Environmental Research 237 (2023) 116968

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Cross-sectional evaluation of the association between greenness and cognitive performance in Mexican pre-pubertal boys

Àurea Cartanyà-Hueso[a], Benito de Celis Alonso[b], Silvia Sandra Hidalgo Tobón[c,d], América Liliana Miranda Lora[e], Miguel Klünder Klünder[f], Briceida López Martínez[g], Pilar Dies Suárez[c], Eduardo Barragán Pérez[h], Po-Wah So[i,**], Juana Maria Delgado-Saborit[a,*]

[a] Group of Perinatal Epidemiology, Environmental Health, and Clinical Research, Department of Medicine, School of Health Sciences, Universitat Jaume I, Av. Vicent Sos Baynat, s/n 12071 Castelló de La Plana, Spain
[b] Faculty of Physical and Mathematical Sciences, Benemérita Universidad Autónoma de Puebla, Puebla, Mexico
[c] Departamento de Imagenología, Hospital Infantil de México Federico Gómez, Mexico City Mexico
[d] Departamento de Física de La Universidad Autónoma de México Iztapalapa, Mexico City, Mexico
[e] Unidad de Investigación Epidemiológica en Endocrinología y Nutrición, Hospital Infantil de México Federico Gómez, CDMX, Mexico
[f] Subdirección de Investigación, Hospital Infantil de México Federico Gómez, Mexico City, Mexico
[g] Subdirección de Servicios Auxiliares de Diagnóstico, Hospital Infantil de México Federico Gómez, CDMX, Mexico
[h] Departamento de Neurología, Hospital Infantil de México Federico Gómez, Mexico City, Mexico
[i] Department of Neuroimaging, Institute of Psychiatry, Psychology and Neuroscience, King's College London, United Kingdom

A R T I C L E I N F O

Handling Editor: Jose L Domingo

Keywords:
Greenspace
Children
Cognition
Megacity
Mexico
Male
Wechsler scales
Secondary keywords: boys
Perceptual reasoning skills
Memory
Construction skills
ENI
WISC-IV

A B S T R A C T

Background: Evidence shows that greenspace exposure benefits children's health and cognitive development. However, evidence assessing this association in young children in low- and middle-income economies is scarce.
Objective: To assess the association between exposure to greenness and cognitive performance in pre-pubertal boys living in Mexico City.
Methods: Cross-sectional study using data from 144 boys aged 6–11 years living in Mexico City in 2017 and enrolled in the "MetCog" study. Cognitive performance was evaluated through selected Wechsler Scale for Intelligence in Children Fourth Edition (WISC-IV) and Neuropsychological Assessment of Children (Evaluación Neuropsicológica Infantil, ENI) tests. Exposure to greenness was assessed through Normalised Difference Vegetation Index (NDVI) at 300, 500, 1500, 2000, and 3000 m buffer zones from children's residences. Multiple linear regression analysis was undertaken to assess associations between cognitive performance and greenness (aβ) with 95% confidence intervals (CI) and adjusted for potential confounding variables. Significance was set at $q < 0.05$ after False Discovery Rate (FDR) correction.
Results: A positive association was found between the NDVI Interquartile Range (IQR) at 2000 m and the WISC-IV block design test score ($a\beta_{2000} = 1.18$, 95% CI = 0.31, 2.06; $q < 0.05$), which assesses perceptual reasoning. Positive associations were found with NDVI IQR at 1500 m and WISC-IV block design ($a\beta_{1500} = 1.00$, 95% CI = 0.14, 1.86) and matrix reasoning ($a\beta_{1500} = 0.83$, 95% CI = 0.06, 1.61) scores, but neither survived FDR correction. No significant associations were found between NDVI IQR at any buffer size with other WISC-IV and ENI task scores.
Conclusions: Greater exposure to greenness was associated with higher perceptual reasoning skills in 144 pre-pubertal boys living in Mexico City. Thus, urban planning should consider increasing vegetation in megacities, especially in neighbourhoods with high percentages of young children.

Abbreviations: BMI, Body Mass Index; CI, Confidence Interval; IQR, Interquartile Range; NDVI, Normalised Difference Vegetation Index; SD, Standard Deviation; WISC-III, Weschler Intelligence Scale in Children third edition; WISC-IV, Weschler Intelligence Scale in Children fourth edition; ENI, Neuropsychological Assessment of Children (Evaluación Neuropsicológica Infantil ENI).

* Corresponding author. Group of Perinatal Epidemiology, Environmental Health, and Clinical Research, Department of Medicine, School of Health Sciences, Universitat Jaume I, Av. Vicent Sos Baynat, s/n 12071 Castelló de la Plana, Spain.
** Corresponding author. Department of Neuroimaging, Institute of Psychiatry, Psychology and Neuroscience, King's College London, James Black Centre, 125, Coldharbour Lane, London, SE5 9NU, United Kingdom.
E-mail addresses: po-wah.so@kcl.ac.uk (P.-W. So), delgado@uji.es (J.M. Delgado-Saborit).

https://doi.org/10.1016/j.envres.2023.116968
Received 19 April 2023; Received in revised form 21 August 2023; Accepted 22 August 2023
Available online 23 August 2023

1. Introduction

People living in urban areas generally benefit from a wider social network; more job opportunities; better access to services, including health services; and better communications. According to "Urbanization Prospects: The 2018 revision report of the United Nations", around 55% of the global population lived in urban areas in 2018, with the prevalence increasing to 81% in Latin America and the Caribbean (United Nations, Department of Economic and Social Affairs, P. D, 2018). However, living in urban areas might also risk adverse health effects, such as increased exposure to environmental pollution, noise, and restricted access to green spaces. Current evidence suggests that green spaces, including parks and gardens, have protective effects on cardiovascular health (James et al., 2015; B.-Y. Yang et al., 2021), mental health for Gascon adults (Gascon et al., 2015; Oswald et al., 2020; B.-Y. Yang et al., 2021) and children (McCormick, 2017), normal birth weight (James et al., 2015; B.-Y. Yang et al., 2021), and cognitive development in children (McCormick, 2017).

Increased exposure to green spaces has been associated with health benefits according to four distinct pathways (Hartig et al., 2014). The first is reducing harm or "mitigation", whereby green spaces reduce exposure to environmental stressors, such as air pollution, noise and heat. Several studies have reported that air pollution concentrations are lower in green areas (Nowak et al., 2006; Paolettia et al., 2011). This could be related to the absence of emissions sources of air pollutants in green spaces, such as traffic, domestic heating or industries (Goodsite and Hertel, 2012). It could also be related with the ability of vegetation to remove air pollution via dry deposition of particles in vegetation surfaces, and to uptake gaseous pollutants through leaf stomata (Selmi et al., 2016). It might also be associated with better air circulation and reduction of air temperature near vegetation (Zupancic et al., 2015). Likewise, green areas provide "quiet areas" or "soundscapes" that reduce or eliminate the source of urban noises and reduce noise levels (Dzhambov and Dimitrova, 2015). Urban green spaces have also been related to lower the heat island effect thus providing comfort to the visitors (Aram et al., 2019). The second pathway is the "restorative" capability of green spaces, as being in contact with nature can rapidly evoke positive emotions and block negative thoughts/emotions, thereby ameliorating or terminating stress. For instance, natural sounds in green spaces provide a pleasant acoustical environment facilitating relaxation and withdrawal from stressful and noisy lives (Van Kempen et al., 2014) and reduce the pathophysiological stress response associated with anthropogenic noises (Stansfeld, 1992). Natural landscapes draw spontaneous attention facilitating to bring mental competence back to normal via the Attention Restoration Theory (Kaplan and Berman, 2010; Ohly et al., 2016), thus having mental restorative properties (Herzog et al., 1997). The restorative ability of nature might also be mediated by the feelings of interest, pleasantness and peacefulness associated with nature images, as proposed in the Affective Aesthetic Theory (Ulrich, 1983). Thirdly, interaction with green spaces has been identified as a preventive factor reducing noise-induced stress (Dzhambov and Dimitrova, 2015). Another pathway is through "instauration", since greenspaces encourage healthy lifestyles and facilitate social cohesion (Markevych et al., 2017). In this sense, neighbourhoods with green spaces nearby make it easier for citizens to get around on foot or by bicycle, as they perceive these spaces as safer and of better quality (Gómez Lopera, 2005). In addition, green spaces have been recognised to play a key role in promoting physical activity (H. Wang et al., 2019; M. Wang et al., 2021). Finally, further evidence suggests a fourth pathway, whereby green spaces improve functioning of the immune system (World Health Organization (WHO) Regional Office for Europe, 2016). In this regard, evidence suggests that exposure to nature boost the immune system by decreasing the expression of pro-inflammatory molecules, infiltration of leukocytes and release of cytotoxic mediators (Andersen et al., 2021). This might also be related to effects of nature on the microbiome, since exposure to green spaces enriches the diversity of the human microbiome, which in turn boost the immune system (Flies et al., 2017).

Children are more vulnerable than adults are to the environment as they are still growing and developing, have different behavioural patterns compared to adults, and little control over their environment (World Health Organization, 2022). Childhood and adolescence are crucial stages during which the brain is undergoing rapid growth and development. During these life stages, cognitive and social-emotional skills are acquired, shaping future mental health. These stages are also vital for assuming productive adult roles in society (World Health Organization, 2022). Cognitive development in childhood and adolescence entails learning to think, and encompasses processes associated with perception, knowledge, problem-solving, judgement, language, and memory, all domains vital to the child's overall growth and development (Haddad et al., 2019) and future life skills. Impairments in cognitive skills are markers of numerous psychiatric disorders emerging in childhood, adolescence, and adulthood (Millan et al., 2012).

The environment greatly affects children's health and their development (World Health Organization, 2022). Associations between exposure to greenspaces and cognition in school-aged children have been documented. A longitudinal study published in 2015 showed a beneficial association between green space exposure and cognitive development among school-aged children (7–10 years old) in Barcelona (Spain) (Dadvand et al., 2015). In addition, two recent studies have also found positive associations between exposure to green spaces and cognition. A study conducted in Porto (Portugal) with children, part of the Generation XXI birth cohort, found that residential green spaces were positively associated with performance Intelligence quotient (IQ) and global IQ (Queiroz Almeida et al., 2021). Another longitudinal study conducted in Massachusetts (USA) with the Viva Cohort found that early childhood was associated with an increase in non-verbal intelligence and visual memory in mid-childhood (Jimenez et al., 2022). On the other hand, another longitudinal study published in 2021 showed a positive association between residential exposure to surrounding greenness within 500 m and arithmetic test scores, which assesses attention, concentration and numerical reasoning, in children aged 7 living in Rome (Italy) (Asta et al., 2021).

These studies reported associations on young children in high-income countries. On the other hand, evidence assessing association between green spaces and health in low- and middle income countries, such as Mexico (The World Bank, 2022; United Nations, 2020), is scarcer than evidence focused in high-income countries (Shuvo et al., 2020; Ricciardi et al., 2022; Vella-Brodrick and Gilowska, 2022). Only two papers have assessed the effect of green spaces in cognition in low- and middle-income countries. Liao et al. (2019) assessed neurodevelopment at 2 years old in a birth cohort in Wuhan (China), whereas Requia and Adams (2022) assessed the effect of green spaces on academic performance of students in Distrito Federal in Brazil. This may be especially important, as children in these countries may have lost access to green areas due to the dynamics of urban development/growth.

Moreover, the studies mentioned above were mostly conducted in cities with less than 10 million inhabitants, but there is scarcity of studies conducted in megacities, i.e., cities with more than 10 million of inhabitants. Only the study of Liao et al. (2019) assesses neurodevelopment in a megacity, such as Wuhan. The accessibility to green spaces of children living in megacities needs further consideration, as available urban green spaces in megacities appears to be only a third of the urban area compared to cities (Huang et al., 2017). Furthermore, a systematic review by Rigolon (2016) aimed at revealing the relationship between the size of a city and inequality of access to urban green spaces from global empirical studies focussed on three aspects of urban green spaces: proximity, quantity, and quality, and concluded inequities in quantity, quality and area of parks, with those living in low-income communities being the most disadvantaged (Rigolon, 2016). Another recent review showed that inequality of access to urban green spaces is positively correlated with population size (Sun et al., 2022), and this is very likely to be relevant to those living in megacities. Moreover, the benefits of green spaces on health might be larger for dwellers of megacities than for citizens of smaller cities or rural areas, since the mechanisms by which green spaces improve health might be more strongly activated in large urban areas than in suburban/rural ones, as suggested by a recent review (Browning et al., 2022). For instance, the environmental risks that can be mitigated (air pollution, noise, heat) are larger in megacities, than in smaller cities, less urban or rural places (Kumar et al., 2018; Molina et al., 2020; Rajulapati et al., 2022). The benefit of restoration that can produce green spaces against the stressors found in urban areas are larger (Hartig et al., 2014; Markevych et al., 2017), since those chronic stressors are larger in megacities (Bhugra et al., 2019; Pouya et al., 2016). In addition, the instoration ability of greenspace is higher in large urban areas, since the green spaces in urban areas are known to promote physical activity (Knobel et al., 2021) and social interactions (Adlakha et al., 2021).

Exposure to greenness was evaluated through Normalised Difference Vegetation Index (NDVI) at various buffer zones relative to children's residences. General urban planning practise, Mexican urban planning regulation and the mobility patterns of children residing in a megacity such as Mexico City should be considered when defining appropriate buffers sizes of greenness. This involves re-examining the paradigm of urban planning and areas of influence used in previous studies, with only buffer sizes up to a maximum of 500 m being used (Asta et al., 2021; Dadvand et al., 2015; Queiroz Almeida et al., 2021). In the case of children living in megacities, in developing countries, and in this study in Mexico specifically, the buffer sizes may be larger. In terms of urban planning of green spaces, frequently used local services/facilities should be within 400–1200 m of residences; whereas those used with medium frequency and require public or private transport should be within 1.6–4.8 km (Lotfi and Koohsari, 2009). Furthermore, Mexican regulations recommends that frequently used services/facilities, such as local playgrounds and gardens, ought to be within 350 m; whereas neighbourhood and urban parks should be within 670 m and 30 km, respectively (Secretaría de Desarrollo Social, 1992).

Conversely, (Barton et al., 2003), described actual distances walked within neighbourhoods to reach services/facilities or to socialize varies according to several factors, including age and fitness of individuals, the purpose of the journey, perceived pleasures and or dangers of the route, as well as weather conditions, among others. Urban planners have traditionally assumed that elderly and pre-schoolers walk approximately 5 min to reach distances that are 400 m away from their residences; whereas primary school children walk for 10 min and up to 800 m; and teenagers and adults walk for approximately 12 min over to a km, within their urban environment (Azmi et al., 2012; Barton et al., 2003). However, a British survey conducted in 2015, reported that for 80% of journeys travelling distances less than 1.6 km were made, and 26% of journeys between 1.6 and 3.0 km were made on foot (Mitchell and Bendixson, 2015). This is consistent with other reports that walking distances farther than 400 m were common; and even walking distances up to 1500 m have been reported in the USA (McCormack et al., 2008; Y. Yang and Diez-Roux, 2012). Therefore, population walking distances may well differ from those used by urban planners, highlighting the need to include larger buffer zones to evaluate exposure to greenness for urban dwellers.

Walking distances are also very much dependent on route security, which is an important consideration in urban planning (Barton et al., 2003). Gülgönen and Corona (2019) reported that parents and children living in Mexico City acknowledged safety concerns is a major problem that prevent children from enjoying the immediate public spaces. This is consistent with findings from a Council of Global Development Evaluation of Mexico City survey which reported that 75% of parents do not allow their children to go out on their own (Damián González et al., 2020). Likewise, a recent study reported that only 1.5% of the walking trips undertaken in Mexico City were by individuals less than 18 years old for recreational purposes, and consistent with other Latin-American megacities (Delclòs-Alió et al., 2022). Hence, children in Mexico City do not usually play or walk outside alone, and their mobility depends fundamentally on their parents or other responsible adults. Therefore, the immediate environment and nearby parks may not be the only green space available for children living in Mexico City, i.e., they may travel longer distances to enjoy greenspaces, and this necessitates transportation. In fact, a study conducted in Merida, another Mexican city, reported that some families use parks located at distances greater than those within walking or cycling distances (1200 m), but readily reachable by the widespread use of automobiles (Pérez Medina and Fargher, 2016). However, this dependence on automobile access, and finding time to travel further to enjoy public green spaces, means that many children are unable to do so (Gülgönen and Corona, 2019).

