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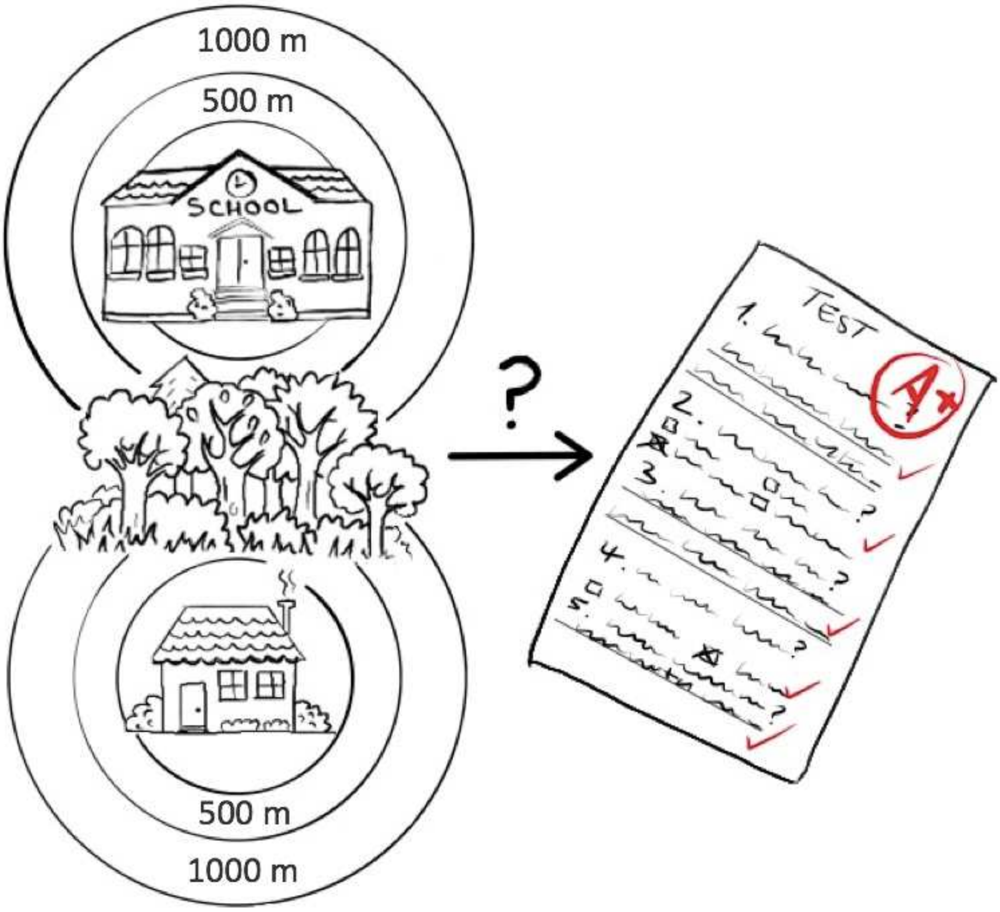
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Residential and school greenspace and academic performance: Evidence from the GINIplus and LISA longitudinal studies of German adolescents

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Abstract

Background: Few studies have reported the association between greenspace and academic performance at school level. We examined associations between both residential and school greenspace and individual school grades in German adolescents.

Methods: German and maths grades from the latest school certificate, residential and school greenspace, and covariates were available for 1351 10 and 15 years old Munich children and 1078 Wesel children from two German birth cohorts – GINIplus and LISA. Residential and school greenspace was assessed by the Normalized Difference Vegetation Index (NDVI), tree cover, and (in Munich only) proportion of agricultural land, forest, and urban green space in 500-m and 1000-m circular buffers. Longitudinal associations between each exposure-outcome pair were assessed by logistic mixed effects models with person and school as random intercepts and adjusted for potential confounders.

