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Green space at school and attention in primary school children in Belgium: A stratified matched case-control study

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A R T I C L E I N F O

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A B S T R A C T

Green spaces help to adapt urban environments to warming and other global change challenges. At school, green playgrounds help to incorporate natural elements into the daily lives of children, potentially improving well-being and academic performance. This study analyzed relationships between green space within and around the school, the landscape context, and well-being and sustained attention in 526 fifth-grade children (10–11 years old) in 37 Belgian schools, using a matched case-control design. By design, school level greenness did not vary with school level socioeconomic status. Attention was measured with the d2 sustained-attention test and well-being with the KIDSCREEN-27 questionnaire. Results of generalized multilevel models fitted within a Bayesian framework showed that attention was higher in schools located in more urbanized environments and that attention primarily increased with socioeconomic status. In models that accounted for partial missing data, attention was higher and attention waning lower in schools with green playgrounds, but only in low naturalness landscapes, and these associations were most prominent in high SES schools. Overall, our study suggests that green space within the school may partially compensate limited exposure to green space in highly urbanized environments, with beneficial effects on attention and well-being. Greening existing school playgrounds is expected to benefit child development in urbanized environments while simultaneously improving urban green space cover, with health benefits that extend beyond the school boundaries.

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1. Introduction

Urban green spaces, defined as areas within the city that are dominated by vegetation such as parks, gardens, and lawns, help to adapt built-up environments to climate change and other urban challenges (Fang et al. 2023; Plazas et al. 2023; Sanz-Mas et al. 2025). For children, green spaces offer opportunities for active play, exploration, and stress relief and therefore play a critical role in fostering mental and physical health (Schipperijn et al. 2024), including improved cognitive skills and lower risks of obesity and hypertension (Shoari et al. 2021; Bao et al. 2024). Green playgrounds at school help to incorporate natural elements into the daily life of school children (Akoumianaki-Ioannidou et al. 2016), potentially reducing stress and increasing wellbeing and performance (Li and Sullivan, 2016; Amicone et al. 2018; Vella-Brodrick and Gilowska, 2022). Green playgrounds may help to achieve these goals by promoting outdoor play, and by providing a more conducive learning environment (Bagot et al. 2015; Ulset et al. 2017; Mason et al. 2022). Furthermore, green at school provides an ecological buffer against the cognitive stressors typically encountered within urban school settings (Chawla et al. 2014). These stressors include traffic and aircraft noise, air pollution, and the lack of open space, all of which have been associated with adverse impacts on children's attention, cognitive development, and health, particularly in dense urban areas (Sunyer et al. 2015; Forns et al. 2016; Sunyer et al. 2017; Clark et al. 2021; Matthaios et al. 2024). For these reasons, there is an increasing interest in greening playgrounds as a nature-based solution to these environmental challenges (Browning and Rigolon, 2019; Luque-Garciá et al. 2022; Fang et al. 2023; Plazas et al. 2023; van den Bogerd et al. 2023). However, the presence and accessibility of green space within the school environment and their impact remain understudied despite the significant time children spend in schools during critical developmental periods.

1.1. Conceptual framework

Exposure to green space has been associated with enhanced cognitive functioning, emotional regulation, and reduced stress levels in children (Li and Sullivan, 2016; Ohly et al. 2016; Gunn et al. 2022; Buczyłowska et al. 2023). The Attention Restoration Theory (ART) posits that natural environments provide a restorative effect on cognitive resources, particularly attention, by allowing mental recovery from directed attention fatigue (Kaplan, 1995). This theory is particularly relevant in educational settings, where prolonged periods of focus are required (Sakhvidi et al. 2023).

Primary school children are particularly sensitive to environmental influences due to their developmental plasticity (Mualem et al. 2024). School environments lacking access to nature may inadvertently contribute to cognitive overload and increased stress, potentially impairing academic performance and overall well-being. Conversely, integrating green spaces within or near schools may foster better attentional control, emotional stability, and social cohesion among students of all ages (Dadvand et al. 2015; Bijnens et al. 2021; Dockx et al. 2022 Saenen et al. 2023). Furthermore, these effects may be amplified in children from urbanized or socioeconomically disadvantaged backgrounds, where access to natural environments outside school may be limited compared to more privileged groups (Rigolon et al. 2021; Fernandes et al. 2023; Liu et al. 2024).

The objective of this study is to examine the impact of school-based green spaces on two critical outcomes: well-being and attention in primary school children. Well-being encompasses emotional, psychological, and social dimensions, while attention pertains to the ability to maintain focus and avoid distractions. Investigating these outcomes within the context of the school environment is essential for developing evidence-based policies and interventions aimed at optimizing educational settings for child development. This research also aligns with the broader goals of promoting school green areas as important components of sustainable and resilient urban environments (Ioja et al. 2014).

2. Methods

2.1. Study design and population

The selection and inclusion of subjects in this study was performed in two stages: first we included schools, then we included children (Fig. 1). For the selection and inclusion of schools we adopted a stratified matched case-control design (Rosenbaum, 2010). Schools with high greenness playground were considered cases and schools with low greenness playground controls. Case-control pairs were selected from a national inventory of schools and matched to have similar geographical location, outdoor air pollution levels, and socioeconomic status. The school-level inclusion criteria were: (1) schools must have more than 120 children in total; (2) schools must be regular primary schools (excluding specialized schools); and (3) the landscape within 2 km from the school had to be classified as either low or high naturalness landscape. In brief, high naturalness was defined as high cumulative relative tree and grassland cover and low cover of impervious surfaces (for details: see supplementary methods). These strict selection requirements reduced the number of eligible schools from $N = 5582$ at national level to $N_e = 600$ (Fig. 1). The details of the calculation of school greenness are described in the exposure assessment.