Another aspect to be considered is that, according to the report "Mexico City 2020. A diagnosis of socio-territorial inequality", approximately 2–18% of children have to travel to other neighbourhoods to attend their primary school (Damián González et al., 2020). In addition, the Mexican National Institute of Statistic and Geography reported that 42% of the school commute journeys were by foot, whilst 68% were by an automobile. Similarly, 40% of these journeys were less than 15 min long; whilst 29% were 15–30 min; 19%, 30–60 min, and 12% 60 min in duration (Instituto Nacional de Estadística y Geografía (INEGI), 2018). Therefore, the green spaces surrounding a child's home is unlikely to be the only green space that the child has regular access to. With children travelling longer distances to attend school, safety concerns regarding the immediate residential area, many families travelling some distance to enjoy green spaces, many walk further than the 400 m assumed by urban planners, larger buffer areas than those traditionally used in studies from developed countries are required to evaluate exposure to green spaces for children residing in Mexico City.

Importantly, modifiable risk factors need to be identified that can improve cognitive development in pre-puberty, a critical window in brain development. However, evidence assessing the associations between greenness and cognitive performance in pre-pubertal children is scarce, with a few studies from high-income cities. In this study, we will investigate the associations between exposure to green spaces and cognitive development in pre-pubertal children living in Mexico City, a megacity in a low- and middle-income country. We used buffers of 300, 500, 1500, 2000, and 3000 m from the children's residences, selected according to urban green spaces distribution in Mexico City (Mayen Huerta, 2022), and appropriate for children mobility patterns in a megacity.

2. Materials and methods

2.1. Subject recruitment

This is a cross-sectional study using data of 190 boys aged 6–11 years old, living in the urban area of Mexico City in 2017–2019, participating in the "Predicting Metabolic Risk and Correlations with Cognitive Function in Mexican Pre-pubertal Children" (MetCog) study, which focused only on boys as child development differs temporally between sexes. Children were recruited from three local schools with a mixture of private and state education from middle-class neighbourhoods as well as adverts posted in local newspapers and clinics in the Hospital Infantil de México Federico Gómez, Mexico City, and enrolled as the project progressed. Children enrolled from the hospital included siblings of patients of the hospital, as well as children from healthcare practitioners and clerical and services staff, representative of low- and middle-income families. Inclusion criteria: male, Tanner pubertal development Stage I (Emmanuel and Bokor, 2022), ability to breath hold for 10–15s while supine (for imaging, not reported in this study). Exclusion criteria: having metabolic or liver disease, metabolite profile-altering medication e.g. metformin, infections, psychiatric or neurological disorders e.g., depression; metallic implants that are imaging-contraindicated or being claustrophobic.

Some MetCog study participants were excluded from the current study because (1) information on their residential addresses was not available (n = 37) and (2) cognitive performance scores were missing (n = 9). Final data includes 144 pre-pubertal boys (6–11 years) living in Mexico City in 2017–2019.

2.2. Research ethics

The investigation was conducted according to the Declaration of Helsinki (2013). The study received ethical approval from the King's College London Psychiatry, Nursing and Midwifery Research Ethics Subcommittee (RESCM-18/19–4156) and from Hospital Infantil de México Federico Gómez (HIM/2016/105, SSA-1369). All children gave their written informed assent, and their legal guardians/caregivers also gave written informed consent for the children to undertake the study.

2.3. Assessment of cognitive performance

Children underwent cognitive testing from (November 13, 2017 to January 14, 2019). Cognitive performance was assessed through selected tests of the Wechsler Scale for Intelligence in Children Fourth Edition (WISC-IV) (Wechsler, 2003) and the Neuropsychological Assessment of Children (Evaluación Neuropsicológica Infantil, ENI), adapted for Spanish-speaking population (Matute et al., 2014).

Tests were selected after careful considerations, including time required to perform the tests, which should be suitable for the population under study, and whether these were validated and standardized for Mexican people. Taking into account these considerations, the principal cognitive testing tool was WISC-IV and tests were selected following recommendations of (Crawford et al., 2010; Dasi et al., 2014; White et al., 2009). WISC-IV provides a score ranging from 40 to 160, which can then be categorized in 7 classifications from extremely low (≤69), to extremely high (≥130), in intervals of 10. Individual WISC-IV test scores are described in Abdelhamid et al. (2021). Moreover, as cognition was an important readout in the study, the selected WISC-IV test were supplemented with complementary cognitive tests from ENI. ENI is well-known to the consultant psychologist of the study, is popular for a Mexican population, and tasks are of short duration. ENI scores depend on the specific task, and range between 8, e.g. for the verbal auditory recognition task, and 48, e.g. for the Coding List task (Matute et al., 2014). Cognitive tests were applied by a certified/professional psychologist. Tests were performed after imaging (not reported here) and having had breakfast. The tests lasted almost 3 h, with occasional breaks. The room in which the tests were performed was brightly lit and in complete silence, and the parents were not present during the testing.

In this study, we used the individual scores from the selected WISC-IV tests to assess comprehension (similarities and vocabulary tests), perceptual reasoning (block design and matrix reasoning tests), working memory (digit span and letter-number sequencing tests) and processing speed (coding and symbol search test). The selected ENI tasks assessed the following domains: construction skills (figure copying and complex figure tasks), memory by coding (word coding list task), memory by deferred evocation (spontaneous recovery word list, clues recovery, and verbal auditory recognition tasks), and executive function (number trials, correct percentage answer, number categories, poor organization, and perseverance tasks). Higher test scores for both WISC-IV tests and ENI tasks indicated better cognitive performance.

2.4. Assessment of greenness

Greenness in Mexico City was assessed through the mean NDVI score derived from satellite images obtained from the Moderate-Resolution Imaging Spectroradiometer (MODIS) on board the Terra satellite (Vegetation Indices 16-Day L3 Global 250 m, Terra Prod ID/DAAC Link MOD13Q1) (Didan, 2015). NDVI is a dimensionless index that describes the difference between visible and near-infrared reflectance of vegetation cover to estimate the density of green in an area (Weier and Herring, 2000), ranging from −1 to 1, with higher values indicating more greenness. Day-only satellite images showing NDVI at 250 m resolution for Mexico City (sector h08) over a 16-day period were examined from December 19, 2017 to January 3, 2019. The satellite image corresponding to the period with the highest NDVI values with least cloud cover, and lowest missing data for Mexico City was selected, i.e., 14th to the September 29, 2018, following a similar approach to that used in previous studies in Rome (Asta et al., 2021) and Barcelona (Dadvand et al., 2015). For each child, the NDVI was calculated in buffers of 300, 500, 1500, 2000, and 3000 m around their residential address.

2.5. Assessment of cohort characteristics

A comprehensive questionnaire was completed by each child's legal or guardian to assess demographic, socioeconomic, lifestyle and health status for each child. Weight and height measurements were recorded (SECA® directprint 284 scale stadiometer) and Body-Mass-Index (BMI) was calculated as weight (kg) divided by height squared (m^2). BMI was also categorized using (Centers for Disease Control and Prevention, 2020) percentiles: normal weight, 5th to < 84th; overweight 85th to < 95th; and obese ≥95th. Legal guardians provided socio-economic information through questionnaires including their age, highest academic level achieved and number of years after finishing education, type of employment and whether permanent or temporary employment. Information on family circumstances was also gathered: marital status, who acts as the family head, and availability of childcare. Residential information collected included source of drinking water, number of rooms and bedrooms in the house, number of people living in the house, how many people shared the child's bedroom, and house ownership.

Moreover, neighbourhood socioeconomic status in 2020 was included using the Percentage of the Population at Risk of Poverty by municipality. This was calculated for each municipality from where participants were recruited by dividing the Population in Poverty (numerator) by the Total Population (denominator) in the municipality to which the participant belongs, and multiplied by 100%. The Total Population and Population at Risk of Poverty per neighbourhood was obtained from the "Annual Report of the situation of poverty and social backwardness 2022" (in Spanish "Informe anual sobre la situación de pobreza y rezago social 2022" by the General Directorate of Planning and Analysis of the Welfare Secretariat of the Mexican Government (Secretaría de Bienestar del Gobierno de México, 2022). Total Population per neighbourhood was obtained from the "2020 Population and Housing Census, Main results by locality" (in Spanish, "Censo de Población y Vivienda, 2020; Principales resultados por localidad) (INEGI, 2020). The Population in a Situation of Poverty comprises the sum of the populations in extreme poverty and in moderate poverty and were obtained from the "2020 Multidimensional Measurement of Poverty report" (in Spanish, "Medición Multidimensional de la Pobreza, 2020) (Consejo Nacional de Evaluación de la Política de Desarrollo Social, 2020). This calculation is exemplified for one of the municipalities in the Supplementary Material.

2.6. Statistical approach

We described cognitive performance variables and cohort characteristics using absolute frequency and percentage for categorical variables, and mean and standard deviation (SD) for continuous variables, since the properties of the continuous variables and the sample size were appropriate to assume normality (Table S1). Minimum, maximum, first and third quartiles, median, Interquartile Range (IQR: difference between third and first quartile), mean, and SD of NDVI average were calculated for each buffer. Linear regression assumptions (linearity, normality of residuals, collinearity, heteroscedasticity, and outliers) were tested. Adjusted multiple linear regression analysis (RStudio version 4.0.3) according to confounding variables was conducted to determine the association of NDVI with WISC-IV tests and ENI tasks scores. Adjusted multiple linear regression coefficients (aβ) with corresponding 95% confidence intervals (CI) were estimated for each increase in IQR NDVI for different buffer distances.

Multiple linear regression analysis was adjusted for potential confounders: age of children (in years); BMI status categorized according to the CDC criteria (CDC, 2020) (3 categories: normal weight, overweight, and obese); family figure head (4 categories: mother, father, both parents, and or another relatives); maternal and paternal age in years, maternal and paternal academic achievement (4 categories: primary, secondary, professional training, and university); marital status (4 categories: married, single, co-habiting, and divorced/widowed), number of individuals sharing the child's bedroom (4 categories: 1–2, 3, 4, +5); house ownership (3 categories: own, rent, and other ownership) and the percentage of the population at risk of poverty by municipality in 2020. The variables included in the adjustment of the models were selected using expert judgment and were based on variables included in previous studies (Asta et al., 2021; Dadvand et al., 2015; Queiroz Almeida et al., 2021) and those available in the MetCog database. These variables were included in a directed acyclic graph as shown in Figure S1.

Significance was set to be $p < 0.05$. However, due to multiple testing across five variables representing greenness (i.e. NDVI average across 5 buffers), we controlled for the False-Discovery Rate (FDR) using the q-value (Storey and Tibshirani, 2003) (Table S2) with significance set to q-value <0.05.

3. Results

3.1. Cohort characteristics and socioeconomic status

The cohort (n = 144) were aged 8.7 (SD: 1.2) years old with 45.1%, 9.8% and 45.1%, being normal or overweight, or obese, respectively. Socioeconomics factors regarding the cohort are detailed in Table 1. The distance between participants was also calculated and 22% of the participants live within 250 m from each other, whereas the other 78% live at more than 250 m distance, with 51% living more than 1 km from each other.

3.2. Cognitive performance

Scores for the individual WISC-IV and ENI cognitive tests are shown in Table 1, and ranged from 9.0 (SD: 2.6) for the ENI number trials task to 11.3 (SD: 3.0) for the WISC-IV vocabulary test. Note, for all tests higher scores relate to better cognitive performance.

3.3. Greenness

The median, mean, minimum, maximum, first and third quartiles, and IQR of the NDVI for different buffers were calculated (Fig. 1 and Table S1). The m edian of the NDVI ranges from 0.217 (IQR: 0.133) at 300 m to 0.318 (IQR: 0.191) at 3000 m from children's residences (Fig. 1 and Table S1).

3.4. Relationship between individual cognitive tests and greenness

Positive associations between NDVI IQR at 1500 and 2000 m with block design scores ($a\beta_{1500} = 1.00$, 95% CI = 0.14, 1.86 and $a\beta_{2000} = 1.18$, 95% CI = 0.31, 2.06, respectively) was observed at p-value < 0.05 (Table 2, Fig. 2). In addition, adjusted positive associations were also found between an IQR increase in NDVI at 1500 m with matrix reasoning scores, another perceptual reasoning domain assessment ($a\beta_{1500} = 0.83$, 95% CI = 0.06, 1.61) at the p-value < 0.05 (Table S2, Fig. 3). However, only perceptual reasoning assessed by block design within a buffer size of 2000 m was significantly associated with greenness after FDR correction (Table 2).

Associations between NDVI IQR and other WISC-IV cognitive tasks (Table 2) or ENI tests were not significant (Table S2).

4. Discussion

The current study was conducted in 144 Mexican pre-pubertal boys and showed that greater exposure to green spaces within 2000 m of their home were more likely to be related to better scores on perceptual reasoning skills. This association was also suggested to occur at smaller distances (1500 m), but significance was not maintained after FDR correction. No association was observed across the other cognitive function domains assessed, nor for the smaller (300 m and 500 m) or larger buffer sizes (3000 m).

Exposure to more green spaces (as measured by NDVI) was associated with greater perceptual reasoning in Mexican boys aged 6–11 years, assessed by WISC-IV block design test. While an association was observed between another perceptual reasoning test, the WISC-IV matrix reasoning test, significance was not maintained after FDR correction. Perceptual reasoning is the ability to take in visual information, organize and interpret the information to solve problems and requires nonverbal reasoning (Practical Psychology, 2022). Perceptual reasoning relies on the way that information is perceived and incorporated into thought processes (Kellman and Garrigan, 2009). It involves solving problems that cannot be taught (Dowell and Mahone, 2011), but instead is enhanced through experience (Dowell and Mahone, 2011). Therefore, our study suggests that access to green spaces allows children to learn through experimentation/experiencing nature to develop and enhance their perceptual reasoning skills, since nature allows children to play unorganised, stimulating children to explore the environment (De Keijzer, 2020). In addition, evidence suggest that green spaces motivates children being more active (Markevych et al., 2017), and physical activity benefits cognition by increasing oxygen supply to the brain, helping stimulation of the maturation on the motor areas in the brain, and stimulating the increase of neurohormonal secretion (Bidzan-Bluma and Lipowska, 2018). Likewise, time spent in green environments reduces mental fatigue and improves concentrations, according to the Attention Restoration Theory (Kaplan and Berman, 2010; Ohly et al., 2016). Exposure to green spaces has also been associated with better performance and development in the areas of concentration (Taylor et al., 2002), working memory and attention (Bratman et al., 2015; Dadvand et al., 2015; Taylor et al., 2002). Therefore, the more concentration and attention, the more working memory and the less mental fatigue, the easier it becomes to interpret visual information to solve problems, as required in perceptual reasoning. Another possibly biological mechanism underlying the effects observed might be associated with the Stress reduction theory, for which nature scenes reduce our stress levels and autonomic arousal, as from an evolutionary aspect, these are perceived as safe and plentiful spaces helping our subsistence (Ulrich, 1983). Stress has been associated with poorer working memory and executive function (McManus et al., 2022). Therefore, the less stress levels through experimenting nature, the better working memory and executive function abilities required for problem solving in perceptual reasoning.

