m, this current study was conducted in an area with an Atlantic climate in which larger trees predominate. Therefore, in this case, we could expect significant results with the use of VCF. On the other hand, as the participants were in an Atlantic climate with a lot of vegetation, this could lead to almost no variability in exposure to green spaces and it could be that the high exposure to greenspace around the neighbourhood does not lead to significant restoration of attention. Just as the possible restorative effect of different types of greenspace should be studied, it would be interesting to analyze whether those who are more exposed on the day-to-day restore less attention than those who interact with greenspace sporadically.

At 8 years, in an Atlantic climate, we observed higher NDVI levels than in similar studies conducted by Dadvand et al. (2017) in Sabadell and Valencia (Spain) with 7-year-olds and by Asta et al. (2021) conducted in Rome (Italy) also with 7-year-olds in areas with a Mediterranean climate. On the one hand, despite having higher levels of greenspace (measured as the NDVI average) in the Atlantic zone, no associations were observed at 8 years of age. On the other hand, significant associations between average of NDVI in a 500 m buffer around residential address and attention were observed at 7 years in Sabadell and Valencia and Rome. It should be noted that Asta et al. found an association between NDVI at 500 m around the residence and attention with very similar values of this study, but no association was found in our study. We postulate that this may be due to two possible reasons. On the one hand, it could be the different types of vegetation that can be found in different climates and on the other hand, it could be due to our relatively modest sample size that limited our statistical power.

Greenspaces could have an effect on health through three pathways: the mitigation of environmental pollutants such as air pollution or noise, the instoration of social cohesion and physical activity and through the reduction of stress linked to the Stress Reduction Theory (STR), and the restoration of attention linked to the ART theory (Markevych et al., 2017). According to scientific literature, it is not only exposure to greenspaces that can have an effect on attention via ART. According to several studies, exposure to greenspaces can reduce air pollution

(Dadvand et al., 2012; Dadvand et al., 2015a, 2015b) and noise (Van Renterghem et al., 2015), factors that have been linked to poorer attention (Sunyer et al., 2015; van Kempen et al., 2012). In addition, the promotion of physical activity by greenspaces (James et al., 2015) may improve attention (de Greeff et al., 2018), and it may be that the promotion of social cohesion by greenspaces is also an enhancing mechanism for improving attention (Markevych et al., 2017).

With respect to limitations, it should be noted that this study is not free of them. Firstly, due to the COVID-19 pandemic, data collection for the 11–13 years phase in Asturias was suspended and, therefore, only part (approximately 50%) of the total sample of the Asturias cohort could be included. This may be one of the reasons for the differences in socioeconomic status between those included and excluded from this phase in the Asturias cohort. In addition, there may be some variables not collected in the present study like family context or bio-genetic factors that are interfering in the relationship between greenspace exposure and attention. Second, given that we had collected the social class variable individually in the pregnancy follow-up and this measure was probably outdated for the current analyses, we decided to use the MEDEA deprivation index. Despite this latter measure was more recent in time, it is less informative because it is calculated at census section level (smallest administrative unit) so we could lose accuracy. However, it is also true MEDEAs deprivation index comprises several socio-economic indicators making it more complete than the simple social class variable (Domínguez-Berjón et al., 2008). Third, the possible effect of blue spaces, as a co-exposure with greenspace, has not been taken into account (Amoly et al., 2015). Finally, no measures have been taken for exposure to greenspaces in children's schools, where they spend a relevant part of their time during work days and the quality of greenspaces has also not been measured.

5. Conclusion

The present study provides evidence on a potential beneficial impact of exposure to greenspace on attention in childhood. Specifically, a significant and positive association was found between greenspace measured by NDVI in 300 of the home and attention at 11–13 years of age, but not at 8 years of age. These results highlight both the need for further research on the subject and the need to create healthy spaces in cities, such as greenspaces, as a priority. It would be recommended that future studies take into account the possible exposure of participants to the noise, in order to measure the indirect effect between greenspaces and attention. Including exposure to blue spaces would also be important. Our findings, if confirmed by future studies, could inform policymakers about implementing interventions aimed at improving attention and neurodevelopment in general in urban children.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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