Results: No associations were observed between any of the greenspace variables and grades in Wesel children. Several statistically significant associations were observed with German and maths grades in Munich children, however associations were inconsistent across sensitivity analyses.

Conclusions: There is no evidence of an association of higher greenspace at residence, school or combined with improved academic performance in German adolescents from the GINIplus and LISA longitudinal studies.

Capsule

Higher residential or school greenspace does not appear to improve academic performance in 10- and 15-years old children from two study areas in Germany.

Key words: greenness, green space, grades, learning, children, epidemiology.

Introduction

Reviews of current scientific evidence suggest improvements in academic performance can be made by supporting health and health-related behaviours in children within and outside of school settings (Donnelly et al., 2016; Owen et al., 2016; Rampersaud et al., 2005; Trudeau and Shephard, 2008). Upstream factors that support potential means of stimulating greater academic performance, such as greenspace (e.g., parks and tree cover) are of interest to policy makers. Studies often (though not always) report larger amounts of residential greenspace are associated with factors that likely support learning, such as child emotional wellbeing and overall child cognitive development (Gascon et al., 2015; McCormick, In press; de Keijzer et al., 2016; Feng and Astell-Burt, 2017; Ward et al., 2016; Dadvand et al., 2015). In sum, this would appear to suggest the potential for greenspace provision and preservation as a means to support and contribute to improvements in child academic performance.

Surprisingly few studies have attempted to examine this hypothesis thus far. A study in Massachusetts reported stronger school-wide academic performance among schools situated within greener environs, even after adjustment for socioeconomic factors (Wu et al., 2014). A similar study in Toronto found an association between tree cover at school and students' performance (Sivarajah et al., 2018). A study in Minnesota found no evidence of an association between academic performance and greenness in the school area *per se*, but did report a positive correlation between reading performance and nearby tree cover (Hodson and Sander, 2017). By contrast, a study in New Zealand found the percentage of children achieving academic attainment above expectations to be weakly and negatively associated with nearby green space (Beere and Kingham, 2017). Given that areas of low socioeconomic status (SES) were on average greener in the latter study, such an observation is not surprising.

These equivocal findings may be attributable to heterogeneity in a variety of important factors such as exposure location (e.g., residential compared with around the school), exposure definition (e.g., tree cover compared with parklands) and academic systems that vary between schools, states and countries. Residual confounding by urbanicity and SES may offer further explanation, given that all four studies on greenspace and academic performance (Wu et al., 2014; Hodson and Sander, 2017; Beere and Kingham, 2017; Sivarajah et al., 2018) were ecological. More prosperous neighbourhoods can be greener in urban areas (Astell-Burt et al., 2014), as often, only families with higher incomes can afford to live close to a park or a forest (Markevych et al., 2017b). The opposite situation has been reported in rural areas (Markevych et al., 2017b). Research in different countries and contexts is necessary before conclusions are drawn on to what extent greenspace planning can play a role in lifting academic performance and, potentially, ameliorating educational inequalities. Although inequality in health and living conditions in Germany is lower than in many other non-European countries, still, Germany's educational system is less equitable than the average across the Organisation for Economic Co-operation and Development (OECD) countries. In particular, 16% of variation in students' academic performance in science is attributed to differences in students' SES (OECD, 2016).

Accordingly, the aim of this paper was to conduct a longitudinal study to examine associations between residential greenspace and academic performance in two cohorts of adolescents living in one urban and one rural area in Germany. Unlike previous research, we utilized individual grades rather than percentage of students with high grades and greenspace at both school and residential addresses.