An association between nonverbal reasoning and greenness has been previously reported in a study with a children cohort from Massachusetts (USA), part of the Viva project (Jimenez et al., 2022). In the Viva study, early childhood exposure to greenness was associated with a 0.48% increase in nonverbal intelligence, although at a closer buffer of 90 m compared to 2000 m in our study. On the contrary, no association was observed in a longitudinal Roman study with children enrolled at birth from two large obstetric hospitals in Rome between surrounding residential greenness measured at 300 m or 500 m, through NDVI, with the Perceptual Organization Index, which is a measure of nonverbal reasoning (Asta et al., 2021). No such comparisons could be made with the Portuguese study published in 2021 with data from children living in the Porto metropolitan area, who are part of the Generation XXI birth cohort (Queiroz Almeida et al., 2021) or 2015 study of a cohort of

Table 1
Descriptors of Weschler Intelligence Scale for Children fourth version (WISC-IV) scores, Neuropsychological Assessment of Children (ENI) scores and cohort characteristics, overall and stratified by NDVI quartiles, for 144 pre-pubertal Mexican boys in 2017–2019 included in the MetCog cohort. Note that higher cognitive scores relate to better cognition.

NDVI		300 m				500 m			
	Overall	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max
Similarities WISC-IV test[a]	9.8 (3.7)	10.2 (3.7)	10.4 (4.1)	9.3 (3.9)	8.9 (3.3)	9.3 (3.6)	9.1 (3.3)	11.7 (4.2)	9.2 (3.7)
Vocabulay WISC-IV test[a]	11.3 (3)	11.4 (3.5)	11.5 (2.9)	11.1 (2.9)	11.1 (2.1)	11.6 (3)	10.3 (2.5)	12 (3.4)	11.1 (2.9)
Block Design WISC-IV test[a] **(0,48–66)**	10.8 (3.4)	11 (3.6)	11.6 (3.9)	10 (2.9)	10.3 (3.1)	9.8 (2.6)	10.9 (3.1)	11.7 (3.8)	10.7 (3.4)
Matix Reasoning WISC-IV test[a]	9.9 (2.7)	10.1 (3.4)	9.7 (2.4)	9.9 (2.9)	9.4 (2.3)	9.3 (2.7)	9 (2.3)	11.1 (2.5)	10.4 (3.1)
Digit Span WISC-IV test[a] **(0,1)**	9.1 (2)	9.6 (2.4)	9.5 (2)	8.7 (1.9)	8.2 (1.7)	8.6 (1.9)	9 (2)	9.6 (2.1)	9.4 (1.9)
Letter Number Sequencing[a]	9.8 (2.4)	10.1 (2.7)	10.5 (2.1)	9.3 (2.8)	9.4 (2.2)	9.9 (2.1)	9.8 (2.5)	10.6 (2.4)	9.4 (2.4)
Coding WISC-IV test[a]	9.6 (2.6)	9.6 (2.9)	10.4 (2.4)	9.6 (2.4)	9.1 (2.2)	9.6 (2.4)	9 (2.6)	10 (2.8)	9.9 (2.3)
Symbol Search WISC-IV test[a]	10.4 (2.3)	10.4 (2.2)	10.8 (2.2)	10.2 (2.4)	10.1 (2.6)	10.4 (1.9)	9.9 (2.1)	10.6 (2.8)	10.2 (2.5)
Figure Copying ENI task[a]	10 (2.2)	9.8 (2.5)	9.9 (2.1)	9.7 (2.2)	9.6 (2.2)	9.7 (2.5)	9.5 (1.9)	10.6 (2.1)	10.3 (2.4)
Complex Figure Recovery ENI task[a]	11.1 (1.9)	11 (1.8)	11.5 (2.2)	10.4 (2.1)	10.9 (1.7)	10.8 (2.1)	11.3 (1.8)	11.6 (1.9)	10.8 (2)
Coding List ENI task[a]	10.3 (2.7)	10 (2.7)	11.7 (2.3)	10.2 (3)	9.7 (2.2)	10.4 (2.7)	9.7 (3.2)	10.4 (2.5)	10.2 (2.6)
Spontaneous Recovery Word List ENI task[a]	10.9 (2.3)	10.4 (2.2)	11.5 (2.1)	10.9 (2.4)	11.1 (2.3)	11.3 (2.4)	10.3 (2.5)	10.8 (2.5)	11 (1.8)
Clues Recovery ENI task[a]	10.4 (2.5)	9.7 (2)	11.5 (2.2)	9.9 (3.5)	10.1 (2.4)	10.9 (2.4)	9.9 (2.4)	9.8 (3.4)	10.5 (1.8)
Verbal Auditory Recognition ENI task[a]	10.5 (1.6)	10.3 (1.6)	11 (0.8)	10.6 (1.5)	10.5 (1.3)	10.8 (0.9)	10 (2.2)	10.4 (1.9)	10.6 (1.1)
Number Trials[a]	9 (2.6)	8.6 (2.6)	9.6 (3.1)	8.9 (2.5)	8.7 (2.4)	8.8 (2.2)	9.2 (3.1)	8.8 (2.8)	8.9 (2.4)
Correct Answer Percentage[a]	9.4 (2.9)	9 (2.6)	10.1 (2.7)	9.3 (3.1)	9.1 (3.3)	9.7 (2.2)	9.2 (3)	9.2 (3.3)	9.8 (2.8)
Number Categories[a]	10.5 (2.7)	9.8 (3)	11.1 (1.9)	10.4 (2.8)	10.2 (3.2)	10.8 (2.5)	10.6 (2.6)	10.2 (2.7)	10.7 (2.5)
Poor Organization[a]	10.2 (2.7)	9.8 (2.9)	10.5 (2.4)	9.5 (3.3)	10.6 (2.2)	10.3 (2.7)	9.8 (2.9)	10.3 (2.5)	10.1 (3)
Perseverance[a]	10.9 (2.5)	10.9 (2.6)	11.8 (1.8)	10.9 (2.1)	10.4 (2.8)	11.3 (1.8)	10.6 (2.7)	10.9 (3.4)	10.9 (2)
Child's age in years[a]	8.7 (1.2)	8.9 (1)	8.9 (1.4)	8.8 (1.1)	8.4 (1)	8.6 (1.2)	8.8 (1)	9 (1)	8.8 (1.3)
Mother's age in years[a]	35.7 (6.2)	35 (5.5)	36.5 (6.8)	36.6 (5.8)	34.6 (6.4)	35.8 (6)	34.7 (6.4)	36.4 (6.7)	36.6 (5.4)
Father's age in years[a]	37.8 (7)	36.6 (6)	38.7 (6.8)	37.8 (7.1)	37.4 (7.7)	39.4 (6.7)	36.7 (7)	38.5 (8.6)	37.8 (5.6)
Mother's number in years of last education level[a]	3.3 (1.2)	3.2 (1.4)	3.2 (0.9)	3.1 (1.1)	3.5 (0.9)	3.2 (0.8)	3.3 (1.3)	3.5 (1.5)	3 (1)
Father's number in years of last education level[a]	3.4 (1.3)	3.4 (2.1)	3.1 (0.8)	3.6 (1.2)	3.1 (0.7)	3.2 (0.6)	3.2 (1.2)	3.6 (2.1)	3.3 (1)
Percentage of the population at risk of poverty by municipality in 2020[a]	39.7 (11.7)	38 (11.4)	38.8 (10.1)	41.1 (11.8)	36.2 (10)	37.3 (13)	36.2 (11)	40.1 (10.6)	46 (11.1)
Child's Body Mass Index (BMI) goups[b]									
Normal weight	65 (45.1)	12 (40)	10 (32.3)	12 (40)	19 (61.3)	12 (36.4)	13 (39.4)	15 (45.5)	16 (48.5)
Overweight	14 (9.7)	1 (3.3)	5 (16.1)	5 (16.7)	1 (3.2)	4 (12.1)	4 (12.1)	2 (6.1)	3 (9.1)
Obese	65 (45.1)	17 (56.7)	16 (51.6)	13 (43.3)	11 (35.5)	17 (51.5)	16 (48.5)	16 (48.5)	14 (42.4)
Mother's highest academic level[b]									
Primary	10 (7)	1 (3.3)	1 (3.2)	3 (10.3)	3 (10)	2 (6.1)	1 (3.1)	3 (9.1)	2 (6.2)
Secondary	72 (50.7)	19 (63.3)	16 (51.6)	11 (37.9)	16 (53.3)	18 (54.5)	15 (46.9)	13 (39.4)	20 (62.5)
Professional training	55 (38.7)	9 (30)	14 (45.2)	13 (44.8)	10 (33.3)	12 (36.4)	15 (46.9)	16 (48.5)	8 (25)
University	5 (3.5)	1 (3.3)	0 (0)	2 (6.9)	1 (3.3)	1 (3)	1 (3.1)	1 (3)	2 (6.2)
Father's highest ac ademic level[b]									
Primary	7 (5.3)	1 (3.7)	0 (0)	4 (16.7)	1 (3.4)	0 (0)	1 (3.4)	2 (6.7)	3 (9.7)
Secondary	85 (64.9)	16 (59.3)	21 (72.4)	15 (62.5)	23 (79.3)	19 (65.5)	25 (86.2)	15 (50)	18 (58.1)
Professional training	33 (25.2)	8 (29.6)	7 (24.1)	5 (20.8)	4 (13.8)	9 (31)	3 (10.3)	9 (30)	9 (29)
University	6 (4.6)	2 (7.4)	1 (3.4)	0 (0)	1 (3.4)	1 (3.4)	0 (0)	4 (13.3)	1 (3.2)
Mother's employment[b]									
Home	66 (47.5)	19 (63.3)	14 (45.2)	9 (32.1)	16 (57.1)	16 (50)	18 (56.2)	16 (50)	12 (38.7)
Services	12 (8.6)	3 (10)	2 (6.5)	1 (3.6)	4 (14.3)	2 (6.2)	2 (6.2)	2 (6.2)	4 (12.9)
Factory or Retail Employee	17 (12.2)	4 (13.3)	3 (9.7)	3 (10.7)	3 (10.7)	5 (15.6)	4 (12.5)	3 (9.4)	4 (12.9)
Office Worker	19 (13.7)	1 (3.3)	5 (16.1)	7 (25)	1 (3.6)	4 (12.5)	1 (3.1)	7 (21.9)	5 (16.1)
Professional	25 (18)	3 (10)	7 (22.6)	8 (28.6)	4 (14.3)	5 (15.6)	7 (21.9)	4 (12.5)	6 (19.4)

(*continued on next page*)

Table 1 (*continued*)

NDVI		300 m				500 m			
	Overall	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max
Father's employment[b]									
Services	42 (33.1)	9 (34.6)	10 (35.7)	8 (36.4)	9 (31)	8 (28.6)	12 (44.4)	8 (26.7)	11 (36.7)
Factory or Retail Employee	29 (22.8)	7 (26.9)	5 (17.9)	3 (13.6)	11 (37.9)	5 (17.9)	7 (25.9)	6 (20)	7 (23.3)
Office Worker	24 (18.9)	2 (7.7)	9 (32.1)	5 (22.7)	2 (6.9)	5 (17.9)	3 (11.1)	9 (30)	5 (16.7)
Professional	28 (22)	8 (30.8)	4 (14.3)	5 (22.7)	5 (17.2)	8 (28.6)	3 (11.1)	7 (23.3)	7 (23.3)
Retired, unemployed, others	4 (3.1)	0 (0)	0 (0)	1 (4.5)	2 (6.9)	2 (7.1)	2 (7.4)	0 (0)	0 (0)
Mother's employment security[b]									
Permanent	55 (41)	8 (28.6)	15 (50)	16 (59.3)	10 (37)	14 (46.7)	9 (28.1)	11 (34.4)	15 (51.7)
Temporary	28 (20.9)	7 (25)	3 (10)	4 (14.8)	7 (25.9)	7 (23.3)	8 (25)	6 (18.8)	6 (20.7)
No security	51 (38.1)	13 (46.4)	12 (40)	7 (25.9)	10 (37)	9 (30)	15 (46.9)	15 (46.9)	8 (27.6)
Father's employment security[b]									
Permanent	98 (77.2)	20 (80)	25 (86.2)	16 (69.6)	23 (82.1)	21 (75)	21 (75)	22 (73.3)	24 (82.8)
Temporary	25 (19.7)	5 (20)	4 (13.8)	6 (26.1)	4 (14.3)	5 (17.9)	6 (21.4)	7 (23.3)	5 (17.2)
No security	4 (3.1)	0 (0)	0 (0)	1 (4.3)	1 (3.6)	2 (7.1)	1 (3.6)	1 (3.3)	0 (0)
The family heads[b]									
Mother	23 (16.7)	7 (23.3)	4 (13.8)	6 (22.2)	3 (10)	6 (18.8)	6 (20)	5 (15.2)	4 (12.9)
Father	77 (55.8)	19 (63.3)	14 (48.3)	11 (40.7)	21 (70)	16 (50)	16 (53.3)	23 (69.7)	15 (48.4)
Both parents	8 (5.8)	1 (3.3)	2 (6.9)	0 (0)	2 (6.7)	2 (6.2)	2 (6.7)	2 (6.1)	2 (6.5)
Other family members	30 (21.7)	3 (10)	9 (31)	10 (37)	4 (13.3)	8 (25)	6 (20)	3 (9.1)	10 (32.3)
Maternal marital status[b]									
Single	28 (19.7)	5 (16.7)	5 (16.1)	8 (27.6)	7 (23.3)	7 (21.2)	6 (18.8)	6 (18.2)	7 (21.9)
Married	77 (54.2)	15 (50)	17 (54.8)	17 (58.6)	14 (46.7)	17 (51.5)	18 (56.2)	17 (51.5)	18 (56.2)
Cohabiting	31 (21.8)	8 (26.7)	7 (22.6)	3 (10.3)	8 (26.7)	8 (24.2)	4 (12.5)	9 (27.3)	7 (21.9)
Divorced/Widow	6 (4.2)	2 (6.7)	2 (6.5)	1 (3.4)	1 (3.3)	1 (3)	4 (12.5)	1 (3)	0 (0)
Availability of childcare[b]									
No one	23 (16.2)	5 (16.7)	6 (19.4)	3 (10.3)	5 (16.7)	4 (12.1)	4 (12.5)	10 (30.3)	4 (12.5)
Dad	61 (43)	13 (43.3)	12 (38.7)	17 (58.6)	12 (40)	10 (30.3)	17 (53.1)	13 (39.4)	16 (50)
Grandparents	44 (31)	8 (26.7)	11 (35.5)	9 (31)	10 (33.3)	13 (39.4)	10 (31.2)	8 (24.2)	8 (25)
Uncles	9 (6.3)	3 (10)	1 (3.2)	0 (0)	2 (6.7)	5 (15.2)	0 (0)	2 (6.1)	1 (3.1)
Employee	2 (1.4)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (6.2)
Other	3 (2.1)	1 (3.3)	1 (3.2)	0 (0)	1 (3.3)	1 (3)	1 (3.1)	0 (0)	1 (3.1)
Residence ownership[b]									
Own	45 (33.6)	8 (29.6)	10 (33.3)	11 (42.3)	8 (26.7)	9 (28.1)	7 (24.1)	14 (45.2)	11 (35.5)
Rent	36 (26.9)	8 (29.6)	8 (26.7)	5 (19.2)	9 (30)	7 (21.9)	10 (34.5)	8 (25.8)	8 (25.8)
Others house ownership	53 (39.6)	11 (40.7)	12 (40)	10 (38.5)	13 (43.3)	16 (50)	12 (41.4)	9 (29)	12 (38.7)
Availability of drinking water[b]									
In the house	112 (78.9)	19 (63.3)	27 (87.1)	25 (86.2)	23 (76.7)	25 (75.8)	26 (81.2)	24 (72.7)	28 (87.5)
Shared with neighbours	13 (9.2)	6 (20)	0 (0)	3 (10.3)	3 (10)	3 (9.1)	3 (9.4)	3 (9.1)	2 (6.2)
Public fountain	6 (4.2)	2 (6.7)	1 (3.2)	1 (3.4)	1 (3.3)	2 (6.1)	2 (6.2)	1 (3)	1 (3.1)
Others water source	11 (7.7)	3 (10)	3 (9.7)	0 (0)	3 (10)	3 (9.1)	1 (3.1)	5 (15.2)	1 (3.1)
Number of rooms in the residence[b]									
1-2 rooms	58 (41.1)	13 (43.3)	12 (38.7)	10 (35.7)	16 (53.3)	14 (42.4)	11 (35.5)	16 (48.5)	12 (37.5)
3 rooms	42 (29.8)	8 (26.7)	8 (25.8)	11 (39.3)	9 (30)	10 (30.3)	11 (35.5)	5 (15.2)	9 (28.1)
4 rooms	19 (13.5)	5 (16.7)	3 (9.7)	6 (21.4)	2 (6.7)	3 (9.1)	4 (12.9)	7 (21.2)	5 (15.6)
+5 rooms	22 (15.6)	4 (13.3)	8 (25.8)	1 (3.6)	3 (10)	6 (18.2)	5 (16.1)	5 (15.2)	6 (18.8)
Number of bedrooms in the residence[b]									
1 rooms	24 (17)	3 (10)	5 (16.1)	6 (21.4)	6 (20)	4 (12.1)	6 (18.8)	6 (18.2)	4 (12.9)
2 rooms	68 (48.2)	12 (40)	13 (41.9)	17 (60.7)	17 (56.7)	19 (57.6)	14 (43.8)	13 (39.4)	15 (48.4)
3 rooms	25 (17.7)	5 (16.7)	8 (25.8)	3 (10.7)	4 (13.3)	3 (9.1)	7 (21.9)	8 (24.2)	7 (22.6)
4 rooms	15 (10.6)	4 (13.3)	5 (16.1)	2 (7.1)	3 (10)	4 (12.1)	4 (12.5)	4 (12.1)	3 (9.7)
+5 rooms	9 (6.4)	6 (20)	0 (0)	0 (0)	0 (0)	3 (9.1)	1 (3.1)	2 (6.1)	2 (6.5)
Number of individuals sharing the participant's bedroom[b]									
0 people	11 (7.9)	3 (10)	4 (12.9)	4 (14.8)	0 (0)	0 (0)	8 (25.8)	0 (0)	3 (9.7)
1 people	30 (21.4)	3 (10)	7 (22.6)	7 (25.9)	9 (30)	6 (18.2)	4 (12.9)	10 (30.3)	6 (19.4)
2 people	57 (40.7)	12 (40)	13 (41.9)	11 (40.7)	11 (36.7)	13 (39.4)	11 (35.5)	11 (33.3)	16 (51.6)
3 people	17 (12.1)	5 (16.7)	4 (12.9)	1 (3.7)	3 (10)	4 (12.1)	2 (6.5)	8 (24.2)	3 (9.7)

