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Higher surrounding green space is associated with better attention in Flemish adolescents

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ABSTRACT

Introduction: Previous studies suggested that green space is beneficial for the cognitive development in children. However, evidence in adolescents is limited. Therefore, we aim to investigate green space exposure in association with attention and behaviour in adolescents.
Methods: This study includes 596 Flemish adolescents between 13 and 17 years old. Attention was assessed with Stroop Test (selective attention) and Continuous Performance Test (sustained and selective attention). Behaviour was determined based on the Strengths and Difficulties Questionnaire. Green space was estimated in several radius distances around their current residence and school based on high-resolution land cover data. Multilevel regression analyses were used adjusting for participant's age, sex, education level of the mother, and area deprivation index.
Results: Surrounding green space in a 2000 m radius is associated with a faster reaction time in adolescents. An IQR (13%) increment in total green space within 2000 m of the residence and school combined, is associated with a 32.7 ms (95% CI: −58.9 to −6.5; p = 0.02) and a 7.28 ms (95% CI: −11.7 to −2.8; p = 0.001) shorter mean reaction time between the presentation of a stimulus and the response based on the Stroop Test and the Continuous Performance Test. Subdividing green space based on vegetation height, shows that green space higher than 3 m is associated with a faster reaction time of the Continuous Performance Test (−6.50 ms; 95% CI: −10.9 to −2.2; p = 0.004), while low green is not. We did not find an association between green space and behavioural development in adolescents.
Conclusions: Our study shows that green space, especially trees, surrounding the residence and school combined is associated with better sustained and selected attention in adolescents. These findings indicate that the availability of green is important for adolescents that are growing up in a rapidly urbanizing world.

1. Introduction

Adolescence is the stage of development that occurs between childhood and adulthood, from ages 10 to 19. During this critical period of neurodevelopment, experience and neurobiological factors interact to shape the brain to fit the environment and alter behaviour (Larsen and Luna, 2018). On the one hand, the enhanced plasticity at this time may lead to vulnerability to disorders in response to environmental stressors.

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On the other hand, it provides an opportunity to alter developmental trajectories (Larsen and Luna, 2018).

Previous studies have already shown that green space is important for cognitive development in children and is beneficial for working memory (Dadvand et al., 2015), attention (Dadvand et al., 2015; Dadvand et al., 2017), and intelligence (Bijnens et al., 2020; Lee et al., 2021). The literature on green space around schools and academic performance in childhood shows mixed results (Browning and Rigolon, 2019). Although there is evidence for an association between green space and cognition in children, studies in adolescents are limited (Wallner et al., 2018; Cherrie et al., 2019). A study in 64 pupils aged 16–18 years shows that breaks in larger green space, either parks or forests, improved wellbeing and cognitive performance of adolescents (Wallner et al., 2018). Furthermore, public park availability for the adolescent activity space (home, school, route to secondary school) was positively associated with better cognitive aging in later life (Cherrie et al., 2019).

Moreover, residential green space is associated with behavioural development in adolescence. A study in children and adolescents shows that greenness of the residential neighborhood was associated with lower problematic behaviour scores, especially aggressive behaviours and attention problems (Lee et al., 2019). In addition, reduced aggressive behaviour was noted in association with more surrounding residential green space in urban dwelling adolescents (Younan et al., 2016). Studies in children show that green space exposure is beneficial for the behavioural development showing less hyperactivity and inattention problems based on the Strengths and Difficulties Questionnaire (SDQ) (Vanaken and Danckaerts, 2018; Amoly et al., 2014; Balseviciene et al., 2014; Markevych et al., 2014; Zach et al., 2016; Richardson et al., 2017) and less externalizing behaviour problems based on the Child Behavior Checklist (Bijnens et al., 2020; Lee et al., 2019).