Methods

Data were obtained from the two ongoing multicentre German birth cohorts – GINIplus and LISA (von Berg et al., 2010; Zutavern et al., 2006). Briefly, healthy, full-term newborns with normal birth weight were recruited in selected maternity wards of the cities of Munich (n = 4413), Leipzig (n = 976), Bad Honnef (n = 306) and Wesel (n = 3390) between 1995 and 1999. Both GINIplus and LISA have been approved by local ethics committees and informed consent was obtained from all families and subjects. Originally, both cohorts were tailored to investigate environmental and lifestyle factors, as well as genetic markers, in development of allergic diseases. Later, the cohorts were extended to incorporate data on comorbidities, physical activity, diet and mental health. Over the course of 15 years of follow-up, some of the families moved out of the cities of recruitment. The current analysis is based on participants recruited, residing and attending school in the Munich area (including the city of Munich and the adjacent regions of Upper Bavaria and Swabia) and the Wesel area (including the city of Wesel and the adjacent regions of Münster and Düsseldorf) at the time of both 10- and 15-year follow-ups, when the data on academic performance were collected. Bad Honnef and Leipzig participants were not considered for this analysis, as their home addresses were only partially available. Analytic samples included participants with complete data on outcomes, greenspace, and main covariates (except for income where missing values were assigned to a separate category) at both 10- and 15-year follow-ups. Additionally, participants who resided at their current address for shorter than one year and those who were ever diagnosed with dyslexia or dyscalculia were excluded (Figure S1). Final samples comprised 1351 participants from Munich and 1078 participants from Wesel.

Residential and school greenspace was measured by mean values of greenness (i.e. vegetation level) and tree cover density, as well as proportions of agricultural land, forest, and urban green space in circular buffers around a residential address and a school address at 10- and 15-year follow-ups. Greenness (-1 to +1) was defined by the Normalized Difference Vegetation Index (NDVI; Tucker, 1979). The May to August mean NDVI for the years 2005 to 2009 (referring to 10-year follow-ups) and 2011 to 2014 (15-year follow-ups) was assessed from the MODerate-resolution Imaging Spectroradiometer (MODIS) satellite images in resolution of 250 m (https://search.earthdata.nasa.gov/). The May to August NDVI was selected to grasp the maximum vegetation contrasts (Dadvand et al. 2012). Tree cover density (%) was calculated from the developed by the European Environmental Agency Tree Cover Density 2012 raster in resolution of 20 m (http://land.copernicus.eu/pan-european/high-resolution-layers/forests/tree-cover-density/view). Proportions of agricultural land, forest and urban green space were calculated from the local Bavarian land use dataset from the Bavarian Survey Office for the year 2008, and were available only for Munich area. Our main variables of interest were combined home-school greenspace variables. They were created in line with the previous research (Amoly et al. 2014) as averages of home and school exposures with weighting by the daily time that children in Germany typically spend at school (6 hours) and at home (18 hours). We also present the results for home and school exposures separately. In line with previous research on academic performance, emotional wellbeing and cognitive development (e.g., Wu et al., 2014; Amoly et al., 2014, Markevych et al., 2014; de Keijzer et al., 2018), we selected 500-m Euclidean buffer as a main analysis, but the results for 1000-m buffer are also presented. In addition to continuous greenspace variables, we also categorized them into tertiles to check potential non-linearity of exposure-response relationships. Geographic data management and calculations were conducted using ArcGIS 10.4 Geographical Information System (GIS) (ESRI, Redlands, CA).

Academic performance was measured by the parent (10-years follow-up) and child (15-years follow-up) report of the latest certificate grades in German and maths. In the German educational system, grades range from one (highest) to six (lowest, failed). To enable sufficient statistical power while properly translating the local grade system for international comparisons, we categorized each of the grades into high (1 and 2) and low (3 to 6) levels.

In Germany, 10-years-old children typically attend primary schools while at 15 years, they attend different types of high schools, which determines the possibilities for their future education (i.e. access to university). Considering the longitudinal data structure and clustering of adolescents within different schools at two time points, logistic mixed effects models with person and school as random intercepts were used to model the associations of greenspace at 10- and 15-year follow-ups with German and maths grades of 10- and 15-year-old children. All results are presented as odds ratios (ORs) and corresponding confidence intervals (CIs), for Munich and Wesel areas separately.