(*continued on next page*)

Table 1 (*continued*)

NDVI		300 m				500 m			
	Overall	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max
+4 people	25 (17.9)	7 (23.3)	3 (9.7)	4 (14.8)	7 (23.3)	10 (30.3)	6 (19.4)	4 (12.1)	3 (9.7)

NDVI	1500 m				2000 m				3000 m			
	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max
Similarities WISC-IV test[a]	8.9 (3.5)	10.7 (4.2)	10.6 (3.3)	9.4 (3.7)	8.8 (3.4)	10.3 (4.4)	10.8 (3.3)	9.8 (3.8)	10 (4.1)	9.8 (3.6)	9.5 (2.4)	8.4 (4.1)
Vocabulay WISC-IV test[a]	11.2 (3.2)	11.6 (3.1)	11.2 (2.9)	11 (3)	11.4 (3.3)	11.4 (2.7)	11.6 (3.3)	10.8 (2.8)	11.2 (3)	11.4 (3)	11.1 (2.4)	11.2 (1.7)
Block Design WISC-IV test[a]	10.1 (2.1)	11 (4)	11.2 (3.4)	10.8 (3.3)	10.2 (2.4)	10.7 (4.1)	11.3 (2.8)	10.8 (3.6)	10.8 (3.6)	10.1 (3)	11 (3.4)	10 (2.9)
Matix Reasoning WISC-IV test[a]	9.3 (3)	9.8 (2.5)	10.7 (2.4)	10.1 (3)	9.2 (3.1)	10 (1.9)	10.8 (2.6)	9.9 (3)	9.8 (2.8)	9.7 (2.6)	10.1 (2.2)	8.5 (1.9)
Digit Span WISC-IV test[a]	8.5 (1.9)	9.7 (2.1)	9.4 (2.1)	9.2 (2)	8.3 (1.9)	9.5 (1.9)	9.6 (2.3)	9.3 (2)	9.2 (1.9)	9.1 (1.9)	8.1 (2.1)	8.4 (1.4)
Letter Number Sequencing[a]	9.4 (2.5)	10.5 (2.3)	10.2 (2.2)	9.4 (2.5)	9.9 (2.3)	10.1 (2.3)	10.3 (2.4)	9.5 (2.5)	10 (2.2)	9.5 (3.1)	9.2 (2.2)	9.7 (2.1)
Coding WISC-IV test[a]	8.7 (2.3)	10 (2.6)	10.1 (2.5)	9.4 (2.7)	8.5 (2)	10.2 (2)	10.1 (3)	9.3 (2.7)	9.7 (2.2)	9.7 (2.8)	8.9 (2.7)	9.5 (1.6)
Symbol Search WISC-IV test[a]	10.4 (1.8)	10.3 (2.3)	10.7 (2.5)	10.1 (2.5)	10.4 (1.6)	10.1 (2.5)	10.4 (2.4)	10.3 (2.5)	10.4 (2.1)	10.1 (2.6)	10.6 (2.5)	9.7 (2.9)
Figure Copying ENI task[a]	9.7 (2.3)	9.6 (2.2)	10.5 (2.1)	10.4 (2.2)	9.3 (2.2)	10.2 (2.4)	10.3 (2.2)	10.3 (2.1)	9.7 (2.2)	9.8 (2.2)	10 (2)	9 (2.2)
Complex Figure Recovery ENI task[a]	11.2 (2.2)	11.2 (2.1)	11.3 (1.7)	10.8 (1.9)	11 (2.1)	11.2 (1.9)	11.4 (2)	10.9 (1.8)	11 (2)	10.5 (2.2)	11.2 (1.8)	10.6 (1.8)
Coding List ENI task[a]	10.3 (3.1)	10.4 (2.4)	10.4 (2.4)	10 (3)	10 (3.1)	10.5 (2.6)	10.9 (1.9)	9.5 (3)	11 (2.8)	10.5 (2.4)	9.9 (2.5)	9.5 (2.2)
Spontaneous Recovery Word List ENI task[a]	11 (2.7)	10.7 (2)	11.1 (2.4)	10.8 (1.8)	10.8 (2.7)	11 (2.3)	10.6 (2.1)	11.1 (1.9)	11.2 (2.1)	10.9 (2.6)	11.4 (1.9)	10.6 (2.6)
Clues Recovery ENI task[a]	10.4 (3)	9.9 (2.1)	10.4 (3.1)	10.6 (1.9)	10.1 (2.8)	10.2 (2.4)	10 (3)	10.8 (1.9)	11 (2.2)	9.6 (3.7)	10 (3.1)	10.1 (1.9)
Verbal Auditory Recognition ENI task[a]	10.8 (1.1)	10.2 (1.6)	10.4 (1.7)	10.5 (2)	10.5 (1.6)	10.5 (1.3)	10.5 (1.6)	10.4 (2)	10.7 (1.3)	10.5 (1.7)	10.4 (0.9)	10.5 (1.7)
Number Trials[a]	8.9 (2.4)	8.3 (2.6)	9.5 (3.1)	9 (2.4)	9.2 (2.7)	8.8 (2.8)	8.6 (2.7)	9.2 (2.5)	9 (2.7)	9.1 (2.7)	8.6 (2.3)	8.6 (2.7)
Correct Answer Percentage[a]	9.5 (2.5)	8.7 (3)	9.5 (3.1)	9.9 (2.6)	9.8 (2.4)	8.7 (3.3)	9 (3.2)	10.2 (2.2)	9.4 (2.7)	9.4 (3.4)	9.4 (3.3)	8.6 (3.4)
Number Categories[a]	10.9 (2.2)	9.8 (3.2)	10.6 (2.5)	10.7 (2.4)	11.2 (1.5)	9.8 (3.5)	10 (3)	11.1 (1.8)	10.6 (2.5)	10.3 (3.1)	10.6 (3.1)	9.5 (3.6)
Poor Organization[a]	10 (2.8)	10.3 (2.3)	10.4 (2.5)	9.8 (3.4)	10.5 (2.2)	10.4 (2.1)	9.9 (2.8)	9.8 (3.4)	10.6 (2.2)	8.9 (3.7)	11.1 (1.8)	10 (2.6)
Perseverance[a]	11.3 (1.8)	10.6 (2.8)	10.3 (3.3)	11.3 (1.7)	11.5 (2)	10.8 (2.8)	10.1 (3.2)	11.3 (1.8)	11.2 (2)	11 (2.4)	10.9 (2.5)	10 (3.2)
Child's age in years[a]	8.7 (1)	8.8 (1)	8.7 (1.2)	8.9 (1.3)	8.8 (1.1)	8.7 (1)	9 (1.2)	8.7 (1.3)	8.8 (1.2)	8.9 (1.2)	8 (0.8)	8.9 (1)
Mother's age in years[a]	35.8 (6.3)	36.9 (5.8)	35.1 (6.4)	35.6 (6)	35.6 (6.2)	36.5 (6.5)	36.3 (5.8)	34.9 (6.1)	36.5 (6)	36.8 (5.9)	34.5 (5.2)	34.6 (7.7)
Father's age in years[a]	39.3 (7.5)	37.6 (6.6)	38.3 (8.2)	37.3 (5.9)	38.1 (7.3)	39.2 (7.5)	38.7 (8)	36.7 (5)	38.1 (6.9)	37.9 (7.2)	37 (6.8)	37.4 (9.1)
Mother's number in years of last education level[a]	3.2 (0.9)	3.2 (1)	3.4 (1.4)	3.2 (1.5)	3.3 (0.9)	3.2 (1.2)	3.4 (1)	3.4 (1.8)	3.2 (0.9)	3.2 (1.2)	3.8 (0.9)	3.3 (0.9)
Father's number in years of last education level[a]	3.1 (0.7)	3.1 (0.9)	3.5 (2)	3.5 (1.5)	3.1 (0.7)	3 (0.9)	3.4 (1)	3.8 (2.4)	3.2 (0.9)	3.4 (1.2)	3.2 (1.1)	3 (0)
Percentage of the population at risk of poverty by municipality in 2020[a]	37.3 (10.9)	36.1 (13)	41.9 (11.6)	44.6 (10.8)	33.6 (9.1)	42.2 (14.7)	38.4 (10.1)	45.2 (11)	39.2 (10.6)	39.8 (10.8)	34.4 (9)	36.1 (10.6)
Child's Body Mass Index (BMI) goups[b]												
Normal weight	14 (42.4)	12 (36.4)	14 (42.4)	16 (48.5)	12 (37.5)	12 (37.5)	11 (34.4)	18 (54.5)	19 (37.3)	7 (31.8)	8 (57.1)	9 (60)
Overweight	4 (12.1)	3 (9.1)	2 (6.1)	3 (9.1)	5 (15.6)	2 (6.2)	2 (6.2)	3 (9.1)	7 (13.7)	4 (18.2)	1 (7.1)	0 (0)
Obese	15 (45.5)	18 (54.5)	17 (51.5)	14 (42.4)	15 (46.9)	18 (56.2)	19 (59.4)	12 (36.4)	25 (49)	11 (50)	5 (35.7)	6 (40)
Mother's highest academic level[b]												
Primary	3 (9.1)	1 (3)	3 (9.4)	2 (6.2)	1 (3.1)	2 (6.2)	3 (9.4)	2 (6.5)	1 (2)	3 (13.6)	1 (7.7)	2 (13.3)
Secondary	19 (57.6)	8 (24.2)	17 (53.1)	22 (68.8)	17 (53.1)	9 (28.1)	15 (46.9)	22 (71)	25 (50)	10 (45.5)	4 (30.8)	10 (66.7)
Professional training	10 (30.3)	22 (66.7)	11 (34.4)	7 (21.9)	14 (43.8)	20 (62.5)	11 (34.4)	6 (19.4)	22 (44)	9 (40.9)	7 (53.8)	3 (20)
University	1 (3)	2 (6.1)	1 (3.1)	1 (3.1)	0 (0)	1 (3.1)	3 (9.4)	1 (3.2)	2 (4)	0 (0)	1 (7.7)	0 (0)
Father's highest ac ademic level[b]												
Primary	0 (0)	1 (3.4)	2 (6.7)	3 (9.7)	0 (0)	1 (3.6)	2 (6.9)	3 (10)	1 (2.1)	3 (17.6)	1 (7.7)	0 (0)

(*continued on next page*)

Table 1 (*continued*)