Markevych et al. (Markevych et al., 2017) present the potential underlying pathways between greenspace and health in three domains emphasizing general functions of green space (Markevych et al., 2017). The first is reducing harm (e.g. reducing exposure to air pollution, noise and heat). Most emission sources of air pollution and sources of traffic noise are absent in green spaces. The second functional domain of greenspace on health is the ability to restore capacities. People spend time in natural environments to relax and recover from demanding situations and tasks (Ward Thompson et al., 2012; Kaplan and Kaplan, 1989; Kaplan, 1995). The attention restoration theory suggest that interacting with nature can enhance directed-attention abilities (Kaplan and Kaplan, 1989; Kaplan, 1995). Unlike urban environments, filled with stimuli that require attention, creating a less restorative environment (Berman et al., 2008). Finally, the third domain is the potential of greenspace to provide an opportunity to build capacities, such as the encouragement of physical activity (Dadvand et al., 2016; Lachowycz and Jones, 2011) and the facilitating of social cohesion (Dadvand et al., 2016; Maas et al., 2009; de Vries et al., 1982). Contrary to the two first domains, consciously engaging with green space and actual green space visits are likely to be important to increase physical activity and social interaction (Bloemsma et al., 2018; Hartig et al., 2014).

In this study, we investigate surrounding green space at the residential address and the school location combined in association with attention in adolescents. We use different measures of green space, such as vegetation height and accessibility, based on high-resolution land cover models to understand which types of green space are important. We also study the association between green space and behavioural development. We hypothesize that in parallel to children, green space has a beneficial impact on attention and behaviour in adolescents.

2. Methods

2.1. Study population

The study was part of a biomonitoring program for environmental health surveillance (Flemish Environmental Health Surveys, FLEHS) in Flanders, Belgium. In the course of 2017–2018, 610 adolescents between 13 and 17 years old were recruited in the fourth FLEHS campaign (FLEHS 4). A total of 428 participants were examined at 21 schools spread over Flanders, and constitute a representative sample of the Flemish population with respect to sex, geographic area (provinces, rural–urban classification of schools) and socio-economic status (household education level). In addition, 182 adolescents were recruited among participants of a previous newborn cohort (FLEHS 1) and were examined at home. We excluded 14 participants from our analysis because of missing data on maternal educational level. This resulted in 596 individuals included in our analysis. The study protocol was approved in June 2017 by the Antwerp University Hospital Ethical committee (registration number B300201732753).

2.2. Data collection

Both during home visits and in schools, the fieldwork was done by experienced field workers of the Provincial Institute of Hygiene (PIH). The adolescents underwent a clinical examination and biological samples were taken. All samples and data were collected as agreed upon in the study protocol. From each participant and its parent questionnaire data was collected that provided information on their environment, life style, dietary habits, socio-economic status, health and perception of their eco-behaviour through questionnaires. Measurement of body weight, height, waist circumference, blood pressure and neurological tests were performed. The educational level of the mother as a proxy of socioeconomic status (SES) was categorized into 3 groups low, medium, and high. We assessed neighborhood socioeconomic status (SES) using the Area Deprivation Index (ADI), which is calculated at a sub-municipality level in Flanders on a yearly basis (Guio and Vanderbroucke, 2019). The area deprivation index of 2018 considers all children born in year 2018, 2017 and 2016 that live in deprived households in a given neighborhood in Flanders, divided by the total number of children born in this neighborhood during the same period. Selection criteria for deprivation are the family's monthly income, the parents' educational attainment and employment situation, development of the children, housing and health. A lower limit is set for each criteria, if a family scores below the limit for at least three criteria, it is considered to be deprived.

2.3. Surrounding green space

Residential and school addresses of the adolescents at time of the study were geocoded. All analyses were carried out using Geographic Information System (GIS) functions with ArcGIS 10 software (Esri Inc., US). Residential location was categorised into urban, suburban, and rural based on a map (Flemish Government – Department Environment) containing all statistical sectors in Flanders classified as urban, suburban, and rural areas depending on their population density, employment, location, and spatial planning.