In line with our previous analyses (Markevych et al., 2014; Fuertes et al., 2016), we considered the following covariates – cohort (GINIplus observation *vs* GINIplus intervention *vs* LISA), urbanicity (urban and rural, as defined by percent sealed soil in 5-km radius, ≥25% *vs* <25%, respectively; Markevych et al., 2017b), parental education (based on the highest number of years of school education of either parent: <10 years *vs* =10 years *vs* >10 years), single parent status at follow-up, net equivalent income at follow-up (tertiles and a category for missing values; Markevych et al., 2017b), sex, season of answering the questionnaire at follow-up (winter *vs* spring *vs* summer *vs* autumn), type of school at 15-years follow-up (low *vs* medium *vs* high *vs* other, based on the German educational system), time spent outdoors at follow-up (≤4 h/day in summer and ≤2 h/day in winter *vs* >4 h/day in summer or >2 h/day in winter), time spent in front of a screen at follow-up (<1 h/day in summer and ≤2 h/day in winter *vs* ≥1 h/day in summer or >2 h/day in winter), and general mental health, as defined by a total score of the Strengths and Difficulties Questionnaire (Goodman, 1997; Woerner et al., 2004). We used Directed Acyclic Graph (DAG, Figure S2 and S1), as implemented in dagitty.net, to define minimal sufficient set of adjustment for obtaining unbiased estimates (Greenland et al., 1999). Thus, our main models are adjusted for parental education, urbanicity (only Munich), and net equivalent income. We also present models with additional adjustment for all other factors, except for those, which are presumably on the pathway between exposures and outcomes (time spent outdoors at follow-up, time spent in front of a screen at follow-up, and general mental health).

To test potential effect modification, we stratified our main models by sex, net equivalent income at 15 years, as a proxy for socioeconomic status, and urbanicity at 15 years (for Munich only; as nearly all Wesel participants were rural dwellers, few urban dwellers were excluded). All of the listed factors were reported to modify greenspace-health relationships at least in several studies (Markevych et al., 2017a).

Data pre-processing was conducted in SAS 9.2 (SAS Institute Inc., Cary, NC, USA). Statistical analyses were conducted using R 3.5.0 (Vienna, Austria; R Core Team, 2012). Logistic mixed models were fitted by *glmer* function from the *lme4* package.

Results

Analytic samples from Munich and Wesel differed in most of the family, personal and area-level characteristics (Tables 1 and S1). While Munich participants resided in both urban and rural surroundings, nearly all Wesel participants were rural dwellers. Consequently, Wesel participants resided in greener places, as characterized by NDVI and tree cover (Table S1). Also, a higher proportion of Munich children had high latest grade at their certificate in German and maths at 10-years follow-up. Contrary to that, at 15-years follow-up, more Wesel children had high maths grade.