NDVI	1500 m				2000 m				3000 m			
	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max
Secondary	22 (75.9)	16 (55.2)	20 (66.7)	20 (64.5)	22 (75.9)	17 (60.7)	15 (51.7)	21 (70)	32 (68.1)	10 (58.8)	8 (61.5)	13 (92.9)
Professional training	6 (20.7)	11 (37.9)	4 (13.3)	8 (25.8)	6 (20.7)	10 (35.7)	8 (27.6)	5 (16.7)	13 (27.7)	4 (23.5)	3 (23.1)	1 (7.1)
University	1 (3.4)	1 (3.4)	4 (13.3)	0 (0)	1 (3.4)	0 (0)	4 (13.8)	1 (3.3)	1 (2.1)	0 (0)	1 (7.7)	0 (0)
Mother's employment[b]												
Home	15 (46.9)	19 (57.6)	15 (48.4)	13 (41.9)	15 (48.4)	17 (53.1)	14 (45.2)	13 (43.3)	24 (48)	7 (33.3)	5 (38.5)	9 (69.2)
Services	4 (12.5)	1 (3)	2 (6.5)	4 (12.9)	4 (12.9)	1 (3.1)	2 (6.5)	4 (13.3)	4 (8)	0 (0)	3 (23.1)	1 (7.7)
Factory or Retail Employee	3 (9.4)	3 (9.1)	6 (19.4)	3 (9.7)	3 (9.7)	4 (12.5)	6 (19.4)	3 (10)	5 (10)	2 (9.5)	2 (15.4)	1 (7.7)
Office Worker	3 (9.4)	3 (9.1)	4 (12.9)	7 (22.6)	2 (6.5)	3 (9.4)	5 (16.1)	6 (20)	5 (10)	7 (33.3)	1 (7.7)	0 (0)
Professional	7 (21.9)	7 (21.2)	4 (12.9)	4 (12.9)	7 (22.6)	7 (21.9)	4 (12.9)	4 (13.3)	12 (24)	5 (23.8)	2 (15.4)	2 (15.4)
Father's employment[b]												
Services	7 (25)	6 (22.2)	12 (40)	14 (46.7)	7 (25.9)	8 (29.6)	9 (31)	14 (48.3)	15 (34.1)	6 (37.5)	4 (30.8)	5 (35.7)
Factory or Retail Employee	8 (28.6)	7 (25.9)	5 (16.7)	6 (20)	6 (22.2)	7 (25.9)	6 (20.7)	5 (17.2)	10 (22.7)	2 (12.5)	4 (30.8)	6 (42.9)
Office Worker	7 (25)	4 (14.8)	6 (20)	5 (16.7)	6 (22.2)	4 (14.8)	7 (24.1)	4 (13.8)	10 (22.7)	4 (25)	0 (0)	1 (7.1)
Professional	4 (14.3)	8 (29.6)	7 (23.3)	5 (16.7)	6 (22.2)	7 (25.9)	6 (20.7)	6 (20.7)	8 (18.2)	4 (25)	4 (30.8)	1 (7.1)
Retired, unemployed, others	2 (7.1)	2 (7.4)	0 (0)	0 (0)	2 (7.4)	1 (3.7)	1 (3.4)	0 (0)	1 (2.3)	0 (0)	1 (7.7)	1 (7.1)
Mother's employment security[b]												
Permanent	13 (41.9)	13 (40.6)	9 (29)	14 (48.3)	13 (43.3)	14 (43.8)	10 (32.3)	12 (42.9)	22 (44.9)	12 (60)	8 (61.5)	2 (16.7)
Temporary	6 (19.4)	7 (21.9)	9 (29)	5 (17.2)	5 (16.7)	6 (18.8)	11 (35.5)	5 (17.9)	6 (12.2)	3 (15)	2 (15.4)	4 (33.3)
No security	12 (38.7)	12 (37.5)	13 (41.9)	10 (34.5)	12 (40)	12 (37.5)	10 (32.3)	11 (39.3)	21 (42.9)	5 (25)	3 (23.1)	6 (50)
Father's employment security[b]												
Permanent	21 (72.4)	22 (81.5)	23 (76.7)	22 (75.9)	19 (70.4)	23 (82.1)	23 (79.3)	21 (75)	37 (80.4)	11 (68.8)	11 (84.6)	10 (76.9)
Temporary	6 (20.7)	4 (14.8)	6 (20)	7 (24.1)	6 (22.2)	4 (14.3)	5 (17.2)	7 (25)	8 (17.4)	5 (31.2)	2 (15.4)	2 (15.4)
No security	2 (6.9)	1 (3.7)	1 (3.3)	0 (0)	2 (7.4)	1 (3.6)	1 (3.4)	0 (0)	1 (2.2)	0 (0)	0 (0)	1 (7.7)
The family heads[b]												
Mother	7 (21.9)	6 (18.8)	3 (9.7)	5 (16.1)	8 (25)	4 (12.9)	6 (19.4)	3 (10)	8 (16.7)	5 (25)	2 (15.4)	1 (6.7)
Father	12 (37.5)	21 (65.6)	21 (67.7)	16 (51.6)	12 (37.5)	20 (64.5)	20 (64.5)	17 (56.7)	25 (52.1)	7 (35)	10 (76.9)	9 (60)
Both parents	4 (12.5)	1 (3.1)	1 (3.2)	2 (6.5)	3 (9.4)	1 (3.2)	1 (3.2)	2 (6.7)	3 (6.2)	0 (0)	0 (0)	2 (13.3)
Other family members	9 (28.1)	4 (12.5)	6 (19.4)	8 (25.8)	9 (28.1)	6 (19.4)	4 (12.9)	8 (26.7)	12 (25)	8 (40)	1 (7.7)	3 (20)
Maternal marital status[b]												
Single	9 (27.3)	6 (18.2)	5 (15.6)	7 (21.9)	5 (15.6)	9 (28.1)	7 (21.9)	4 (12.9)	8 (16)	7 (31.8)	2 (15.4)	5 (33.3)
Married	13 (39.4)	20 (60.6)	18 (56.2)	18 (56.2)	12 (37.5)	20 (62.5)	16 (50)	20 (64.5)	28 (56)	13 (59.1)	6 (46.2)	7 (46.7)
Cohabiting	9 (27.3)	4 (12.1)	8 (25)	7 (21.9)	11 (34.4)	2 (6.2)	8 (25)	7 (22.6)	9 (18)	2 (9.1)	4 (30.8)	3 (20)
Divorced/Widow	2 (6.1)	3 (9.1)	1 (3.1)	0 (0)	4 (12.5)	1 (3.1)	1 (3.1)	0 (0)	5 (10)	0 (0)	1 (7.7)	0 (0)
Availability of childcare[b]												
No one	6 (18.2)	7 (21.2)	6 (18.8)	3 (9.4)	6 (18.8)	4 (12.5)	6 (18.8)	5 (16.1)	7 (14)	3 (13.6)	3 (23.1)	1 (6.7)
Dad	8 (24.2)	17 (51.5)	14 (43.8)	16 (50)	9 (28.1)	19 (59.4)	13 (40.6)	14 (45.2)	20 (40)	13 (59.1)	5 (38.5)	7 (46.7)
Grandparents	14 (42.4)	7 (21.2)	9 (28.1)	9 (28.1)	13 (40.6)	5 (15.6)	11 (34.4)	8 (25.8)	20 (40)	6 (27.3)	3 (23.1)	7 (46.7)
Uncles	5 (15.2)	0 (0)	2 (6.2)	2 (6.2)	3 (9.4)	3 (9.4)	1 (3.1)	2 (6.5)	1 (2)	0 (0)	1 (7.7)	0 (0)
Employee	0 (0)	0 (0)	1 (3.1)	1 (3.1)	0 (0)	0 (0)	1 (3.1)	1 (3.2)	0 (0)	0 (0)	0 (0)	0 (0)
Other	0 (0)	2 (6.1)	0 (0)	1 (3.1)	1 (3.1)	1 (3.1)	0 (0)	1 (3.2)	2 (4)	0 (0)	1 (7.7)	0 (0)
Residence ownership[b]												
Own	8 (24.2)	10 (34.5)	12 (40)	11 (35.5)	8 (26.7)	8 (28.6)	13 (40.6)	11 (36.7)	19 (39.6)	7 (36.8)	5 (38.5)	3 (20)
Rent	5 (15.2)	10 (34.5)	10 (33.3)	8 (25.8)	5 (16.7)	10 (35.7)	9 (28.1)	9 (30)	11 (22.9)	4 (21.1)	6 (46.2)	3 (20)
Others house ownership	20 (60.6)	9 (31)	8 (26.7)	12 (38.7)	17 (56.7)	10 (35.7)	10 (31.2)	10 (33.3)	18 (37.5)	8 (42.1)	2 (15.4)	9 (60)
Availability of drinking water[b]												

(*continued on next page*)

Table 1 (*continued*)

NDVI	1500 m				2000 m				3000 m			
	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max	Min-Q1	Q1-Q2	Q2-Q3	Q3-Max
In the house	26 (78.8)	24 (72.7)	24 (75)	29 (90.6)	25 (78.1)	20 (62.5)	28 (87.5)	26 (83.9)	43 (86)	19 (86.4)	9 (69.2)	12 (80)
Shared with neighbours	4 (12.1)	3 (9.1)	4 (12.5)	1 (3.1)	4 (12.5)	4 (12.5)	2 (6.2)	2 (6.5)	3 (6)	2 (9.1)	1 (7.7)	2 (13.3)
Public fountain	2 (6.1)	2 (6.1)	1 (3.1)	1 (3.1)	1 (3.1)	4 (12.5)	0 (0)	1 (3.2)	1 (2)	1 (4.5)	0 (0)	1 (6.7)
Others water source	1 (3)	4 (12.1)	3 (9.4)	1 (3.1)	2 (6.2)	4 (12.5)	2 (6.2)	2 (6.5)	3 (6)	0 (0)	3 (23.1)	0 (0)
Number of rooms in the residence[b]												
1-2 rooms	12 (36.4)	10 (31.2)	16 (50)	14 (43.8)	13 (40.6)	11 (35.5)	15 (46.9)	13 (41.9)	17 (34)	8 (38.1)	5 (38.5)	10 (66.7)
3 rooms	12 (36.4)	11 (34.4)	3 (9.4)	10 (31.2)	10 (31.2)	12 (38.7)	2 (6.2)	10 (32.3)	16 (32)	8 (38.1)	6 (46.2)	2 (13.3)
4 rooms	4 (12.1)	4 (12.5)	6 (18.8)	5 (15.6)	4 (12.5)	3 (9.7)	8 (25)	4 (12.9)	5 (10)	5 (23.8)	1 (7.7)	1 (6.7)
+5 rooms	5 (15.2)	7 (21.9)	7 (21.9)	3 (9.4)	5 (15.6)	5 (16.1)	7 (21.9)	4 (12.9)	12 (24)	0 (0)	1 (7.7)	2 (13.3)
Number of bedrooms in the residence[b]												
1 rooms	4 (12.1)	3 (9.1)	8 (25)	5 (16.1)	3 (9.4)	4 (12.5)	9 (28.1)	3 (10)	6 (12)	6 (28.6)	2 (15.4)	3 (20)
2 rooms	19 (57.6)	14 (42.4)	12 (37.5)	17 (54.8)	18 (56.2)	15 (46.9)	11 (34.4)	16 (53.3)	22 (44)	13 (61.9)	6 (46.2)	10 (66.7)
3 rooms	4 (12.1)	8 (24.2)	8 (25)	5 (16.1)	3 (9.4)	6 (18.8)	8 (25)	7 (23.3)	14 (28)	1 (4.8)	3 (23.1)	1 (6.7)
4 rooms	4 (12.1)	5 (15.2)	3 (9.4)	2 (6.5)	5 (15.6)	5 (15.6)	3 (9.4)	2 (6.7)	7 (14)	1 (4.8)	2 (15.4)	1 (6.7)
+5 rooms	2 (6.1)	3 (9.1)	1 (3.1)	2 (6.5)	3 (9.4)	2 (6.2)	1 (3.1)	2 (6.7)	1 (2)	0 (0)	0 (0)	0 (0)
Number of individuals sharing the participant's bedroom[b]												
0 people	1 (3)	6 (18.8)	1 (3.1)	3 (9.7)	3 (9.7)	4 (12.5)	1 (3.1)	3 (10)	8 (16.3)	3 (14.3)	0 (0)	0 (0)
1 people	8 (24.2)	4 (12.5)	8 (25)	7 (22.6)	5 (16.1)	6 (18.8)	9 (28.1)	6 (20)	8 (16.3)	6 (28.6)	8 (61.5)	1 (6.7)
2 people	9 (27.3)	16 (50)	11 (34.4)	14 (45.2)	9 (29)	15 (46.9)	11 (34.4)	15 (50)	21 (42.9)	8 (38.1)	3 (23.1)	8 (53.3)
3 people	5 (15.2)	2 (6.2)	7 (21.9)	3 (9.7)	3 (9.7)	1 (3.1)	9 (28.1)	2 (6.7)	8 (16.3)	1 (4.8)	1 (7.7)	1 (6.7)
+4 people	10 (30.3)	4 (12.5)	5 (15.6)	4 (12.9)	11 (35.5)	6 (18.8)	2 (6.2)	4 (13.3)	4 (8.2)	3 (14.3)	1 (7.7)	5 (33.3)

[a] Values are given as mean (Standard deviation).
[b] Values are given as absolute frequency (percentage).

school-aged children living in Barcelona (Dadvand et al., 2015) as a nonverbal reasoning test was not employed. Moreover, consistent with the Viva study, we also did not report an association between surrounding residential greenness and executive function (Jimenez et al., 2022).

As with our study, the Roman study, neither found associations between NDVI within 300 or 500 m buffers from children's residences, and the Weschler Intelligence in Children Scale third edition (WISC-III) scores for similarities, vocabulary, digit span, block design, coding, and symbol search tests (Asta et al., 2021). However, Asta et al. (2021) found a positive association between working memory skills measured through the WISC-III arithmetic test and NDVI at 500 m from children's residences. No associations between working memory and the different NDVI were observed in our study, but in contrast to the Roman study, we did not employ an arithmetic memory test in our study (Asta et al., 2021). Our results are also consistent with those obtained in a Portuguese study (Queiroz Almeida et al., 2021). The Portuguese study assessed the association between exposure to greenness and accessibility to green and blue spaces with WISC-III intelligence/cognition scores (Queiroz Almeida et al., 2021). Similar to our own study, associations between verbal, performance or full intelligence quotient scores, with NDVI values within 100, 250, and 500 m buffers from children's residences were also absent.

The results of the current study suggest a possible association between exposure to green spaces at shorter distances (300 m) and working memory, but it does not reach statistical significance ($p < 0.10$). The absence of associations between working memory skills measured through the WISC-IV digit span and letter number sequencing tests were also consistent with the Barcelona study (Dadvand et al., 2015). That study did not find an association between surrounding residential greenness and working memory, although they found a positive association considering the weighted average greenness index of home, school and commuting (Dadvand et al., 2015). Conversely, a study with a cohort of 11-year-old children living in English urban areas, participating in the United Kingdom (UK) Millennium Cohort Study, found a positive association between quantity of neighbourhood greenspace and spatial working memory (Flouri et al., 2019). The difference between our study and the Barcelona study with the English study may result from the different tools used to measure greenness. In the English study, greenness was assessed using the Multiple Environmental Deprivation Index, while in the current study, as well as in the study from Barcelona, greenness was assessed using the NDVI measured at different buffers zones from children's residences, besides the Barcelona study also assessed greenness within children's schools and communities. Furthermore, both the current study and the Barcelona study had low NDVI values with little variability compared to the English study. In the current study, 75% of the NDVI values were 0.069–0.313, at 300 m from children's homes whereas in the Barcelona study, the median and IQR NDVI were 0.091 and 0.053, respectively (Dadvand et al., 2015). Conversely, in the English study, 54% of children lived in a neighbourhood with low greenness and 46% lived in a neighbourhood with high greenness, resulting in a greater variability in levels of greenness accessed.

The range of greenness levels vary between our study and others, which might be another factor contributing to the variability of results observed on the available studies. In our study, NDVI median values

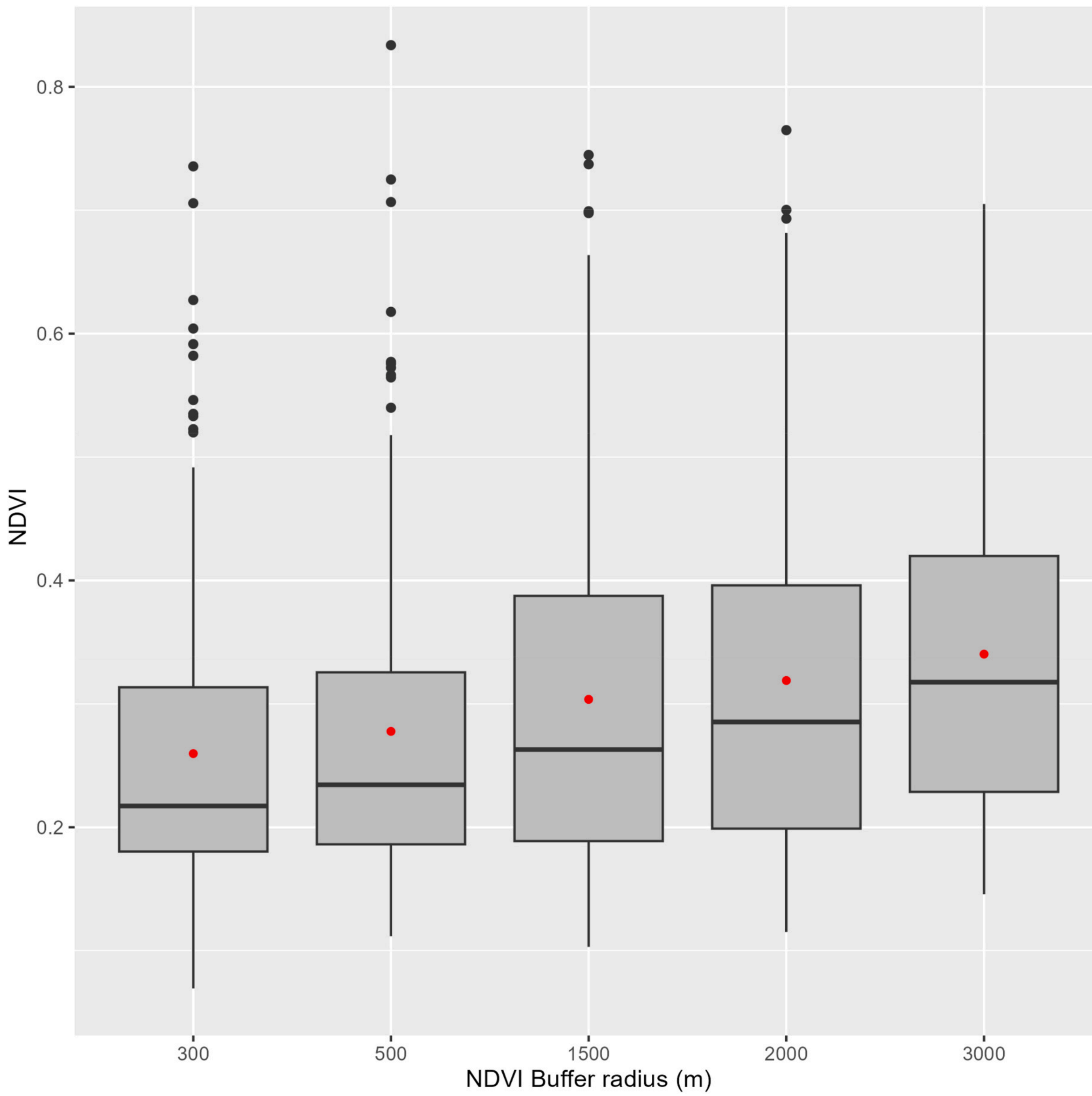

Fig. 1. Normalised Difference Vegetation Index (NDVI) at 300, 500, 1500, 2000, and 3000 m from children's home distributions of 144 pre-pubertal Mexican boys in 2017–2019 included in the MetCog study. Red points refer to mean.

were 0.22 and 0.23 at 300 and 500 m distances from children's residence, respectively, compared to greater greenness values in the Roman study with NVDI median values of 0.37 and 0.39 at 300 and 500 m, respectively (Asta et al., 2021). Conversely, the mean NDVI at 500 m was 0.28 in Mexico City compared to 0.20 in Porto (Queiroz Almeida et al., 2021). The NDVI median value was 0.091 at 250 m in Barcelona (Dadvand et al., 2015) compared to 0.22 in Mexico City for a buffer of 300 m, the closest buffer to children's homes in this study. The Roman study had higher greenness scores than in ours in Mexico City, although ours were higher than those in the Porto and Barcelona studies (Asta et al., 2021; Dadvand et al., 2015; Queiroz Almeida et al., 2021). The lower greenness in the Barcelona study may result from the assessment being made in July, one of the hottest and driest months of the Mediterranean climate (Dadvand et al., 2015).