Green space was estimated in several radii (50, 100, 300, 500, 1000, and 2000 m) around the residence/school based on a high-resolution (1 m^2) land cover dataset, Green Map of Flanders 2012 from the Agency for Geographic Information Flanders (AGIV). We used three measures from this high-resolution dataset: (1) high green (vegetation height higher than 3 m), (2) low green (vegetation height lower than 3 m), and (3) total vegetation cover. The third measure was the sum of the other two. Finally, we developed a combined surrounding green space index (combined residence and school) by averaging residential green space and green space around the school weighted by the time adolescent are assumed to spend at home (16 h), and school (8 h).

2.4. Proximity to accessible green space

We calculated the availability of green space, accessible to the public by road, based on a map (Flemish Government – Department Environment). In brief, green space is based on the land use map 2013 and includes scrub, forest, semi-natural grassland, heathland, dune, inland marches, mud flats/salt marches and other low and high green vegetation. Green on cemeteries, golf courses, zoo and amusement parks, sports fields and camping sites are not included, since this is not considered as freely accessibly. Areas divided by major roads, rail or waterways are considered as separate clusters of green space. Green space is considered accessible when a road (no major road) runs through, in or near the area. The distance between the residence and the green area is calculated by road. The presence (yes–no) of accessible green space was classified based on minimum area size and maximum distance resulting in five indicators; green in neighbourhood (>0.2 ha, <400 m), green in district (>10 ha, <800 m), small urban green (>30 ha, <1600 m), urban green (>60 ha, <3200 m) and urban forest (>200 ha, <5000 m).

2.5. Ambient air pollution and road noise exposure

We calculated the regional background levels of black carbon (BC) for the residential - and the school address using a high-resolution spatiotemporal interpolation method (Janssen et al., 2008) that takes into account land-cover data obtained from satellite images (CORINE land-cover dataset) and pollution data from fixed monitoring stations in combination with a dispersion model (Lefebvre et al., 2013; Lefebvre et al., 2011). This interpolation method uses hourly measured BC pollution data collected at 34 fixed-site monitoring stations. We calculated individual BC concentrations (μg/m^3) one year before the measurement.

Individual road noise exposure (dB), expressed as total exposure over an entire day (L_{den}), on the residential was calculated based on a region-wide noise map based on the environmental reporting (MIRA) from the Flanders Environment Agency (VMM.) The modelling of road noise level is provided for all main and secondary roads in Flanders and is calculated based on road traffic intensity and speed, vehicle-type-specific traffic density and type of street surface. Small-scale topography of the area, and shielding by dwellings the presence or dimensions of buildings and reflecting objects are not taken in to account. Its main asset is the spatial accuracy of the lower order roads. Further traffic noise exposure in Flanders is estimated based on a detailed propagation model (ISO9613-2).

2.6. Cognitive outcomes

Cognitive performance was assessed with a computer version of the Stroop Test (Dutch translated version from Xavier Educational Software Ltd, UK) and four specific tests from the Neurobehavioural Evaluation System 3 (NES3) battery: Continuous Performance, Digit Span, Digit-Symbol, and Pattern Comparison (Letz, 2000; White et al., 2003). We used as performance parameters, the mean reaction time in the Continuous Performance Test and the Stroop Test, the maximum span forward and backward in the Digit Span Test, and the total latency or the average latency in the Digit-Symbol Test and Pattern Comparison Test respectively.

The Stroop Test was used to evaluate selective attention. The subjects had to identify the name of the color of the word displayed on the screen correctly and as fast as possible and not the color the word is printed on. Before the test, eight practice trials take place followed by 48 test trials. The correct percentage, number of trials attempted and the average speed taken to answer the test parameters are recorded. The mean reaction time is recorded in milliseconds (msec). This performance indicator was only calculated when the total number of test trails with wrong responses was smaller than or equal to 16.

Sustained attention and selective was assessed with the Continuous Performance Test. During this test a series of 48 letters are displayed on the screen and the task is to react as fast as possible to the letter S, but not to other letters. We used the mean reaction time in milliseconds as indicator of sustained and selective attention.