Table 1. Characteristics of the analytic samples

		Munich (n = 1351)		Wesel (n = 1078)	
Variable	**Category**	**n**	**%**	**n**	**%**
Candidate confounders/effect modifiers					
Study	*GINIplus observation*	490	36.3	599	55.6
	GINIplus intervention[1]	383	28.3	369	34.2
	LISA	478	35.4	110	10.2
Urbanicity 10 y[2]	*Rural*	693	51.3	1067	99.0
	Urban	658	48.7	11	1.0
Urbanicity 15 y[2]	*Rural*	706	52.3	1067	99.0
	Urban	645	47.7	11	1.0
Sex	*Female*	689	51.0	538	49.9
	Male	662	49.0	540	50.1
Parental education[3]	*Low*	61	4.5	96	8.9
	Medium	307	22.7	532	49.4
	High	983	72.8	450	41.7
Single parental status 10 y	*No*	1194	88.4	994	92.2
	Yes	131	9.7	62	5.8
	Missing	26	1.9	22	2.0
Single parental status 15 y	*No*	1123	83.1	930	86.3
	Yes	167	12.4	109	10.1
	Missing	96	7.1	129	12.0
Tertiles of net equivalent household income 10 y, euro/month	*Low (mean, SD)*	1102.0	273.3	731.2	178.8
	Medium (mean, SD)	1781.5	198.5	1154.9	112.9
	High (mean, SD)	2308.6	199.6	1831.7	368.0
	Missing	96	7.1	129	12
Tertiles of net equivalent household income 15 y, euro/month	*Low (mean, SD)*	1209.9	306.6	800.1	196.7
	Medium (mean, SD)	1924.1	198.7	1263.2	109.3
	High (mean, SD)	2936.5	405.9	2042.8	585.4
	Missing	142	10.5	157	14.6
Season of answering a questionnaire 10 y	*Winter*	272	20.1	238	22.1
	Spring	370	27.4	363	33.7
	Summer	346	25.6	263	24.4
	Autumn	363	26.9	214	19.9
Season of answering a questionnaire 15 y	*Winter*	195	14.4	214	19.9
	Spring	302	22.4	353	32.7
	Summer	461	34.1	276	25.6
	Autumn	330	24.4	227	21.1
	Missing	63	4.7	8	0.7
Type of school 15 y[4]	*Low*	48	3.6	128	11.9
	Medium	294	21.8	390	36.2
	High	991	73.4	500	46.4
	Other	18	1.3	60	5.6
Outcomes					
German grade 10 y[5]	*Low*	313	23.2	459	42.6
	High	1038	76.8	619	57.4

German grade 15 y[5]	*Low*	886	65.6	709	65.8
	High	465	34.4	369	34.2
Maths grade 10 y[5]	*Low*	259	19.2	386	35.8
	High	1092	80.8	692	64.2
Maths grade 15 y[5]	*Low*	853	63.1	598	55.5
	High	498	36.9	480	44.5

SD – standard deviation; y - years.

[1] Group that participated in an intervention trial with hypoallergenic formulae.

[2] Definition based on percent sealed soil in 5-km radius. Residences at places with <25% soil sealed were classified as rural, ≥25% as urban.

[3] Definition based on highest parental level of education: both parents with less than 10 years of school (low, which refers to vocational school-preparatory schools), at least one parent with 10 years of school (medium, which is roughly comparable to General Certificate of Secondary Education in the UK), at least one parent with more than 10 years of school (high, which refers to university-preparatory schools), classified according to the German education system.

[4] "Low" refers to vocational school-preparatory schools and "high" refers to university-preparatory schools. "Medium" schools grant school leaving certificate which is roughly comparable to General Certificate of Secondary Education in the UK.

[5] "High" comprises two highest grades, 1 and 2, and "low" comprises 3 to 6, according to the German educational system.

A small proportion of associations of greenspace in 500-m buffer and academic performance reached formal statistical significance in Munich children and none – in Wesel children (Table 2). In particular, more home-school and school forest were related to lower odds of high grades in German and higher home tree cover was related to lower odds of high grades in maths. The association with forests was also significant in the additionally adjusted model (Table S2). No significant associations were observed with any of the greenspace variables in 1000-m buffer (Table S3).

Stratification by sex, income and urbanicity did not reveal any evidence of effect measure modification (Table S4).

Table 2. Adjusted ORs with 95% CIs of residential and school greenspace (combined and presented separately) and the latest school certificate grade in 10- and 15-years-old children estimated by logistic mixed effects models[1]