Unlike the studies conducted in Rome (Asta et al., 2021), Porto (Queiroz Almeida et al., 2021), the current study and the one conducted in Barcelona (Dadvand et al., 2015) used buffers greater than 500 m from the children's residences. In Barcelona, Dadvand et al. (2015) assessed association between cognitive development and green exposure at 500 and 1000 m. However, no results were shown for the 1000 m in the Barcelona study since no notable differences were found except with greeness at 250 m from residences.

According to our results, we found no association between the greenness index NDVI and cognitive functions tested at closer distances, 300 m and 500 m buffers. This might be due to the fact that Mexican residents may have little green spaces at distances of less than 500 m according to Mayen Huerta (2022). This could be an important explanatory factor for the lack of association observed, as more than two thirds of neighbourhoods in Mexico City do not have access to green spaces of any size within 300 m, and only 29% have access to a children's park (within a buffer area of 400 m) (Mayen Huerta, 2022). This is consistent with the lack of green spaces for residents of other megacities, as an assessment of 28 megacities reported that the mean availability of urban green spaces in megacities was only 32% in 2015 (Huang et al., 2017). On the other hand, our study observed an association between greenness, measured as NDVI, and cognitive functions associated with perceptual reasoning at larger distances from residences, 1500 m and 2000m buffers. This is in consistent with the reported distances at which Mexico City residents have access to green spaces according to Mayen Huerta (2022). Children in Mexico City have

Table 2
Adjusted Coefficient (aβ), 95% confidence interval (CI), and p-value of multiple linear regression analysis between WISC-IV test scores and normalised difference vegetation index (NDVI) at buffers: 300, 500, 1500, 2000, and 3000 m from children's residences for 144 pre-pubertal Mexican boys in 2017–2019 included in the MetCog study. Multiple regression models were adjusted for children age, body mass index, paternal and maternal ages, family head, highest academic level of father and mother, marital status of the mother, number of individuals sharing the participant's bedroom, house ownership, and percentage of the population at risk of poverty by municipality in 2020.

Domain	Test	NDVI				
		Buffer 300 m	Buffer 500 m	Buffer 1500 m	Buffer 2000m	Buffer 3000 m
		aβ (95% CI) p-value	aβ (95% CI) p-value	aβ (95% CI) p-value	aβ (95% CI) p-value	aβ (95% CI) p-value
Comprehension	Similarities	−0.21 (−0.98,0.56) 0.590	−0.28 (−1.15,0.59) 0.522	−0.03 (−1.17,1.11) 0.959	0.04 (−1.13,1.21) 0.943	−0.29 (−1.62,1.03) 0.663
	Vocabulary	−0.07 (−0.65,0.52) 0.823	0.26 (−0.41,0.93) 0.449	0.39 (−0.51,1.29) 0.389	0.31 (−0.62,1.23) 0.511	0.52 (−0.50,1.54) 0.313
Perceptual Reasoning	Block Design	−0.36 (−1.00,0.29) 0.273	0.51 (−0.13,1.16) 0.117	1.00 (0.14,1.86) 0.023*	**1.18 (0.31,2.06) 0.008****	0.84 (−0.12,1.80) 0.087
	Matrix Reasoning	−0.05 (−0.58,0.49) 0.863	0.57 (−0.01,1.16) 0.055	0.83 (0.06,1.61) 0.036*	0.65 (−0.16,1.45) 0.114	0.75 (−0.15,1.65) 0.102
Working Memory	Digit Span	−0.43 (−0.87,0.02) 0.058	0.22 (−0.24,0.69) 0.338	0.48 (−0.15,1.11) 0.135	0.55 (−0.10,1.20) 0.095	0.39 (−0.28,1.07) 0.248
	Letter Number sequencing	−0.22 (−0.75,0.31) 0.406	−0.10 (−0.67,0.48) 0.737	0.03 (−0.73,0.80) 0.931	0.08 (−0.70,0.87) 0.836	0.12 (−0.76,1.00) 0.791
Processing Speed	Coding	−0.20 (−0.71,0.30) 0.428	0.35 (−0.22,0.92) 0.225	0.48 (−0.29,1.25) 0.221	0.52 (−0.26,1.30) 0.187	0.47 (−0.37,1.32) 0.267
	Symbol Search	−0.05 (−0.50,0.40) 0.833	0.29 (−0.20,0.77) 0.242	0.34 (−0.27,0.96) 0.273	0.35 (−0.28,0.97) 0.276	0.17 (−0.53,0.87) 0.633

*Significant with a p-value <0.05.
** Significant after applying the False Discovery Rate correction.

access to parks located within their neighbourhood, district or city parks at distances of 800, 2000 and 5000 m, in 51%, 58%, and 88% of neighbourhoods, respectively (Mayen Huerta, 2022). Furthermore, we found no associations between greenness and cognition in the largest buffer (3000 m), although Mayen Huerta (2022) stated that the vast majority of residents in Mexico City had green spaces available at a distance of up to 5000 m. The lack of association at large distances (3000 m) may be associated with children accessibility to these green spaces. Whereas some children (2–18%) in Mexico City travel long distances to attend school, located in a different neighbourhood (Damián González et al., 2020), they may not do so to access green spaces. On the other hand, it has been reported that some children have to travel some distance in automobiles to access and enjoy green spaces (Gülgönen and Corona, 2019; Pérez Medina and Fargher, 2016). However, not all children (or their families) might have the means, nor the motivation to travel long distances to benefit from green spaces. Overall, this may suggest that residents might not take advantage of green spaces located at those longer distances (3000 m) and the possible need to take a car or use public transport to reach them may be difficult. For this reason, children mobility patterns need to be considered when planning green spaces in urban areas.

In addition, safety has been highlighted as an important reason, preventing children enjoying the immediate residential space (Damián González et al., 2020; Gülgönen and Corona, 2019). The safety aspect might be an important factor in all buffer sizes, as it might affect both green spaces located near (e.g. less than 500 m) or at larger distances from the home depending on the residential area and neighbourhood of each participant.

Therefore, when assessing the association of availability and access to green spaces in megacities with health-related endpoints, we suggest that it is important to consider the following recommendations to define the buffer sizes. It should include a range of buffer sizes that capture the area near the residential area and include distances greater than 500 m. Buffer sizes should also consider different aspects such as safety, mobility patterns and availability of green areas.

When evaluating the current results and those from other studies published previously, we should note that the NDVI assessment does not distinguish between different types of vegetation (e.g. pine vs. elm), vegetation volume, and the different types of green spaces, e.g. whether just a piece of lawn, a park, or a forest. The index is poor in capturing the greenness in grasslands, in areas with late onset of growth, in irrigated agriculture, and after a peak in biomass (Garroutte et al., 2016). The index is also poor in assessing the usability of the green spaces. Thus, the NDVI may not appropriately capture the amount and quality of vegetation and may not be the best indicator to assess the protective effect of greenness. Other alternative greenness indexes that could be explored include the Enhanced Vegetation Index, Adjusted Vegetation Index, and Modified Soil Adjusted Vegetation Index. Several studies have reported that these indices better capture greenness than NDVI (Ramadhani Yusuf et al., 2019), especially since the latter is sensitive to soil background and atmospheric effects, e.g. aerosol column concentration, and possible saturation in high biomass regions (Jiang et al., 2008). A useful alternative could be also to use maps indicating land use that catalogue the presence of parks, playgrounds, forests and other green areas within the area of study, such that distance to these features, as well as percentage of these features within a buffer could be used to assess exposure to green spaces. Therefore, in future, studies aimed at assessing the protective effect of nature near residential areas are advised to combine NDVI with other greenness measures, at least in a sensitivity analysis.

The results of this study may be representative of children from low and middle-income social class living in Mexico City, but would not be applicable to children from a high social class (2–3% of population in Mexico) (Dirección General Adjunta de Investigación del INEGI, 2021). Through the combination of different recruitment methods, randomly targeting private and local schools in Mexico City, alongside siblings of patients and family members of the top children hospital, the recruited children come from 37 different neighbourhoods across Mexico City. These neighbourhoods have a mean percentage of the population at risk of poverty of 39.7 ± 11.7%. Whereas, some recruited children are living in neighbourhoods with a lower percentage (18.8%) and others are living in a neighbourhood with a higher percentage (45.8%). Also, some children live in houses that only have one bedroom (17%) or that have to share the bedroom between 3 or more people (30%), whilst others live in houses with more than 4 bedrooms in the residence (17%) or have a bedroom on their own (29.3%). In addition, some children recruited from the hospital are family members of medical staff (likely to be middle and upper-middle class), whilst others are family members from clerical and service support staff at the hospital (likely to be lower and

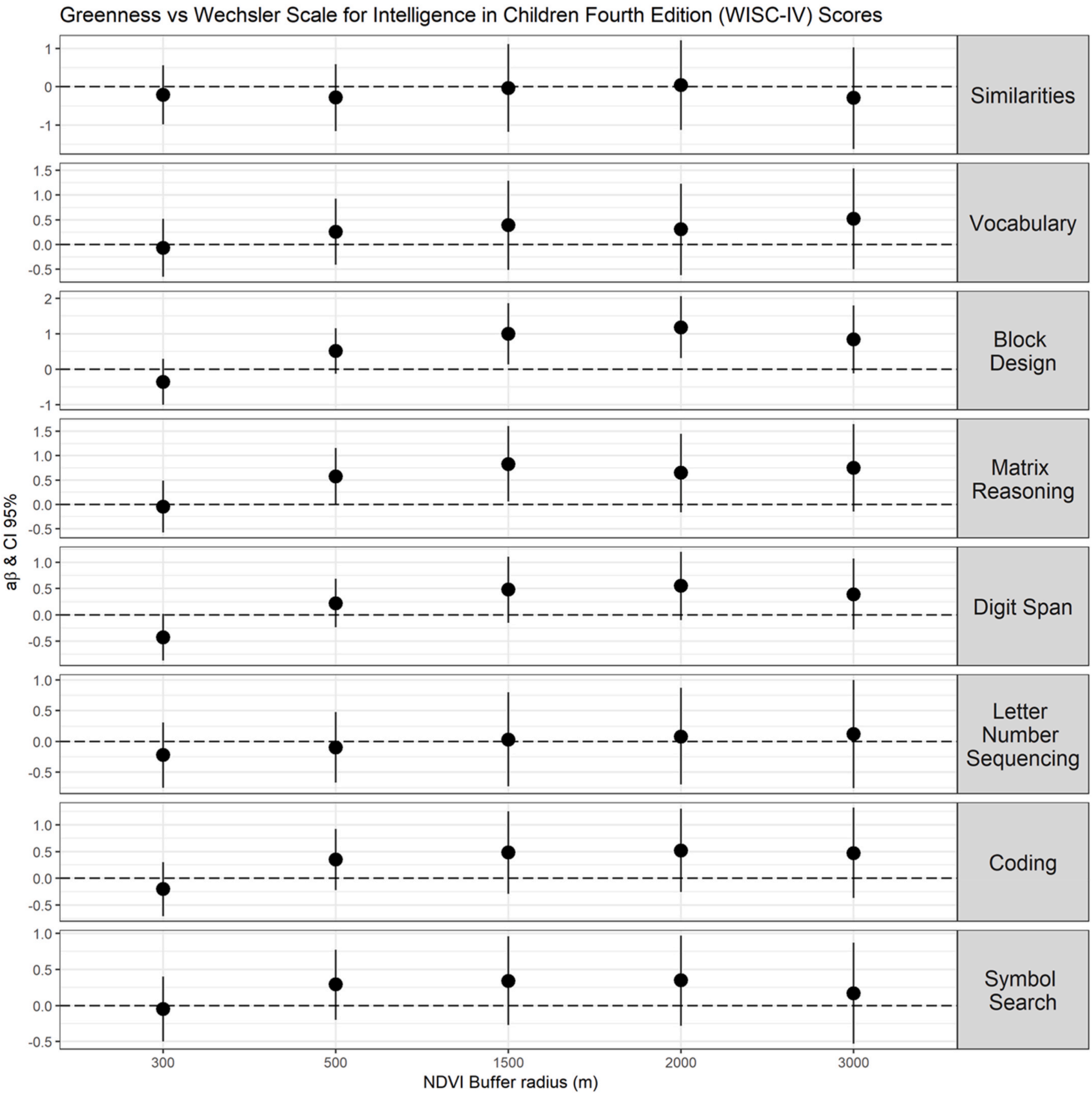

Fig. 2. Adjusted Coefficient (aβ) and 95% confidence interval (CI) of multiple linear regression analysis between Weschler Scale for Intelligence in Children fourth edition (WISC-IV) test scores and normalised difference vegetation index (NDVI) at buffers: 300, 500, 1500, 2000, and 3000, m from children's residences for 144 pre-pubertal Mexican boys in 2017–2019 included in the MetCog study. Multiple regression models were adjusted for body mass index, paternal and maternal ages, family head, highest academic level of father and mother, marital status of the mother, number of individuals sharing the participant's bedroom, house ownership, and percentage of the population at risk of poverty by municipality in 2020. Note that higher cognitive scores relate to better cognition.

lower-middle class). Also, the participants recruited as siblings of patients at the Hospital Infantil de México Federico Gómez, are likely to be from low- and middle-income families, since this hospital is the referral centre for paediatric care for all the population. Thus, patients will include children from families that cannot pay for private care and/or difficult cases that cannot be treated in private medical care. With all these considerations, although the children participating in this study were not recruited using probability sampling methods, they may be representative of the lower- and middle-class school-aged boys living across Mexico City. It also should be highlighted that these children do not represent the upper 2–3% class, i.e. the very rich children, who will not go to the enrolled schools, nor would seek medical treatment in the referal hospital of Mexico, but instead will go abroad for these medical services. Therefore, the current results would be applicable to children from lower and middle-income class families living in Mexico City, which represents 97–98% of the population in Mexico City.