Children were recruited in 2021 from 37 schools that agreed to participate. The child-level inclusion criteria of the study required that participants (1) were attending fifth grade of primary school (in Belgium, education is compulsory between the ages 6 and 18; the primary school consists of a period of six years; and in fifth grade, children are typically 10–11 years old); (2) understood Dutch or French (the languages in which the questionnaires were administered); (3) that parents gave consent to participate; and (4) that parents agreed to provide and provided detailed socioeconomic status background information.

The study protocol was approved by the Committee for Medical Ethics UZA-UA of the University of Antwerp prior to recruitment (Belgian registration number B3002020000242). Informed consent was obtained and documented.

2.2. Definition of attention as the outcome variable

Attention is a multifaceted cognitive function, which plays a pivotal role in the academic and personal development of children and which has a bidirectional relationship with cognitive resilience (i.e. attention may contribute to the development of cognitive resilience, and cognitive resilience may improve sustained attention) (Stevens and Bavelier, 2012; Lundervold et al. 2017; Filippetti et al. 2022). In the context of this study, attention is defined as the capacity to focus on specific objects or tasks despite distractions, sustain concentration, and effectively filter and process information, all of which are fundamental for successful learning and classroom performance (van de Weijer-Bergsma et al. 2008; Wray et al. 2017). We used the d2 Test of Attention, one of the most widely used measures of visual attention (Brickenkamp and Zillmer, 1998). The d2 Test is a cancellation test to measure attention in different dimensions, including speed, accuracy (omission and commission errors) and consistency (variability). Practically, the d2 Test is a trial where participants are asked to assess 47 characters on each of 14 lines. The participant gets 20 seconds to process a line – the entire test is completed in 4 minutes and 40 seconds. A character is either a 'p' or a 'd' with between one and four dots ('.') placed above and/or below the 'p' or 'd'. The participant is asked to process a line from left to right and strike out (cancel) every 'd' character that has exactly two dots placed above and/or below (can also be one above and one below) the 'd' character. The final cancelled character on a line determines the number of characters that a participant could process for that line within 20 seconds. The participants received detailed instructions and processed a sample line prior to the actual test. The sample line was scored, with explanations, in front of the class. The test was then administered in

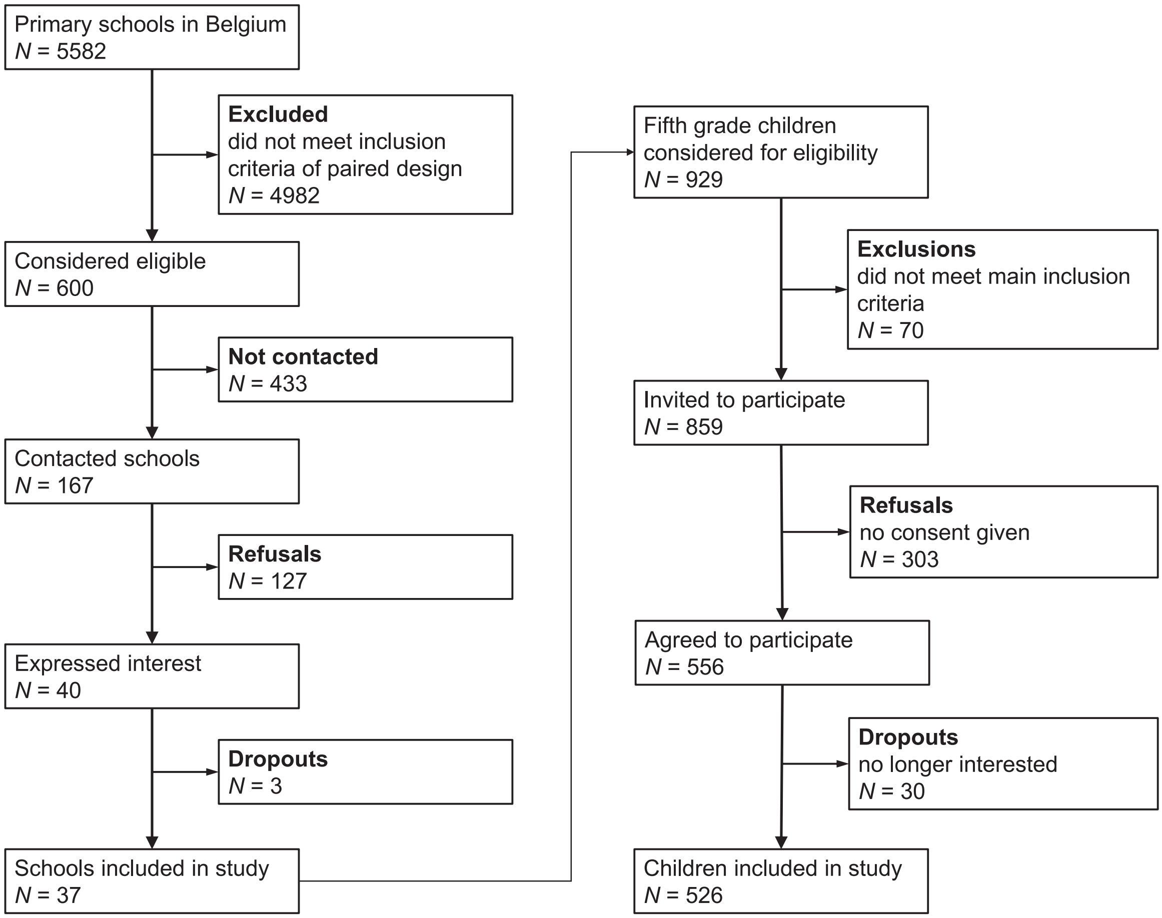

Fig. 1. Flow diagram of schools and children included in the study.

group and in silence.