	German grade high[2] *vs* low[3]			**Maths grade high[2] *vs* low[3]**		
	Home-school[4]	**Home**	**School**	**Home-school**	**Home**	**School**
Munich						
NDVI $_{500m}$, tertiles[5]						
Low	1	1	1	1	1	1
Medium	0.92 (0.71 – 1.20)	0.89 (0.69 – 1.14)	1.16 (0.82 – 1.66)	0.87 (0.68 – 1.12)	0.87 (0.69 – 1.10)	0.95 (0.68 – 1.34)
High	0.97 (0.72 – 1.29)	1.02 (0.77 – 1.34)	0.94 (0.66 – 1.32)	0.96 (0.73 – 1.26)	0.93 (0.72 – 1.21)	1.05 (0.75 – 1.46)
NDVI $_{500m}$, continuous (per 0.1)	0.90 (0.77 – 1.06)	0.91 (0.79 – 1.04)	0.99 (0.84 – 1.17)	0.89 (0.77 – 1.04)	did not converge	did not converge
Tree cover density $_{500m}$, tertiles[5]						
Low	1	1	1	1	1	1
Medium	0.90 (0.69 – 1.17)	0.85 (0.65 – 1.11)	0.77 (0.55 – 1.10)	0.87 (0.68 – 1.12)	0.85 (0.67 – 1.09)	0.79 (0.57 – 1.10)
High	0.93 (0.70 – 1.25)	0.92 (0.69 – 1.21)	0.95 (0.66 – 1.36)	0.82 (0.62– 1.07)	**0.76 (0.59 – 0.99)**	0.78 (0.55 – 1.11)
Tree cover density $_{500m}$, continuos (per 10%)	0.97 (0.85 – 1.10)	0.99 (0.89 – 1.09)	0.91 (0.77 – 1.08)	0.94 (0.84– 1.06)	0.96 (0.87 – 1.06)	0.93 (0.79 – 1.09)
Agricultural land $_{500m}$, tertiles[5]						
Low	1	1	1	1	1	1
Medium	0.76 (0.57 – 1.01)	0.80 (0.61 – 1.05)	0.91 (0.61 – 1.34)	0.82 (0.63 – 1.07)	0.81 (0.63 – 1.05)	1.13 (0.78 – 1.64)
High	0.77 (0.56 – 1.05)	0.78 (0.59 – 1.03)	0.88 (0.63 – 1.24)	0.85 (0.63 – 1.14)	0.85 (0.65 – 1.10)	1.04 (0.75 – 1.44)
Agricultural land $_{500m}$, continuous (per 0.1)	0.98 (0.90 – 1.07)	0.98 (0.92 – 1.05)	1.01 (0.92 – 1.12)	0.97 (0.89 – 1.04)	did not converge	1.02 (0.93 – 1.13)
Forest $_{500m}$, tertiles						
Low	1	1	1	1	1	1
Medium	**0.67 (0.50 – 0.90)**	0.83 (0.61 – 1.13)	0.79 (0.47 – 1.32)	0.91 (0.69 – 1.19)	1.00 (0.75 – 1.33)	0.81 (0.50 – 1.33)
High	0.79 (0.59 – 1.06)	0.94 (0.73 – 1.21)	0.77 (0.56 – 1.07)	0.86 (0.65 – 1.13)	0.86 (0.69 – 1.09)	0.89 (0.66 – 1.21)
Forest $_{500m}$, continuous (per 0.1)	1.01 (0.89 – 1.14)	1.03 (0.94– 1.13)	**0.81 (0.69 – 0.95)**	0.99 (0.89 – 1.11)	1.00 (0.92 – 1.10)	0.91 (0.78 – 1.06)
Urban green space $_{500m}$, tertiles[5]						
Low	1	1	1	1	1	1
Medium	0.87 (0.67 – 1.14)	0.91 (0.71 – 1.18)	0.91 (0.64 – 1.29)	1.14 (0.88 – 1.48)	0.97 (0.77 – 1.23)	0.96 (0.68 – 1.34)
High	0.99 (0.72 – 1.36)	0.91 (0.69 – 1.21)	1.16 (0.80 – 1.68)	0.95 (0.71 – 1.29)	0.88 (0.68 – 1.15)	1.08 (0.76 – 1.55)