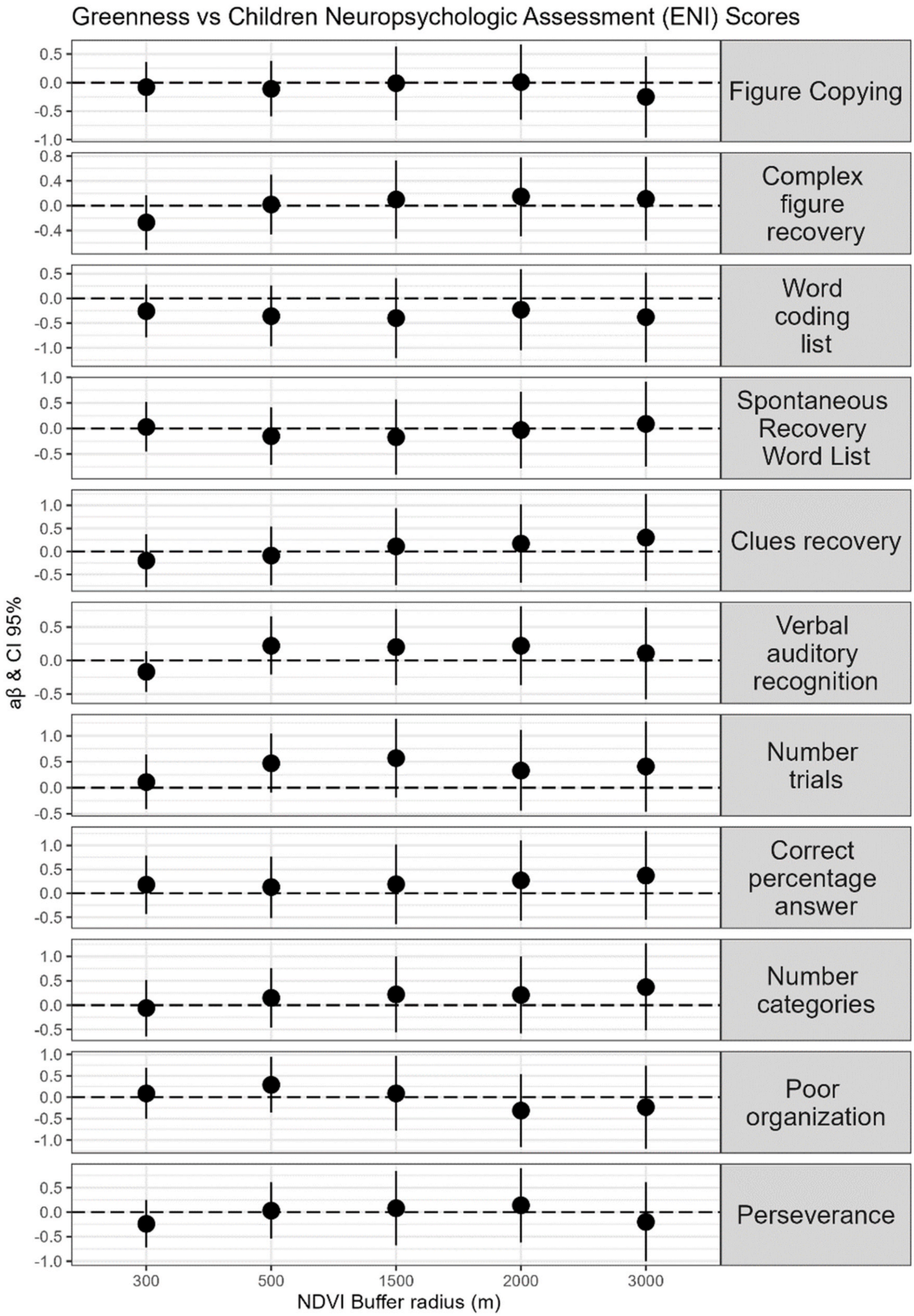

Fig. 3. Adjusted Coefficient (aβ) and 95% confidence interval (CI) of multiple linear regression analysis between Children Neuropsychologic Assessment (ENI) test scores and normalised difference vegetation index (NDVI) at buffers: 300, 500, 1500, 2000, and 3000 m from children's residences for 144 pre-pubertal Mexican boys in 2017–2019 inlcuded in the MetCog study. Multiple regression models were adjusted for body mass index, paternal and maternal ages, family head, highest academic level of father and mother, marital status of the mother, number of individuals sharing the participant's bedroom, house ownership, and percentage of the population at risk of poverty by municipality in 2020. Note that higher cognitive scores relate to better cognition.

5. Strengths and limitations

This is the first study assessing association between greenness and performance in different cognitive domains in children residing in a megacity from a low- and middle-income country. These results add to the body of evidence available from urban areas in high-income countries, mainly from Southern Europe. Our study focuses on pre-pubertal children, which is at an age of critical brain development. The study considers greenness exposure covering a wide range of distances from the residential address, with buffer sizes larger than 500 m from children's residences included, which may be important to capture greenness in neighbourhoods within megacities, such as Mexico City. On the other hand, 22% of the children live within 250 m from each other, which is the spatial resolution of the NDVI index. Therefore, no greenness variability is captured for these children using the NDVI index, which might have lowered the strength of our analysis. Nonetheless, the remaining children (78%) live at larger distances than the spatial resolution of the NDVI index and hence, for these children the greenness index would be an appropriate indicator to capture the green space variability. In addition, this study assessed cognitive performance with two different tools that included tests assessing a wide range of cognitive skills. This study also considered the effect of confounding factors including individual and neighbourhood socioeconomic variables, reporting associations adjusted for potential confounding variables and corrected using the FDR.

However, this study also has some limitations. First, NDVI was used to assess greenness, which is an index that identifies the density of greenness in an area of land. NDVI does not distinguish between types of vegetation, the quality of the green space, nor the accessibility or safety of this green space to the study participants. There may be children participating in this study that, despite having green spaces near their residence, may not be able to profit from access to such natural spaces due to environmental considerations/limitations. Accessibility, quality and safety in using these green spaces cannot be disentangled in the present study, nor can the children affected in this way be identified to allow the implementation of sensitivity analysis. The qualitative information of the green space, which is not captured by the NDVI index, is important to be considered. The evidence suggests that safety, aesthetics, amenities, maintenance, proximity to the home, the provision of activity options and the presence of activity-specific facilities were protective factors for physical activities, while the perceived quality of green spaces in terms of allowing relaxation and recreation were protective factors for mental well-being, rather than quantity or size (WHO Regional Office for Europe, 2016). In addition, greater benefits have been associated with forests than with grasslands (Nguyen et al., 2021), but that information is not captured by the NDVI index. Furthermore, NDVI was calculated at the residence location corresponding with the time that the study took place. However, no information on residential history is available, hence the current residential address used for the study may not reflect where children were living for most of their lives, despite their young age, if any of the included children might have changed residential address. No information on the degree of urbanization was available for the homes of the children participating in the cohort, and hence this could not be taken into account in the analysis. Another limitation of the study is that the full WISC-IV and ENI instruments were not applied as the time required to undertake them would have been very demanding and prevented their use considering the age of the participants of this study. Thus, a global cognitive score could not be calculated, nor a score for specific cognitive domains, such as memory or executive function domains. In addition, the volunteers came from three local schools and the paediatric referral hospital, which is mostly frequented by children from the lower and middle social class. Therefore, the participants are representative of the lower- and middle-income class in Mexico City, approximately 97–98% of the population, but is not representative of children from the upper class, which only represent a very small part of the population of Mexico City (2–3%), was not represented in this study. Lastly, the relatively small sample size limits generalizability and precision, and we recommend that further studies are conducted with larger populations.

6. Conclusions

This is the first study conducted in a megacity in a low- and middle-income country to report associations between scores within the cognitive domain of perceptual reasoning and greenness beyond 500 m in a cohort of pre-pubertal boys, living in a megacity. The current results provide evidence of the influence of exposure to green spaces, an environmental factor, on brain health in 144 pre-pubertal boys living in Mexico City, specifically in cognitive development before puberty, a critical time window in brain development. Future studies studying association between greenness and health outcomes should consider including greenness beyond 500 m around residences, especially those studies conducted in megacities. Urban planners should be encouraged to increase vegetation availability across cities, especially in neighbourhoods with high percentage of young children to enhance cognitive development of future generations, alongside benefiting children health and wellbeing in general. Improved cognitive development alongside education, will greatly contribute to improving the socioeconomic status of a country.

Author contributions

Conception and design of the study: P-WS. Data collection and curation: AC-H, JMD-S, BdCA, SHT, BLM, PDS, ALM, MKK, EBP. Data analysis: AC-H, JMD-S. Writing original draft: AC-H, JMD-S. Writing – Review & Editing: AC-H, P-WS, JMD-S, BdCA, SHT, BLM, PDS, MKK, ALML, EBP. All authors reviewed, discussed, and agreed the manuscript.

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.

Data availability

Deidentified participant are not openly available presently and may be made available to other researchers upon request following permission, investigator support and a signed data access agreement.

Acknowledgements

The investigators gratefully thank the children and their guardians for their participation. The authors acknowledge the following sources of funding. The MetCog project was funded by the Newton Fund Programme. This grant was awarded by the Medical Research Council UK (MR/N029194/1) in collaboration with CONACyT México (FONCICIT/37/2016) to Po-Wah So, Benito de Celis Alonso and Jimmy Bell. Juana María Delgado-Saborit is a recipient of funds from Generalitat Valenciana - Regional Ministry of Education, Research, Culture and Sport under the Talented Researcher Support Programme - Plan GenT (CIDEGENT/2019/064).

Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.envres.2023.116968.

References

Abdelhamid, G.S.M., Bassiouni, M.G.A., Gómez-Benito, J., 2021. Assessing cognitive abilities using the wais-iv: an item response theory approach. Int. J. Environ. Res. Publ. Health 18 (13). https://doi.org/10.3390/ijerph18136835.

Adlakha, D., Chandra, M., Krishna, M., Smith, L., Tully, M.A., 2021. Designing age-friendly communities: exploring qualitative perspectives on urban green spaces and ageing in two Indian megacities. Int. J. Environ. Res. Publ. Health 18 (4), 1–13. https://doi.org/10.3390/IJERPH18041491.

Andersen, L., Corazon, S.S., Stigsdotter, U.K., 2021. Nature exposure and its effects on immune system functioning: a systematic review. Int. J. Environ. Res. Publ. Health 18 (4). https://doi.org/10.3390/ijerph18041416.

Aram, F., Higueras García, E., Solgi, E., Mansournia, S., 2019. Urban green space cooling effect in cities. Heliyon 5 (4), e01339. https://doi.org/10.1016/J.HELIYON.2019.E01339.

Asta, F., Michelozzi, P., Cesaroni, G., De Sario, M., Davoli, M., Porta, D., 2021. Green spaces and cognitive development at age 7 years in a rome birth cohort: the mediating role of nitrogen dioxide. Environ. Res. 196, 110358 https://doi.org/10.1016/J.ENVRES.2020.110358.

Azmi, D.I., Karim, H.A., Amin, M.Z.M., 2012. Comparing the walking behaviour between urban and rural residents. Procedia-Social and Behavioral Sciences 68, 406–416.

Barton, H., Grant, M., Guise, R., 2003. Shaping Neighbourhoods: a Guide for Health, Sustainability and Vitality. Taylor & Francis.

Bhugra, D., Castaldelli-Maia, J.M., Torales, J., Ventriglio, A., 2019. Megacities, migration, and mental health. Lancet Psychiatr. 6 (11), 884–885. https://doi.org/10.1016/S2215-0366(19)30294-9.

Bidzan-Bluma, I., Lipowska, M., 2018. Physical activity and cognitive functioning of children: a systematic review. International Journal of Environmental Research and Public Health 2018 15 (4), 800. https://doi.org/10.3390/IJERPH15040800. *800*, 15.

Bratman, G.N., Daily, G.C., Levy, B.J., Gross, J.J., 2015. The benefits of nature experience: improved affect and cognition. Landsc. Urban Plann. 138 https://doi.org/10.1016/j.landurbplan.2015.02.005.

Browning, M.H.E.M., Rigolon, A., McAnirlin, O., Yoon, H. (Violet), 2022. Where greenspace matters most: a systematic review of urbanicity, greenspace, and physical health. Landsc. Urban Plann. 217, 104233 https://doi.org/10.1016/J.LANDURBPLAN.2021.104233.

Centers for Disease Control and Prevention, 2020. Childhood Obesity Causes & Consequences. Centers for Disease Control and Prevention (CDC). https://www.cdc.gov/obesity/childhood/causes.html.

Consejo Nacional de Evaluación de la Política de Desarrollo Social, 2020. Pobreza por localidad urbana 2020. https://www.coneval.org.mx/Medicion/Paginas/pobreza_localidad_urbana.aspx.

Crawford, J., Anderson, V., Psychology, P.R., et al., 2010. An index-based short-form of the wisc-iv with accompanying analysis of the reliability and abnormality of differences. Wiley Online Library 49 (2), 235–258. https://doi.org/10.1348/014466509X455470.

Dadvand, P., Nieuwenhuijsen, M.J., Esnaola, M., Forns, J., Basagaña, X., Alvarez-Pedrerol, M., Rivas, I., López-Vicente, M., De Pascual, M.C., Su, J., Jerrett, M., Querol, X., Sunyer, J., 2015. Green spaces and cognitive development in primary schoolchildren. Proc. Natl. Acad. Sci. U.S.A. 112 (26), 7937–7942. https://doi.org/10.1073/PNAS.1503402112/-/DCSUPPLEMENTAL.

Damián González, A., Pérez García, M.J., Infanzón Valdivieso, M.J., 2020. Ciudad de México 2020. Un diagnóstico de la desigualdad socioterritorial.

Dasi, C., Soler, M., Bellver, V., Reports, J. R.-P., & 2014, undefined, 2014. Short form of Spanish version of the WISC–IV for intelligence assessment in elementary school children. Journals.Sagepub.Com 115 (3), 784–793. https://doi.org/10.2466/03.PR0.115c32z7.

de Desarrollo Social, Secretaría, 1992. Estructura del sistema normativo *(In English: Structure of the regulartory system)*.

De Keijzer, C.S., 2020. Green Spaces: A Resource for Mental Health. January 8. ISGlobal. https://www.isglobal.org/en/healthisglobal/-/custom-blog-portlet/espacios-verdes-un-recurso-para-la-salud-mental/6113078/0.

Delclòs-Alió, X., Rodríguez, D.A., Medina, C., Miranda, J.J., Avila-Palencia, I., Targa, F., Moran, M.R., Sarmiento, O.L., Quistberg, D.A., 2022. Walking for transportation in large Latin American cities: walking-only trips and total walking events and their sociodemographic correlates. Transport Rev. 42 (3), 296–317.

Didan, K., 2015. MOD13Q1 MODIS/Terra vegetation indices 16-day L3 global 250m SIN grid V006 [data set]. NASA Land Data Products and Services. https://doi.org/10.5067/MODIS/MOD13Q1.006.

Dirección General Adjunta de Investigación del, I.N.E.G.I., 2021. Cuantificando la Clase Media en México 2010-2020. https://www.inegi.org.mx/contenidos/investigacion/cmedia/doc/cm_desarrollo.pdf.

Dowell, L.R., Mahone, E.M., 2011. Perceptual Reasoning Index. Encyclopedia of Clinical Neuropsychology, pp. 1903–1907.

Dzhambov, A.M., Dimitrova, D.D., 2015. Green spaces and environmental noise perception. Urban For. Urban Green. 14 (4), 1000–1008. https://doi.org/10.1016/J.UFUG.2015.09.006.

Emmanuel, M., Bokor, B.R., 2022. Tanner Stages. StatPearls Publishing, Treasure Island (FL. http://europepmc.org/books/NBK470280.