The resulting data can be organized in a two-by-two contingency table containing (1) the number of correctly processed d2-characters (cancelled), (2) the number of correctly processed other characters (not cancelled), (3) the number of cancelled characters that were not d2-characters (commission errors, F2), and (4) the number of not cancelled characters that should have been cancelled (omission errors, F1). Based on these numbers, we calculated the corresponding contingency chi-square statistic χ^2. The theoretical maximum χ^2 statistic for the complete table is obtained for a perfect score on the d2 Test (14 lines containing 47 characters, of which 299 are d2-characters) and equals 654. The attention score was therefore calculated as the observed χ^2 statistic divided by the theoretical maximum χ^2 statistic to obtain values between 0 and 1. This attention score combines precision (both error types are small), accuracy (both error rates are not very different; i.e. unbiased) and speed (a high total table count). The χ^2 statistic was calculated for each line and for the entire test.

2.3. Environmental exposure

2.3.1. School context

At the scale of the school premises itself, we calculated several land-cover based variables using the Lifewatch ecotopes raw pixel based classification product for the year 2015, which covers Belgium entirely (Lifewatch, 2023). For each school, the playground(s) were delineated as well as the school perimeter. The land-cover types were reclassified into 'green' and 'not green'. Land cover types that were considered green included: grasslands, dry and wet vegetation of biological interest, recently disturbed ligneous vegetation, and deciduous and coniferous trees and shrubs (including hedges). Blue spaces were not included. The proportion of greenness was calculated (i) within the playground (in case of several playgrounds, the areas are summed), (ii) within the school limit, but excluding the playground(s), (iii) within 100 m surrounding the school limit, but excluding the area within the school limit, and (iv) within 300 m surrounding the school limit, but excluding the area of the 100 m buffer. Because the four greenness variables are highly correlated, we used k-means (k = 2) clustering to label the school context as "high greenness" or "low greenness". Because our classification is based on land-cover types and not on NDVI, seasonality has no impact on our assessment of greenness.

2.3.2. Air quality

We calculated mean values for the annual means (μg/m^3) of nitrogen dioxide (NO_2), particulate matter smaller than 2.5 μm ($PM_{2.5}$), the difference between particulate matter smaller than 10 μm and 2.5 μm (PM_{10} - $PM_{2.5}$) and black carbon (BC) in a buffer distance of 2000 m around each school. Air quality data were obtained from the Belgian Interregional Environment Agency.

2.4. Well-being and socio-economic background variables

The KIDSCREEN-27 questionnaire (Ravens-Sieberer et al. 2014) was administered after the d2-Test to assess two aspects of health-related quality of life that could have an impact on attention at school, i.e. well-being in the school environment (based on 4 items) and psychological well-being (based on 7 items).

Parents of the children were asked to answer questions about their own education level (4 levels), their employment (4 levels) and their combined income (6 levels) (Reynders et al. 2005). The levels could be ordered and each level was re-coded on a scale from 0 to 1 (for instance for a 4 level factor: 0, 1/3, 2/3, 1). These scores were averaged per child to obtain a socio-economic status (SES) score at child level (with higher values reflecting higher SES).

Further averaging the child-level SES per school gave us a school-level mean SES. We also calculated the difference between the child-level SES and the school-level SES (centered child-level SES), to obtain a variable that captures the child-level SES variation within schools. A flow diagram of exposures, confounders, and outcomes measured in the study is presented in Fig. 2.

2.5. Statistical analysis

Although statistical matching was used in the design phase, in the final sample of recruited schools we did not have a matching school for each school. Furthermore, for some variables that were used for statistical matching during the design phase, such as the proxy for school-level socio-economic status, we collected higher quality data for the recruited schools. We therefore included in the statistical model these higher quality data to statistically control for them when calculating conditional effects for the covariates of interest (landscape type and school context). Furthermore, while the planned design was balanced, the final sample of recruited schools was unbalanced. A further complicating factor was that parts of the data were missing, mainly due to non-response from questionnaires, and we cannot assume that the data are missing completely at random.

To cope with the above, we used a generalized multilevel model – fitted within a Bayesian framework – to relate the attention score to school context and landscape type. By construction, the attention score is a continuous variable attaining values between 0 and 1 which we modeled with a Beta distribution where the mean parameter of the distribution is linked to the linear predictor via a logit-link function. The random part of the linear predictor contains a random effect for school, accounting for the clustering of children in schools.

The fixed effects structure always contained the landscape type and school context variables and their interaction (our main exposures of interest; Fig. 2), as well as potentially relevant confounding variables (school-level SES, child-level SES, well-being at school, psychological well-being, particulate matter $PM_{2.5}$ and biological sex). The interaction between school-level SES and school context (greenness) was also included because our study was designed to be able to also test a differential effect between these covariates. The missing data were imputed during the sampling phase of the Bayesian algorithm. For this to work, any missing data is declared as a parameter to be estimated in the posterior. Additional regression equations were used for each covariate with missing data that included relevant covariates (without missingness) which aid in imputing plausible data. This makes the model essentially a multivariate model. Data were imputed for school-level and child-level SES, well-being at school, and psychological well-being. For each of these variables with missing data, landscape type and school context in interaction and a random effect of school were included in the regression equations and a (truncated) Gaussian distribution was assumed. Truncation between 0 and 1 was only needed for school-level SES. For comparison purposes, we also fitted the model including only complete cases, i.e. excluding all rows where at least one variable is missing. Prior distributions for the fixed effect parameters where drawn from a normal distribution with mean 0 and standard deviation 2.5. For other parameters, the default priors from the brms package were used (Bürkner, 2017).