Urban green space $_{500m}$, continuous (per 0.1)	1.05 (0.87 – 1.27)	1.02 (0.87 – 1.19)	1.13 (0.93 – 1.37)	1.01 (0.85 – 1.21)	1.02 (0.88 – 1.17)	0.97 (0.81 – 0.16)
Wesel						
NDVI $_{500m}$, tertiles[5]						
Low	1	1	1	1	1	1
Medium	0.98 (0.74 – 1.29)	1.11 (0.84 – 1.46)	0.79 (0.56 – 1.12)	0.82 (0.62 – 1.09)	0.89 (0.67 – 1.19)	0.95 (0.67 – 1.35)
High	0.77 (0.57 – 1.04)	0.92 (0.69 – 1.23)	0.75 (0.52 – 1.07)	0.82 (0.61 – 1.11)	0.88 (0.66 – 1.18)	0.89 (0.62 – 1.28)
NDVI $_{500m}$, continuous (per 0.1)	0.90 (0.72 – 1.12)	0.90 (0.75 – 1.08)	1.03 (0.83 – 1.29)	0.92 (0.73 – 1.16)	0.91 (0.75 – 1.10)	1.06 (0.85 – 1.32)
Tree cover density $_{500m}$, tertiles[5]						
Low	1	1	1	1	1	1
Medium	0.89 (0.67 – 1.18)	0.93 (0.71 – 1.23)	1.10 (0.77 – 1.56)	0.88 (0.66 – 1.17)	1.09 (0.82 – 1.45)	0.84 (0.59 – 1.20)
High	0.88 (0.66 – 1.18)	0.89 (0.67 – 1.18)	1.33 (0.94 – 1.89)	0.99 (0.73 – 1.34)	1.11 (0.83 – 1.49)	1.28 (0.90 – 1.83)
Tree cover density $_{500m}$, continuous (per 10%)	0.96 (0.82 – 1.13)	0.97 (0.85 – 1.10)	1.00 (0.82 – 1.23)	1.02 (0.87 – 1.21)	1.02 (0.89 – 1.16)	1.03 (0.84 – 1.26)

CI – confidence interval; NDVI – Normalized Difference Vegetation Index; OR – odds ratio.
Boldface identifies significant associations ($p < 0.05$).
[1] All models are with person and school as random intercepts and adjusted for parental education, net equivalent income at follow-up, and urbanicity at follow-up (Munich only), as defined by Directed Acyclic Graph (see Figure S1).
[2] The category comprises two highest grades, 1 and 2, according to the German educational system.
[3] The category comprises grades 3 to 6, according to the German educational system.
[4] Averaged by weighting of residential and school exposures by the daily time that children in Germany typically spend at school (6 hours) and at home (18 hours).
[5] Tertiles are follow-up specific (see Table S1).

Discussion

This is one of the first studies to investigate the association between greenspace and academic performance. The results of our longitudinal analysis in German 10 and 15 years old children from two different study areas do not support the hypothesis that more greenspace near homes or around schools helps to enhance academic performance. We did observe some statistically significant associations with German and maths grades in the main analysis for Munich children, but they were inconsistent in sensitivity analyses. Keeping in mind that the amount of tests conducted increases the probability of observing false positive associations, we believe the detected isolated associations are false positives.

To the best of our knowledge, only few studies have assessed the potential association between greenspace and academic performance (Wu et al., 2014; Hodson and Sander, 2017; Beere and Kingham, 2017; Sivarajah et al., 2018). These studies differed in greenspace metrics used (greenness, tree cover, proximity to green spaces, species composition) but were similar in two aspects: first, they used school-aggregated data on academic performance, and, second, they linked academic performance to school greenspace. As our study is based on individual academic performance data in both school and residential areas, we advance an emerging field of investigation that has hitherto relied upon greenspace measured around schools. Only one prior study (Beere and Kingham, 2017) has reported weak negative association between school greenspace and academic performance, which is somewhat in line with our observations. Three other studies (Wu et al., 2014; Hodson and Sander, 2017; Sivarajah et al., 2018) were able to detect beneficial associations with educational attainment. As there are only few published studies, further research on the topic is of great interest. Contact with greenspace may help to alleviate restoration from mental fatigue caused by directed attention (Kaplan and Kaplan, 1989), which may stimulate learning abilities. Thus, association between greenspace and academic performance is plausible. We might have not detected associations because of insufficient power, or because in our very green study areas greenspace might be not of such crucial importance as in the areas that lack vegetation. Therefore, future studies on the topic should not be discouraged by the current findings.