In the Digit Span Test measures short-term memory and the task is to reproduce a series of digits in the correct order after an auditory presentation. The number of digits increases until two consecutive incorrect answers are given. The maximum number of digits reproduced in the order of presentation (digit span forward) and the maximum number of digits reproduced in the reverse order (digit span backward) evaluates short-term memory.

The Digit-Symbol Test is used to evaluated visual information processing speed. Participants performed the task by selecting as fast as possible the symbols corresponding to the digits appearing consecutively on the screen. A new digit appears only after the correct symbol has been indicated. A second test to evaluate visual information processing speed is the Pattern Comparison Test. During this test three matrices consisting of 10 × 10 blocks are shown and two of them are identical. The task is to indicate which pattern is different from the other two patterns. The test includes 25 items.

2.7. Behavioural development

The Strengths and Difficulties Questionnaire (SDQ) consisted of five domains, i.e., emotional symptoms, peer problems, hyperactivity and inattention symptoms, conduct problems and prosocial behavior (van Widenfelt et al., 2003). Each subscale consists of five items that can be scored 0, 1, or 2, and the total score on each domain can therefore range from 0 to 10. The first four domains could be summed up resulting in the Total Difficulties Score (range, 0–40). Additionally, an internalizing (emotional symptoms and peer problems) and externalizing subscale (hyperactivity and conduct problems) could be derived. A higher score indicates more behavioural problems.

2.8. Statistical analyses

We used SAS software, version 9.4 (SAS Institute, Cary, NC) for data management and statistical analyses. All reported p-values are two-sided and were considered statistically significant when $p < 0.05$. The distribution of all variables was inspected. We used multiple linear regression models to associate attention with total, high and low green space (combined residence and school) and with the availability of accessible green space at the residence adjusted for covariates selected *a priori*. The models investigating the association between attention and green space during adolescence included participant's age, sex, education level of the mother and area deprivation index. We expressed the effect estimates for an interquartile range (IQR) increment in percentage green space. The effect estimates are presented as change in milliseconds for reaction time of the Continuous Performance Test and the Stroop Test, change in number of digits for the Digit Span Forward and Backward Tests, and change in seconds for the latency of the Digit-Symbol Test, Pattern Comparison Test, and change in scores for the Total Difficulties Score, externalizing subscale and internalizing subscale. A logistic regression model was used to investigate the association between green space and binary outcomes of attention (reaction time longer than 90th percentile). In this model the same covariates were used.

Finally, we conducted a series of sensitivity analysis to check the robustness of the findings. First, we tested the "time spent in green-by-green space interaction" on attention (Continuous Performance test). The statistically significant level of interaction was set at $p \leq 0.10$. The time spent in green was based on information from the questionnaire and adolescent were stratified in two groups; spending time in green space (almost daily) and not spending a lot of time in green space (only in weekend or less). Second, to gain insight into chronic exposure, we investigated the association between green space and attention in a subset of adolescents ($n = 336$) living their whole lives at the current address. Third, to check the effect modification by urbanicity, we investigated the association between green space and attention in adolescents residing in an urban area ($n = 208$) and residing in a rural area ($n = 268$). Fourth, to exclude potential confounding of air pollution and noise, we adjusted the main models for residential exposure to black carbon one year before the measurement and traffic noise. Finally, we additionally adjusted for recruitment type in a sensitivity analysis.

3. Results

3.1. Characteristics of the study population

Our study population compromises 596 adolescents between 13 and 17 years, of which 283 (47.5%) boys. The majority (59.6%) of the adolescents' mothers had a higher education degree and have an average area deprivation index of 12%. Table 1 shows characteristics of the participants and information about the average results in the cognitive and behavioural tests. Table 2 contains the distribution of green space exposure in several buffer sizes around the residential address and the school location. The percentage of adolescents with accessible green space available is indicated in Table 3.