The model was fitted first on aggregated attention data level where we have one attention score for each child. This means that the full d2-Test score sheet was used to calculate the attention score. This allows us to test effects on overall attention levels. An extended version of this model was then fitted on the line-by-line data where we have 14 attention scores for each child (one for each line). This model allowed us to test for effects of school context and landscape type on attention waning (loss of attention during the test). The models were extended in the following ways: (1) a random effect for child was included to account for non-independence of the attention scores belonging to the same child, (2) a fixed effect called line variant was included to account for the fact that in the d2-test lines 1–4–7–10–13, lines 2–5–8–11–14 and lines 3–6–9–12 contain the same information (the same sequence of characters), and (3) a line group factor in interaction with school context and landscape type to learn about possible differential effects of attention waning. The lines were grouped in 1–4 (first four lines), 5–10 (middle six lines) and 11–14 (last four lines). Apart from these new variables, the same covariates and the same model alternatives were explored as for the overall attention models. Because the line-level attention scores also had values exactly equal to 0 and 1, the ordinal Beta distribution was used as statistical distribution instead of the Beta distribution.

All models were fitted using the package *brms* (Bürkner, 2017) implemented in the R system for statistical computing (R Core Team, 2020). The reporting of this study contains the preferred items of the STROBE statement checklist for reports of case-control studies (von Elm et al., 2007) and the relevant items of the PRIGSHARE checklist for reports of green space health research (Cardinali et al. 2023).

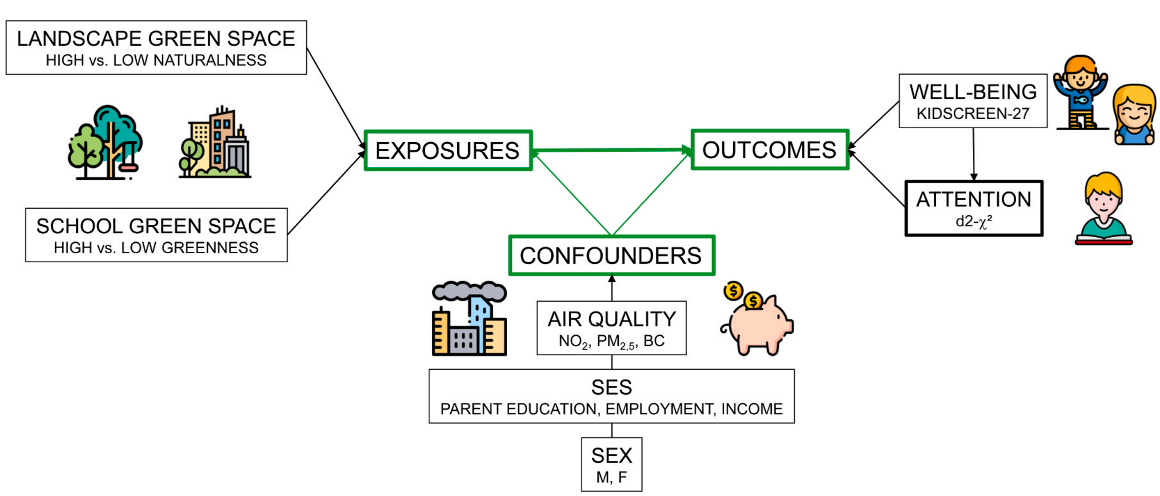

Fig. 2. Flow diagram of exposures, confounders, and outcomes measured in the study. Well-being is an outcome by design, but was used as a confounder in the statistical analysis.

3. Results

3.1. School and participant characteristics

A total of 167 schools were contacted out of which 40 expressed interest to participate and 37 participated; these 37 schools had 929 children in the fifth grade out of which 526 children (57 %) gave consent to participate in at least one of the tests (Fig. 1).

Low naturalness landscape schools were typically found in urbanized areas and characterized by high levels of impervious surfaces and low levels of combined forest and grassland cover. High naturalness landscape schools were found in rural areas with low levels of impervious surfaces and high levels of combined forest and grassland cover. School level SES did not vary with school greenness (both mean SES = 0.6, SD 0.1), an important observation for the interpretation of further results. Air pollution values were typically high for the region: the annual average concentrations of $PM_{2.5}$ in low greenness schools were slightly higher (12.2 μg/m^3, SD 2.8) than those in high greenness schools (11.0 μg/m^3, SD 2.9) and both were well above the WHO threshold of 5 μg/m^3 (indicating suboptimal air quality, typical for the region). Indicators for psychological well-being and well-being at school were comparable between high and low greenness schools (Table 1).

3.2. Attention in the study population

The children processed on average 374 (SD 79) characters, which is 57 % of the total challenge; this corresponds to a processing speed of 1.3 characters per second or 80 characters per minute. Omission errors (13; 3 %) were more frequent than commission errors (3; 1 %). The number of processed characters decreased over time (-5 %, last lines compared to first lines) and the number of errors increased (+30 %), indicating the onset of mental fatigue or attention waning towards the end of the test (Table S1).