The strengths of this study are the longitudinal analysis of prospectively collected data on academic performance and covariates available at two time points. Furthermore, we applied a DAG to select important confounders and at the same time, avoid over-adjustment and multicollinearity in our models. However, as with many others cohort studies, selection is present by design and due to loss to follow-up, which affects external validity of the findings. Only German-speaking families were invited to participate in the GINIplus and LISA studies. Thus, participants from immigrant families are under-represented. Moreover, our analytic samples differed from the original Munich and Wesel GINIplus and LISA cohorts. Most importantly, families with low educational level were more likely to be lost to follow-up. Our income-stratified analyses attempted to estimate whether the associations could have differed depending on socioeconomic status (SES). While parental education can be a better proxy for SES, we could not stratify by this factor due to insufficient number of participants from families with low education. Under-representation of participants with low SES and participants from immigrant families in our analytical samples is in line with other birth cohorts (Jacobsen et al., 2010) and might have under-estimated the associations with academic performance, especially, taking into account that these strata might benefit from greenspace close to their home the most (Markevych et al. 2017b). Unlike previous studies, which utilized area-aggregated data on academic performance, we had individual grades of children. Nevertheless, since the distribution of original grades on the six-point scale differed across study areas and follow-up points, it was challenging to decide on how to analyse the associations in a way that the results are interpretable, while maintaining sufficient statistical power. Moreover, grades were self-reported by parents (at 10 years) and children (at 15 years), which is a potential source of recall bias. Given that we had both home and school addresses, we were able to estimate greenspace for both of them and to create combined home-school greenspace variables. Even so, these combined variables are just proxies and do not take into account greenspace encountered in other domains, for example, while commuting between home and school. We also did not have information on time spent in the neighbourhood and at school, not to even mention actual use of greenspace, which might have underestimated the associations of interest. Nevertheless, we assessed greenspace by several measures. While NDVI provides information on general vegetation degree, tree cover focuses only on one type of vegetation. Usage of proportion of agricultural land, forest, and urban green space was meant to differentiate between different types of green land use types of different structure and functions, at least in Munich area where these data were available. Unfortunately, for Wesel area, no land use data comparable to the quality of the Munich-based sample was available. A further limitation of most of the greenspace variables is that they were assessed at 10- and 15-years addresses from the maps corresponding to one time point - 2012 in case of tree cover and 2008 in case of green spaces. We were able to assess variables corresponding to two follow-up time points only in the case of NDVI. Nevertheless, we assume that land use changes in our study areas were small over these several years and therefore, our tree cover and green spaces estimates are valid. Finally, we used 500- and 1000-m buffers, which represent the wider, background level of vegetation. Smaller buffers were not considered due to the coarseness of the used NDVI data. It may be that the selected buffer sizes were too large and unspecific if viewing/observation is the hypothesized exposure route. Viewshed exposure to greenspace may be a better choice in this case (Nutsford et al., 2016).

In summary, we conclude that there is no evidence that residential and school greenspace could improve academic performance in German adolescents from the GINIplus and LISA longitudinal studies from two different areas.

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Conflict of interests

The authors declare that they have no conflict of interest.

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School greenspace was positively correlated with academic performance in ecological studies

Our individual-level analysis included both residential and school greenspace and their combination

We used data on individual German and maths grades in 10- and 15-year-olds

No beneficial associations were observed in either of the two areas, Munich and Wesel

The link is plausible and more studies with individual data should explore it