3.2. Surrounding green space in association with attention

Higher total and high (vegetation height higher than 3 m) green space within a 2000 m radius (combined residence and school) is significantly associated with a shorter reaction time based on respectively the Stroop Test (selective attention) and the Continuous Performance Test (sustained and selective attention). This was seen while adjusting for participant's age, sex, education level mother and area deprivation index (Fig. 1). This is not observed for the green space buffers of 500 m radius or smaller. An IQR (13%) contrast in total green space (residence-school) within 2000 m is associated with a 32.7 msec (95% CI: −58.9 to −6.5; p = 0.02) and a 7.28 msec (95% CI: −11.7 to −2.8; p = 0.001) decrease in reaction time based on the Stroop Test and the Continuous Performance Test, respectively. Subdividing green space based on vegetation height, shows that a 11% (IQR) increase in green space higher than 3 m within a 2000 m radius is associated with a faster reaction time of the Continuous Performance Test (-6.50 msec; 95% CI: −10.9 to −2.2; p = 0.004), whereas low green space (vegetation height lower than 3 m) is not associated with reaction time. Residential surrounding green space is not significantly associated with short-term memory and visual information processing speed (Supplement Fig. S1).

In addition, an IQR (13%) increase in green space (combined residence and school) within a 2000 m is associated with a 35% lower risk (odds ratio: 0.65; 95% CI: 0.45 to 0.92; p = 0.01) of a mean reaction time longer than 536 ms (90th percentile) based on the Stroop Test. The corresponding odds ratio were 0.76 (95% CI: 0.54 to 1.08; p = 0.23) or a 24% lower risk of a mean reaction time longer than 1467 ms (90th percentile) based on the Continuous Performance Test.

We did not observe an effect modification of time spend in green on the association of green space and attention. Within a subpopulation of adolescents living their whole lives at the current address, we observed stronger effect estimates of total green and high green (>3 m) on attention, especially in smaller buffers around the residence (Fig S2). A second stratified analysis to study the potential effect modification by urbanicity showed only a more pronounced association between low (2000 m) green space and attention in children residing in a rural area (p-interaction low green and urbanicity = 0.07; urban: 4.44 msec; 95% CI: −6.0 to 14.9; p = 0.40; rural: −8.05 msec; 95% CI: −15.7 to −0.4; p = 0.04). Finally, additional adjustment for exposure to black carbon (Fig S3) or exposure to noise (Fig S4) or adjustment for recruitment (Fig S5) did not result in a considerable change in the aforementioned effect estimates.

Table 1
Study population characteristics (n = 596).

Boys	283 (47.5)
Age	14.8 ± 0.5
Level of education of the mother	
Low	47 (7.9)
Medium	194 (32.5)
High	355 (59.6)
Area deprivation index, %	12.5 ± 9.0
Spending time in green space, n = 591	
Almost daily or more	354 (59.9)
Only in weekend or less	237 (40.1)
Not moved since birth, n = 592	336 (56.8)
Urbanicity of residence	
Urban	220 (36.9)
Suburban	102 (17.1)
Rural	274 (46.0)
Cognitive parameters	
Stroop, reaction time, msec, n = 573	1151 ± 256
Continuous Performance, reaction time, msec, n = 587	476 ± 43.7
Digit span forward, number of digits, n = 413	5.5 ± 1.0
Digit span backward, number of digits, n = 413	4.4 ± 1.0
Digit-Symbol, total latency, seconds, n = 415	95.4 ± 13.8
Pattern Comparison, average latency, seconds, n = 417	3.4 ± 0.8
Behavioural development, n = 594	
Total Difficulties Score	10.81 ± 5.2
Externalizing subscale	6.29 ± 3.3
Internalizing subscale	4.53 ± 3.2

Data presented are means ± standard deviation or number (percentage).