3.3. Association with green space and background variables

The fully adjusted overall attention model based on multiple imputation of missing data (Table 2) provided strong evidence for positive associations between attention and school- and child-level SES. The effect of school-level SES was with certainty positive (median = 1.53, 90 % CI [1.12; 1.94]) (Fig. 3b) and the effect of child-level SES had a probability of 99 % of being positive (median = 0.45, 90 % CI [0.17; 0.72]) (Fig. 3c). However, the models provided little or no evidence of beneficial effects of landscape and school greenness on attention across the entire study population. There was relatively more evidence for negative effects of landscape greenness and green at school on attention (high vs low naturalness effect: median = −0.06, 90 % CI [-0.18; 0.06]; high vs. low school greenness effect: median = −0.43; 90 % CI [-0.92; 0.07]) but the probabilities for these effects were low (landscape naturalness: pseudo-p = 0.41; school greenness: pseudo-p = 0.16) (Fig. 3a). There was no evidence for meaningful effects of the other adjustment variables (Fig. 3d-g).

Table 1
Description of the main characteristics of the study population, stratified by playground greenness. N is the number of children in each stratum.

	Low greenness (N = 318)		High greenness (N = 211)	
	Mean	SD	Mean	SD
Attention score	0.5	0.1	0.5	0.1
Well-being at school	52.0	9.3	51.9	9.6
Psychological well-being	50.1	9.8	49.9	10.0
School-level SES	0.6	0.1	0.6	0.1
Child-level (centered) SES	0.0	0.2	0.0	0.2
$PM_{2.5}$ (μg/m^3)	12.2	2.8	11.0	2.9
	N	%	N	%
Landscape type				
Low naturalness	164	51.6	89	42.2
High naturalness	154	48.4	122	57.8
Biological sex				
Female	153	48.1	107	50.7
Male	163	51.3	103	48.8
Community				
Dutch speaking	178	56.0	80	37.9
French speaking	140	44.0	131	62.1

Table 2
Effects[1] of landscape naturalness, school greenness, and SES on attention measured with the d2-Test for sustained attention in fifth-grade school children in Belgium.

Parameter	Median	Q5	Q95	pd (%)[2]	pseudo-p
Landscape naturalness (high)	−0.06	−0.18	0.06	0.79	0.41
School greenness (high)	−0.44	−0.92	0.07	0.92	0.16
Landscape naturalness × School greenness (interaction)	−0.14	−0.31	0.02	0.92	0.15
School-level SES	1.53	1.12	1.94	1.00 *	0.00
Child-level SES	0.45	0.17	0.72	0.99 *	0.01
School-level SES × School greenness (interaction)	0.95	0.14	1.74	0.97 *	0.06
Biological sex (female)	0.02	−0.05	0.10	0.67	0.67
$PM_{2.5}$	0.05	−0.92	0.07	0.93	0.13
Psychological well-being	0.00	0.00	0.01	0.64	0.71
Well-being at school	0.00	0.0	0.01	0.92	0.15

1 Effects are based on multilevel Bayesian models after multiple imputation of missing data and are reported as posterior distribution for each parameter, described by the median as index of centrality and a 90 % credible interval based on the 5th and 95th quantiles.
2 The Probability of Direction (pd) represents the certainty associated with the most probable direction of the effect. *Effects possibly exist if pd > 95 %. For ease of interpretation, corresponding pseudo p-values are also shown.

In the analysis of line-level attention scores, there was clear evidence of attention waning, with attention scores by lines decreasing over time (middle lines vs. first lines effect: median = −0.19, 90 % CI [-0.23; −0.15]; last vs. first lines effect: median = −0.28, 90 % CI [-0.32; −0.23]) (Fig. 4a). School- and child-level SES were positively associated to line-by-line attention scores (school level SES effect: median = 1.56, 90 % CI [1.12; 2.00]; child level SES effect: median = 1.17, 90 % CI [0.94; 1.38]) (Fig. 4b,c).

While school level SES did not vary with school greenness, we observed that the attention was marked by important interaction effects between landscape level naturalness, school greenness, and school-level SES (pd = 1.00; pseudo-p = 0.00). This warranted the evaluation of specific contrasts of attention in high vs. low greenness schools in strata defined by landscape naturalness and SES (Table 3). These pairwise contrasts provided strong evidence for a beneficial association between school greenness and attention in low naturalness landscapes for mean SES (OR = 1.17; 90 % CI [1.03; 1.32]) and high SES schools (OR = 1.31; 90 % CI [1.11; 1.55]). These protective associations were not observed in high naturalness landscapes (Table 3; Fig. S1).

Specific contrasts evaluated for the line-by-line attention scores provided strong evidence for protective effects of school greenness against attention waning in high SES schools, both in low and high naturalness landscapes (high greenness vs. low greenness, low naturalness: OR range for the three line groups = 1.29 – 1.44; overall 90 % CI [1.05; 1.75]; high naturalness: OR range = 1.20 – 1.30; overall 90 % CI [1.01; 1.55]) (Table S2; Fig. S2).

4. Discussion

4.1. Main findings

Attention was higher in schools located in more urbanized

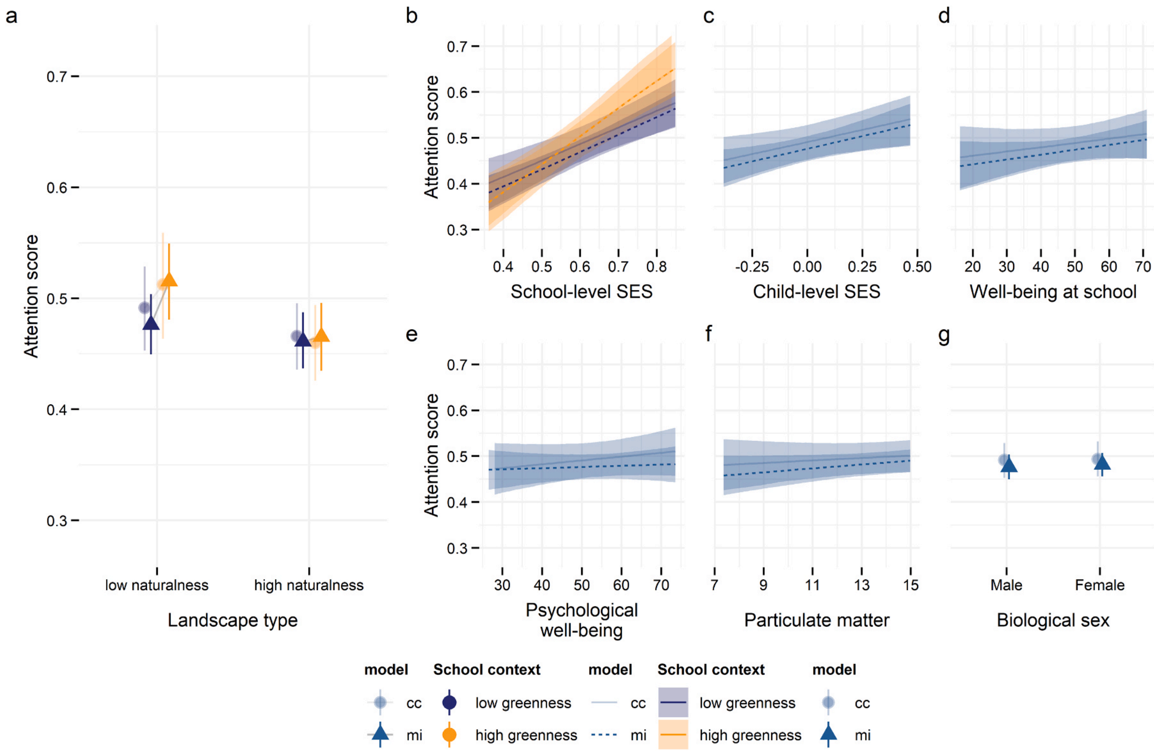

Fig. 3. Association between attention, measured with the d2-Test for sustained attention, and (a) landscape naturalness and school greenness, (b) school-level SES, (c) child-level SES, (d) well-being at school, (e) psychological well-being, (f) air pollution (PM) and (g) biological sex, in fifth-grade school children in Belgium. Results are obtained from multilevel models fitted in a Bayesian framework based on complete data only ("cc") (i.e. excluding children with missing data for one of the variables), and from models based on multiple imputation ("mi"). In panel a, attention score estimates and 95 % credible intervals are presented for mean school-level SES. The interaction between school context and SES is visualized in Fig. S1.

environments, and primarily increased with school- and child-level socioeconomic status. In models that accounted for partial missing data, attention was higher and attention waning lower in schools with green playgrounds, but only in more urbanized environments, and these associations were most prominent in high SES schools.

4.2. Comparison with other studies

First, our findings align with a growing body of evidence that supports the influence of socioeconomic status (SES) as a moderating factor in the relationship between environment, green space, and cognitive development and attention in children (Sakhvidi et al. 2023). Consistent with previous research, our study revealed strong associations between school- and child-level socio-economic status and performance in the attention test. The observed differences in attention skills among children from lower SES backgrounds align with existing literature that highlights the impact of socio-economic context on neurocognitive development (D'Angiulli et al., 2008; Hackman et al. 2010; Ursache and Noble, 2016; Wray et al. 2017), and academic and occupational achievement (Wray et al. 2017).

Our investigation found good evidence for higher attention in urbanized, less green environments and within these landscapes additional evidence for beneficial impacts of green playgrounds or green school environments on attention. Higher performance in more urbanized environments is in line with a study of elementary school performance by Rakowska et al. (2023), who reported a negative association between performance and the proportion of greenness at the 5 km neighborhood level. The beneficial association between school greenness and cognition in our subset of urban schools is partly in line with a number of other studies that have investigated effects of green space at home or at school on attention. For instance, Bijnens et al. (2021) found better attention in adolescents with higher total relative cover of surrounding high green within 2000 m of the residence and school combined; however, they focused on older children (13 and 17 years old) compared to our study. Anabitarte et al. (2022) found an association between residential greenness and attention of children at 8 and 11–13 years but observed no significant associations in a longitudinal analysis of the data. Mårtensson et al. (2009) observed reduced behaviors of inattention in younger children (4.5–6.5 year old) playing in outdoor preschool areas with abundant greenery in Stockholm. Amicone et al. (2018) reported a greater increase in sustained and selective attention and concentration after free play recess time in a natural versus built environment. Van den Berg et al. (2017) reported that children in classrooms where a green wall was placed, scored better on a test for selective attention, but this was a study focusing on indoor green whereas our study focused on components of outdoor green space. Finally, Fernandes et al. (2023) found protective associations between green space exposures (availability, accessibility, and uses of green spaces) and cognitive function outcomes but only in high SES children. The latter is in line with our finding that the association between attention and playground greenspace was most prominent in high SES schools (Fig. S1). These findings challenge the notion that green space is universally beneficial across socioeconomic groups or more beneficial for disadvantaged groups (Rigolon et al. 2021).