3.3. Proximity to accessible green space and attention

Table 3 shows that adolescent having access to small urban green (distance < 1600 m by road, area > 30 ha) or urban green (distance < 3200 m by road, area > 60 ha) have a faster reaction based on both test (Stroop and Continuous Performance Test). Adolescents having access to urban green have a 83.41 msec (95% CI: −142.6 to −24.2 msec; p = 0.006) and a 16.30 msec (95% CI: −26.4 to −6.2 msec; p = 0.002) lower reaction time, based Stroop test and the Continuous Performance Test respectively, then adolescents not having access.

3.4. Surrounding green space in association with behaviour

No significant association was observed between total, high, and low green space (combined residence-school) and behaviour based on the Total Difficulties Score, internalizing (emotional symptoms and peer problems) and externalizing subscale (hyperactivity and inattention symptoms and conduct problems). The results are presented in Supplement Table 1.

4. Discussion

We demonstrated that green space, combination of residence and school, within a 2000 m radius is significantly associated with a faster reaction time based on the Stroop Test and on the Continuous Performance Test in adolescents aged 13–17 years. Further dividing total green space in vegetation higher than 3 m and vegetation lower than 3 m, shows only a significant association between attention and high green and not with low green.

Our results show a beneficial association of especially green space higher than 3 m on attention. In connection to this, Kweon and colleagues (2017) found a positive association between the percentage of the school parcels made up of trees and academic performance, but grass and shrubs negatively correlate with performance (Kweon et al., 2017). In contrast to our results, a previous study based on data from the Sabadell and Valencia (Spain) INMA birth cohorts did not find a significant association between residential surrounding tree cover and attention (Dadvand et al., 2017). The authors suggest that the small contrast in exposure to surrounding tree cover could have unpowered the analyses (Dadvand et al., 2017). Another important difference is the vegetation height. Only trees with a height greater than five meters were taken in to account, whereas we included vegetation higher than three

Table 2
Descriptive statistics for green space variables.

	Total green			High green			Low green		
	25th percentile	median	75th percentile	25th percentile	median	75th percentile	25th percentile	median	75th percentile
Green space (residence-school)									
50 m buffer, %	24.1	32.3	40.2	4.3	7.5	11.9	15.8	21.8	29.9
100 m buffer, %	28.4	35.7	42.8	6.7	9.9	15.0	17.3	23.3	29.9
300 m buffer, %	29.9	36.2	42.5	8.8	12.6	17.4	17.2	22.4	27.0
500 m buffer, %	29.3	35.9	41.5	10.0	13.2	18.1	16.4	20.8	25.1
1000 m buffer, %	28.4	35.6	41.4	10.5	14.4	19.8	15.3	19.2	23.7
2000 m buffer, %	28.7	35.5	41.2	11.0	15.3	21.6	14.6	17.9	21.9

Table 3
Participant's reaction time (msec) during the Stroop Test (n = 573) and during the Continuous Performance Test (n = 587) in association with accessible green space at the residence.

			Reaction time, msec (Stroop Test)				Reaction time, msec (Continuous Performance Test)			
Indicator (% participants)	Distance, m	Area, ha	β	Low 95% CI	High 95% CI	p-value	β	Low 95% CI	High 95% CI	p-value
Residential access to										
Green in neighbourhood (96%)	< 400	> 0.2	−88.42	−190.71	13.88	0.090	−3.42	−21.06	14.22	0.704
Green in district (63%)	< 800	> 10	−51.48	−94.57	−8.38	0.019 *	−3.24	−10.60	4.13	0.389
Small urban green (69%)	< 1600	> 30	−53.38	−99.23	−7.54	0.022 *	−11.58	−19.34	−3.82	0.003*
Urban green (85%)	< 3200	> 60	−83.41	−142.62	−24.19	0.006 *	−16.30	−26.43	−6.18	0.002*
Urban forest (77%)	< 5000	> 200	−55.41	−104.72	−6.10	0.028 *	−1.06	−9.60	7.48	0.807

Models were adjusted for the participant's age, sex, education level mother, and area deprivation index. The estimates (β) represent the change in reaction time for an interquartile range (IQR) increase in greenness in the respective buffer. Statistically significant estimates ($p < 0.05$) at a 95% confidence level are represented by an asterisk (*).

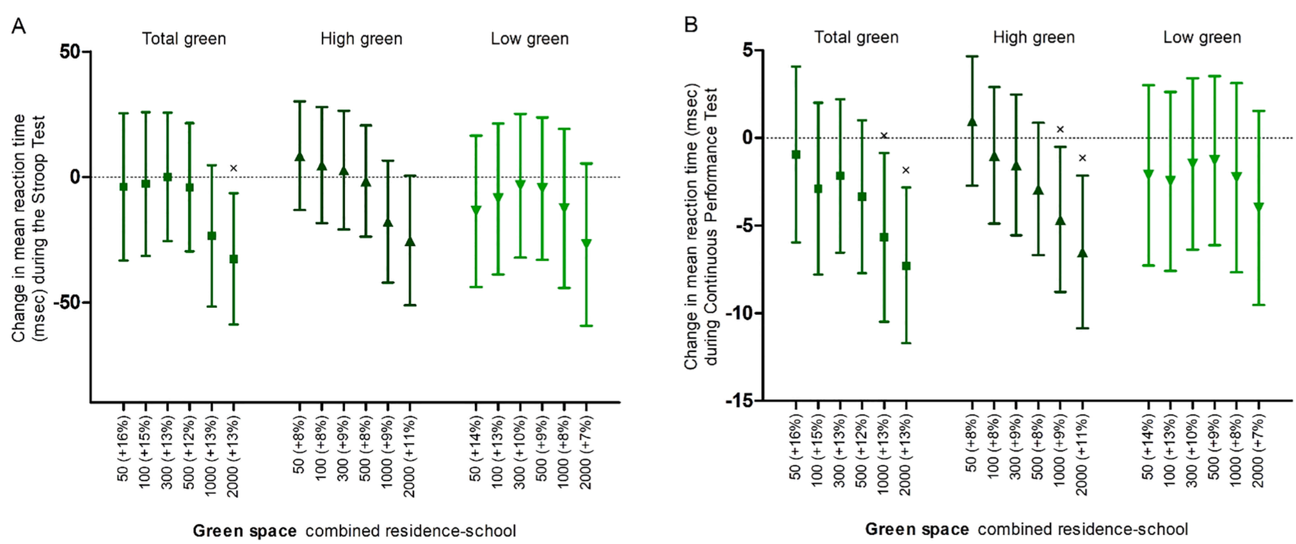

Fig. 1. Association between participant's reaction time and the percentage of green space (combination residence and school) in buffers of several sizes. A) Reaction time (msec) based on the Stroop Test (n = 569) B) Reaction time (msec) based on the Continuous Performance Test (n = 583). We used measures of green; total green, high green (vegetation height higher than 3 m) and low green (vegetation height lower than 3 m). Models were adjusted for the participant's age, sex, education level mother and area deprivation index. The estimates represent the change in reaction time for an interquartile range (IQR) increase in green space in the respective buffer. Statistically significant estimates ($p < 0.05$) at a 95% confidence level are represented by an asterisk (*). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

meters (Dadvand et al., 2017). Previous studies already suggest that trees providing more benefits than other vegetation (Browning and Rigolon, 2019; Kondo et al., 2020).

Green space in multiple buffer sizes was investigated. Only green space in larger buffers (1000 m and 2000 m around the current residence and school combined) is statistical significant associated with attention. This was not found in smaller buffer sizes. In accordance with this, we show that the presence of accessible green space (>60 ha) within 3200 m of the residence is associated with a faster reaction time. In addition to green space within larger buffers, we also observed a significant association between attention and green space within smaller buffer sizes (100 m, 300 m, and 500 m) among a subpopulation living their whole lives at their current address. These results may suggest that the association between green space and attention is a reflection of long-term exposure to green space during development. More research is needed to reveal appropriate time windows and buffer sizes of green space exposure to study cognitive outcomes among adolescents, compared to children.