Our results stand in contrast to a number of earlier studies reporting no associations between exposure to green at school and enhanced attention in children. Specifically in the context of primary schools, Singh et al. (2023) found no consistent associations between academic performance and school or residential green and blue space; and Lindemann-Matthies et al. (2021) observed lower d2-revision test scores in children who perceived stress in school but failed to observe an association between the naturalness of classroom views and attention test performance.

It must be noted that all these studies implemented different

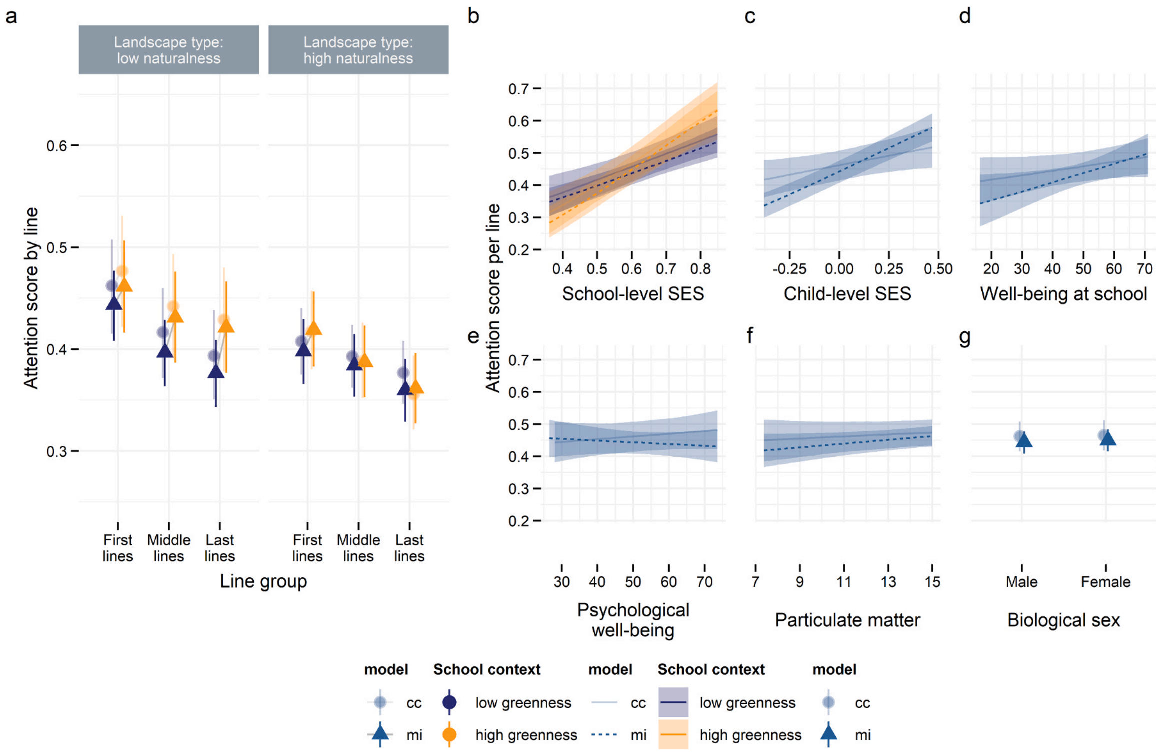

Fig. 4. Association between attention, measured at line level in the d2-Test for sustained attention, and (a) landscape naturalness and school greenness, (b) school-level SES, (c) child-level SES, (d) well-being at school, (e) psychological well-being, (f) air pollution (PM) and (g) biological sex, in fifth-grade school children in Belgium. Results are obtained from multilevel models in a Bayesian framework based on complete data only ("cc") (i.e. excluding children with missing data for one of the variables), and from models based on multiple imputation ("mi"). In panel a, attention score estimates and 95 % credible intervals are presented for mean school-level SES; decreasing attention scores over time (line groups) indicate attention waning. The interaction between school context and SES is visualized in Fig. S2.

Table 3
Effects[1] of school greenness (high vs. low greenness) on attention measured with the d2-Test for sustained attention in fifth-grade school children in Belgium, stratified by landscape naturalness and SES.

Landscape naturalness	SES	OR	Q5	Q95	pd (%)[2]
Low	Low	1.05	0.91	1.21	0.69
	Mean	1.17	1.03	1.32	0.98 *
	High	1.31	1.11	1.55	1.00 *
High	Low	0.91	0.78	1.05	0.14
	Mean	1.02	0.91	1.13	0.59
	High	1.14	0.98	1.31	0.93

1 Contrasts between schools with high greenness vs. low greenness (reference) are reported as odds ratios with a 90 % credible interval based on the 5th and 95th quantiles.
2 The Probability of Direction (pd) represents the certainty associated with the most probable direction of the effect. *Effects possibly exist if pd > 95 %.

attention assessment tools, each focusing on specific attention metrics. In addition to differences in children's age, geographic location and educational settings, this variability between studies could contribute to the observed variation in study outcomes (see also Browning and Rigolon, 2019). The contrasting findings highlight the complexity of the relationship between green space and attention, suggesting that the impact may be highly context-dependent. Other factors influencing attention in primary school encompass classroom design and decoration, the course content and nature of the learning materials, peer interaction and discipline, and teacher-student dynamics (e.g. Fisher et al. 2014; Barrett et al. 2015; Hanley et al. 2017; Godwin et al. 2022). For instance, prolonged exposure to digital screens (in particular smartboards), sounds both within and outside the classroom environment (not exclusively noise), or things taking place beyond the classroom but observable through the window, have been mentioned by children as particularly detrimental to attention (Silva Santos et al. 2022; Shield and Dockrell, 2003). In addition to socioeconomic status, several other background variables (e.g. consumption of synthetic food dyes; Miller et al. 2022), the specific attention measures employed, and variability between school settings may contribute to the variability in study outcomes.