By our knowledge this is the first study investigating surrounding green space and attention in adolescents. This study contributes to the understanding of the specific needs of adolescents in cognitive outcomes. We demonstrated a significant association between exposure to green space and attention. Our results with attention, are in agreement with previous studies in children. A study in Barcelona showed that exposure to surrounding greenness in primary schoolchildren was associated with greater progress in working memory and attention over a 12-month period (Dadvand et al., 2015). In addition, data of two population-based cohorts in Spain, show that more residential surrounding greenness is associated with better attention at age 4–5 y and at 7 y (Dadvand et al., 2017). In contrast to attention, we did not find associations between green space and other cognitive domains such as short-term memory visual information processing speed. Also, previous studies in adults did not find an association with green space and short-term memory assessed with the Digit Span Forward/Backward test (Tennessen and Cimprich, 1995) or a recall test of 20 words (de Keijzer et al., 2018). By our knowledge, no studies investigated visual information processing speed in connection to green space.

We did not find an association between residential green and behavioural development in adolescents. This is in contrast to previous studies, in adolescents and children, showing an association between green space and behavioural development, especially less aggression, hyperactivity and attention problems (Bijnens et al., 2020; Lee et al., 2019; Younan et al., 2016; Vanaken and Danckaerts, 2018; Amoly et al., 2014; Balseviciene et al., 2014; Markevych et al., 2014; Zach et al., 2016; Richardson et al., 2017).

A limitation of this study is that cognition was only assessed at one time point in adolescence, and not at previous stages during childhood. We cannot rule out that the association of green space and attention was already established during childhood. However, we did have information on residential address history. The association between high green and attention, especially attention based on the Continuous Performance Test, is stronger in persons living their whole lives on the same address. This may suggest that chronic exposure to green space is more important than recent exposure. Furthermore, the present study tested an *a priori* hypothesis involving interrelated cognitive outcomes as well as strongly correlated green space indicators. Therefore, the cognitive outcomes or green space variables did not provide a completely independent opportunity for a type I error. For this reason, we did not adjust for multiple testing. Nevertheless, it is unlikely that our consistent findings are only a reflection of chance. Our study has several strengths. First, green space quantification was based on a high-resolution map. Second, additional information was available on the types, accessibility, and use of green space. Finally, an important strength of our study is that we excluded potential confounding effects caused by air pollution and noise. Indeed, in a sensitivity analyses, we account for residential exposure to black carbon and traffic noise.

5. Conclusion

Our results demonstrate that more surrounding green space, especially trees, in the larger neighbourhood of residence and school combined, is associated with better attention in adolescents. These findings contribute to the understanding of the importance of green space and indicate that an effort should be made for the conservation and expansion of available green space for children and adolescent that are growing up in a rapidly urbanizing world.

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Ethics

The study protocol has been revised and approved by the Ethics committee of the Antwerp University Hospital (Belgian Registry Number: B300201732753).

CRediT authorship contribution statement

Esmée M. Bijnens: Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing – original draft, Visualization. **Stijn Vos:** Conceptualization, Formal analysis, Investigation, Writing – review & editing. **Veerle V. Verheyen:** Conceptualization, Investigation, Writing – review & editing, Supervision. **Liesbeth Bruckers:** Conceptualization, Data curation, Writing – review & editing. **Adrian Covaci:** Conceptualization, Writing – review & editing. **Stefaan De Henauw:** Conceptualization, Writing – review & editing. **Elly Den Hond:** Conceptualization, Writing – review & editing. **Ilse Loots:** Conceptualization, Writing – review & editing. **Vera Nelen:** Conceptualization, Writing – review & editing. **Michelle Plusquin:** Conceptualization, Writing – review & editing. **Greet Schoeters:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration, Funding acquisition. **Tim S. Nawrot:** Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Funding acquisition.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envint.2021.107016.

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