The surprising lack of consistent associations across previously published studies (see also Lindemann-Matthies et al. 2021; Singh et al. 2023) underscores the need for more nuanced investigations into the intricate interplay between environmental and socio-economic factors and attention outcomes in children. Attention is vital in the setting of early elementary education (Stipek and Valentino, 2015), where students must adapt to structured classroom environments, engage in learning tasks, and develop essential cognitive skills such as reading and mathematical problem-solving. A lack of attention during primary education may not only compromise the development of these skills and undermine cognitive resilience, it may also contribute to academic underachievement in higher education (Rabiner et al. 2016; Lundervold et al. 2017) and this, in turn, may have potential long-lasting repercussions on socio-economic status and health-related quality of life (Lövdén et al. 2020). Our findings that green space at school supports cognitive development of children in urbanized environments is therefore a strong signal that greening existing school playgrounds may contribute to children's well-being during school age with potential effects that extend well into later life.

4.3. Strength and limitations

A major strength of this study, compared to earlier research on green space and attention, is the stratified matched case-control design.

Matching schools based on landscape context helps to control for confounding environmental variables that could influence the relationship between school context and attention, such as proximity to sources of noise, which are known to affect attention and cognitive function (Bhang et al. 2018). By reducing the potential impact of such external factors, our study benefits from increased statistical power and internal validity. An additional strength of our design is that our models are still controlled for matching variables (SES and air pollution), avoiding the introduction of confounding by design (Pearce, 2016).

Another strength is our application of multiple imputation to deal with missing data. In surveys where respondents are free to choose what background data they are willing to share with researchers, partial non-responses are common. This may lead to non-response bias in the analysis of the association between green playgrounds, wellbeing, and attention (see e.g. Guyot et al. 2023 for an example on green space and mental health). Multiple imputation assigns plausible values for missing data based on multivariate associations in the non-missing part of the dataset, and is therefore a flexible solution that allows statistical analysis of the entire study population and not only those participants without missing data (Li et al. 2015).

Despite these strengths, it is important to acknowledge the potential limitations of matched designs, such as the difficulty we faced in finding perfect matches for all schools and all relevant variables and the possibility of residual confounding. Another limitation of our study is that we did not take into account the timing of the attention tests (before or after recess), individual classroom design variables such as indoor green or view on outdoor green, or residential exposure to green space of children, all of which may impact attention (see e.g. Dadvand et al. 2017; Li and Sullivan, 2016; Amicone et al. 2018; van den Bogerd et al. 2020; Sharam et al. 2023).

The robust association between attention and SES in our study lends credibility to the validity of our χ^2 statistic for attention measurement by the d2-Test, as earlier methodological research has confirmed the influence of SES on attention tests, including the d2-Test (Filippetti et al. 2022). However, the d2-Test is only one of many attention tests and it focusses on sustained attention. We could have included additional attention tests to quantify other aspects of attention, such as the Stroop Test (selective attention) and the Continuous Performance Test (sustained and selective attention) (see e.g. Bijnens et al. 2021), but this would have unnecessarily increased the burden on the children, and would most likely have introduced additional bias in the tests, as the tests themselves may contribute to mental fatigue and reduction of attention (as observed in our line-by-line analysis of the attention test data).

Finally, we want to acknowledge that attention is merely one metric of school performance and by extension only one of many variables that determine or impact well-being later in life. Also, green playgrounds could have other beneficial effects, such as reduction of anxiety (de la Osa et al., 2024) and improved immune system functioning through enhanced contact with environmental microbiota (see Roslund et al. (2022) for a placebo-controlled double-blinded test of the biodiversity hypothesis). Other possible outcomes, such as social skills, self-image, and growth, are not reflected in the attention score. We chose to focus on attention in this study as it is a crucial determinant of academic performance that can be accurately quantified, but future research might benefit from including other metrics for educational outcome, other metrics of health and wellbeing, as well as other metrics of exposure to biodiversity, including exposure to indoor and outdoor microbiomes.

5. Conclusions

Overall, our study demonstrates that green space at school may partially compensate limited exposure to green space in highly urbanized environments with beneficial effects on attention. Future research should consider the multifaceted nature of the green space-attention relationship, acknowledging potential variations based on socioeconomic and cultural factors and the specific characteristics of the green spaces under investigation. Based on the results of our observational study, we can conclude that greening existing playgrounds at school is expected to benefit child development in urbanized environments, while simultaneously improving much needed urban green space cover in cities, with health benefits that extend beyond the school boundaries.

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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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Human subjects

All participants and their parents provided prior informed consent. Health data were anonymized. The protocol for this study was approved on 30 November 2020 by the Committee for Medical Ethics UZA-UA of the University of Antwerp (Belgian registration number B3002020000242).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2025.128680.

Data Availability

The anonymized data collected are available as open data (CC-BY 4.0 International) via the Zenodo data repository: http://doi.org/10.5281/zenodo.10527033.

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