Flies, E.J., Skelly, C., Negi, S.S., Prabhakaran, P., Liu, Q., Liu, K., Goldizen, F.C., Lease, C., Weinstein, P., 2017. Biodiverse green spaces: a prescription for global urban health. Front. Ecol. Environ. 15 (9) https://doi.org/10.1002/fee.1630.

Flouri, E., Papachristou, E., Midouhas, E., 2019. The role of neighbourhood greenspace in children's spatial working memory. Br. J. Educ. Psychol. 89 (2), 359–373. https://doi.org/10.1111/BJEP.12243.

Garroutte, E.L., Hansen, A.J., Lawrence, R.L., Ustin, S.L., Wynne, R.H., Thenkabail, P.S., 2016. Using NDVI and EVI to Map Spatiotemporal Variation in the Biomass and Quality of Forage for Migratory Elk in the Greater Yellowstone Ecosystem. https://doi.org/10.3390/rs8050404.

Gascon, M., Mas, M.T., Martínez, D., Dadvand, P., Forns, J., Plasència, A., Nieuwenhuijsen, M.J., 2015. Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. International Journal of Environmental Research and Public Health 2015 12 (4), 4354–4379. https://doi.org/10.3390/IJERPH120404354, 12, Pages 4354-4379.

Gómez Lopera, F., 2005. Las zonas verdes como factor de calidad de vida en las ciudades. Ciudad Territ. - Estud. Territ. 37 (144), 417.

Goodsite, M.E., Hertel, O., 2012. Urban Air Quality air quality : sources air quality sources and Concentrations air quality concentrations. Encyclopedia of Sustainability Science and Technology 11291–11311. https://doi.org/10.1007/978-1-4419-0851-3_321.

Gülgönen, T., Corona, Y., 2019. ¿Jugar en la ciudad? La percepción de niñas y niños de la Ciudad de México sobre su entorno urbano. Cadernos de Pesquisa Em Educaçao (49), 60–80.

Haddad, A., Doherty, R., Purtilo, R., 2019. Respectful Interaction. Health Professional and Patient Interaction, pp. 167–180. https://doi.org/10.1016/B978-0-323-53362-1.00011-6.

Hartig, T., Mitchell, R., De Vries, S., Frumkin, H., 2014. Nature and health. Erratum Annu. Rev. Public Health 35, 207–228. https://doi.org/10.1146/annurev-publhealth-032013-182443.

Herzog, T.R., Black, A.M., Fountaine, K.A., Knotts, D.J., 1997. Reflection and attentional recovery as distinctive benefits of restorative environments. J. Environ. Psychol. 17 (2) https://doi.org/10.1006/jevp.1997.0051.

Huang, C., Yang, J., Lu, H., Huang, H., Yu, L., 2017. Green spaces as an indicator of urban health: evaluating its changes in 28 mega-cities. Remote Sensing 2017 9 (12), 1266. https://doi.org/10.3390/RS9121266. *Page 1266*, 9.

Instituto Nacional de Estadística y Geografía, 2018. COMUNICADO DE PRENSA NÚM. 104/18 19 DE FEBRERO DE 2018. https://www.inegi.org.mx/contenidos/saladeprensa/boletines/2018/EstSociodemo/OrgenDest2018_02.pdf.

Instituto Nacional de Estadística y Geografía, 2020. Censo de Población y Vivienda 2020. https://www.inegi.org.mx/programas/ccpv/2020/.

James, P., Banay, R.F., Hart, J.E., Laden, F., 2015. A review of the health benefits of greenness. Current Epidemiology Reports 2 (2), 131. https://doi.org/10.1007/S40471-015-0043-7.

Jiang, Z., Huete, A.R., Didan, K., Miura, T., 2008. Development of a two-band enhanced vegetation index without a blue band. Rem. Sens. Environ. 112 (10), 3833–3845. https://doi.org/10.1016/J.RSE.2008.06.006.

Jimenez, M.P., Shoaff, J., Kioumourtzoglou, M.A., Korrick, S., Rifas-Shiman, S.L., Hivert, M.F., Oken, E., James, P., 2022. Early-life exposure to green space and mid-childhood cognition in the project Viva cohort, Massachusetts. Am. J. Epidemiol. 191 (1), 115–125. https://doi.org/10.1093/AJE/KWAB209.

Kaplan, S., Berman, M.G., 2010. Directed attention as a common resource for executive functioning and Self-Regulation. Perspect. Psychol. Sci. 5 (1) https://doi.org/10.1177/1745691609356784.

Kellman, P.J., Garrigan, P., 2009. Perceptual learning and human expertise. Phys. Life Rev. 6 (2), 53. https://doi.org/10.1016/J.PLREV.2008.12.001.

Knobel, P., Maneja, R., Bartoll, X., Alonso, L., Bauwelinck, M., Valentin, A., Zijlema, W., Borrell, C., Nieuwenhuijsen, M., Dadvand, P., 2021. Quality of urban green spaces influences residents' use of these spaces, physical activity, and overweight/obesity. Environ. Pollut. 271, 116393 https://doi.org/10.1016/J.ENVPOL.2020.116393.

Kumar, A., Kumar, P., Mishra, R.K., Shukla, A., 2018. Study of Air and Noise Pollution in Mega Cities of India, vols. 77–84. https://doi.org/10.1007/978-981-10-5792-2_7.

Liao, J., Zhang, B., Xia, W., Cao, Z., Zhang, Y., Liang, S., Hu, K., Xu, S., Li, Y., 2019. Residential exposure to green space and early childhood neurodevelopment. Environ. Int. 128, 70–76. https://doi.org/10.1016/J.ENVINT.2019.03.070.

Lotfi, S., Koohsari, M.J., 2009. Analyzing accessibility dimension of urban quality of life: where urban designers face duality between subjective and objective reading of place. Soc. Indicat. Res. 94, 417–435.

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A.M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M.J., Lupp, G., Richardson, E.A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., Fuertes, E., 2017. Exploring pathways linking greenspace to health: theoretical and methodological guidance. Environ. Res. 158, 301–317. https://doi.org/10.1016/J.ENVRES.2017.06.028.

Matute, E., Inozemtseva, O., González-Reyes, A., Chamorro, Y., 2014. La Evaluación Neuropsicológica Infantil (ENI): historia y fundamentos teóricos de su validación. Un acercamiento práctico a su uso y valor diagnóstico. Revista Neuropsicología, Neuropsiquiatría y Neurociencias 14, 68–95.

Mayen Huerta, C., 2022. Rethinking the distribution of urban green spaces in Mexico City: Lessons from the COVID-19 outbreak. Urban For. Urban Green. 70, 127525 https://doi.org/10.1016/J.UFUG.2022.127525.

McCormack, G.R., Giles-Corti, B., Bulsara, M., 2008. The relationship between destination proximity, destination mix and physical activity behaviors. Prev. Med. 46 (1), 33–40.

McCormick, R., 2017. Does access to green space impact the mental well-being of children: a systematic review. J. Pediatr. Nurs. 37, 3–7. https://doi.org/10.1016/J.PEDN.2017.08.027.

McManus, E., Talmi, D., Haroon, H., Muhlert, N., 2022. Psychosocial stress has weaker than expected effects on episodic memory and related cognitive abilities: a meta-analysis. Neurosci. Biobehav. Rev. 132 https://doi.org/10.1016/j.neubiorev.2021.10.038.

Millan, M.J., Agid, Y., Brüne, M., Bullmore, E.T., Carter, C.S., Clayton, N.S., Connor, R., Davis, S., Deakin, B., Derubeis, R.J., Dubois, B., Geyer, M.A., Goodwin, G.M., Gorwood, P., Jay, T.M., Joëls, M., Mansuy, I.M., Meyer-Lindenberg, A., Murphy, D., et al., 2012. Cognitive dysfunction in psychiatric disorders: characteristics, causes and the quest for improved therapy. Nat. Rev. Drug Discov. 11 (2), 141–168. https://doi.org/10.1038/nrd3628, 2012 11:2.
Mitchell, K., Bendixson, T., 2015. Planning for Walking. Chartered Institution of Highways and Transportation.
Molina, L.T., Zhu, T., Wan, W., Gurjar, B.R., 2020. Impacts of Megacities on Air Quality: Challenges and Opportunities. Oxford Research Encyclopedia of Environmental Science. https://doi.org/10.1093/ACREFORE/9780199389414.013.5.
Nguyen, P.Y., Astell-Burt, T., Rahimi-Ardabili, H., Feng, X., 2021. Green space quality and health: a systematic review. Int. J. Environ. Res. Publ. Health 18 (21). https://doi.org/10.3390/IJERPH182111028/S1.
Nowak, D.J., Crane, D.E., Stevens, J.C., 2006. Air pollution removal by urban trees and shrubs in the United States. Urban For. Urban Green. 4 (3–4), 115–123. https://doi.org/10.1016/J.UFUG.2006.01.007.
Ohly, H., White, M.P., Wheeler, B.W., Bethel, A., Ukoumunne, O.C., Nikolaou, V., Garside, R., 2016. Attention Restoration Theory: a systematic review of the attention restoration potential of exposure to natural environments. J. Toxicol. Environ. Health B Crit. Rev. 19 (Issue 7) https://doi.org/10.1080/10937404.2016.1196155.
Oswald, T.K., Rumbold, A.R., Kedzior, S.G.E., Moore, V.M., 2020. Psychological impacts of "screen time" and "green time" for children and adolescents: a systematic scoping review. PLoS One 15 (9). https://doi.org/10.1371/JOURNAL.PONE.0237725.
Paolettia, E., Bardelli, T., Giovannini, G., Pecchioli, L., 2011. Air quality impact of an urban park over time. Procedia Environmental Sciences 4, 10–16. https://doi.org/10.1016/J.PROENV.2011.03.002.
Pérez Medina, S., Fargher, L.F., 2016. Uso de los parques recreativos en Mérida, Yucatán. Estud. Demográficos Urbanos 31 (3), 775–810.
Pouya, S., Bayramoğlu, E., Demirel, Ö., Teknik Üniversitesi, K., Fakültesi, O., Mimarlığı Bölümü, P., 2016. Restoratıve Garden as an Useful Way to Relıeve Stress In Megacıtıes, a Case Study in Istanbul. Dergipark.Org.Tr. https://doi.org/10.16950/iüstd.55348.
Psychology, Practical, 2022. Perceptual reasoning (definition + examples) | practical Psychology. Practical Psychology. https://practicalpie.com/perceptual-reasoning/.
Queiroz Almeida, D., Barros, H., Isabel Ribeiro, A., 2021. Residential and school green and blue spaces and intelligence in children: the Generation XXI birth cohort. Sci. Total Environ. https://doi.org/10.1016/j.scitotenv.2021.151859.
Rajulapati, C.R., Abdelmoaty, H.M., Nerantzaki, S.D., Papalexiou, S.M., 2022. Changes in the risk of extreme temperatures in megacities worldwide. Climate Risk Management 36, 100433. https://doi.org/10.1016/J.CRM.2022.100433.
Ramadhani Yusuf, F., Budi Santoso, K., Ulul Lizamun Ningam, M., Dolanan Endang Sri Maruti, T., Kuncoro Hadi, P., Muchsin, F., Dirghayu, D., Prasasti, I., Rahayu, M.I., Fibriawati, L., Pradono, K.A., Mahatmanto, B., 2019. Comparison of atmospheric correction models: FLAASH and 6S code and their impact on vegetation indices (case study: paddy field in Subang District, West Java). IOP Conf. Ser. Earth Environ. Sci. 280 (1), 012034 https://doi.org/10.1088/1755-1315/280/1/012034.
Requia, W.J., Adams, M.D., 2022. Green areas and students' academic performance in the Federal District, Brazil: an assessment of three greenness metrics. Environ. Res. 211, 113027 https://doi.org/10.1016/J.ENVRES.2022.113027.
Ricciardi, E., Spano, G., Lopez, A., Tinella, L., Clemente, C., Elia, G., Dadvand, P., Sanesi, G., Bosco, A., Caffò, A.O., 2022. Long-term exposure to greenspace and cognitive function during the lifespan: a systematic review. Int. J. Environ. Res. Publ. Health 19 (18). https://doi.org/10.3390/IJERPH191811700.
Rigolon, A., 2016. A complex landscape of inequity in access to urban parks: a literature review. Landsc. Urban Plann. 153, 160–169. https://doi.org/10.1016/J.LANDURBPLAN.2016.05.017.
Secretaría de Bienestar del Gobierno de México, 2022. Annual Report on the Situation of Poverty and Social Backwardness 2022. https://www.gob.mx/bienestar/documentos/informe-anual-sobre-la-situacion-de-pobreza-y-rezago-social.
Selmi, W., Weber, C., Rivière, E., Blond, N., Mehdi, L., Nowak, D., 2016. Air pollution removal by trees in public green spaces in Strasbourg city, France. Urban For. Urban Green. 17, 192–201. https://doi.org/10.1016/J.UFUG.2016.04.010.
Shuvo, F.K., Feng, X., Akaraci, S., Astell-Burt, T., 2020. Urban green space and health in low and middle-income countries: a critical review. Urban For. Urban Green. 52, 126662 https://doi.org/10.1016/J.UFUG.2020.126662.
Stansfeld, S.A., 1992. Noise, noise sensitivity and psychiatric disorder: epidemiological and psychophysiological studies. Psychol. Med. Monogr. Suppl. 22, 1–44.
Storey, J.D., Tibshirani, R., 2003. Statistical significance for genomewide studies. Proc. Natl. Acad. Sci. U.S.A. 100 (16), 9440–9445. https://doi.org/10.1073/PNAS.1530509100.
Sun, Y., Saha, S., Tost, H., Kong, X., Xu, C., 2022. Literature review reveals a global access inequity to urban green spaces. Sustainability 14 (3), 1062. https://doi.org/10.3390/su14031062.
Taylor, A.F., Kuo, F.E., Sullivan, W.C., 2002. Views of nature and self-discipline: evidence from inner city children. J. Environ. Psychol. 22 (1–2) https://doi.org/10.1006/jevp.2001.0241.
The World Bank, 2022. World Bank Country and Lending Groups. https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.
Ulrich, R.S., 1983. Aesthetic and affective response to natural environment. In: Behavior and the Natural Environment. https://doi.org/10.1007/978-1-4613-3539-9_4.
United Nations, 2020. World Economic Situation and Prospects 2020. https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/WESP2020_Annex.pdf.
United Nations, Department of Economic and Social Affairs, P. D, 2018. World Urbanization Prospects the 2018 Revision.
Van Kempen, E., Devilee, J., Swart, W., Van Kamp, I., 2014. Noise and health. Noise Health 16 (73), 380. https://doi.org/10.4103/1463-1741.144416.
Vella-Brodrick, D.A., Gilowska, K., 2022. Effects of nature (greenspace) on cognitive functioning in school children and adolescents: a systematic review. Educ. Psychol. Rev. 34 (3), 1217–1254. https://doi.org/10.1007/S10648-022-09658-5/TABLES/8.
Wang, H., Dai, X., Wu, J., Wu, X., Nie, X., 2019. Influence of urban green open space on residents' physical activity in China. BMC Publ. Health 19 (1). https://doi.org/10.1186/s12889-019-7416-7.
Wang, M., Qiu, M., Chen, M., Zhang, Y., Zhang, S., Wang, L., 2021. How does urban green space feature influence physical activity diversity in high-density built environment? An on-site observational study. Urban For. Urban Green. 62 https://doi.org/10.1016/j.ufug.2021.127129.
Wechsler, D., 2003. Wechsler intelligence scale for children. In: The Phsycological Corporation, fourth ed.
Weier, J., Herring, D., 2000. Measuring vegetation (NDVI & EVI). NASA Earth Observatory 20.
White, R.F., Campbell, R., Echeverria, D., Knox, S.S., Janulewicz, P., 2009. Assessment of neuropsychological trajectories in longitudinal population-based studies of children. J. Epidemiol. Community Health 63 (Suppl. 1), i15–i26. https://doi.org/10.1136/JECH.2007.071530.
WHO Regional Office for Europe, 2016. Regional Office for Europe. In: Urban Green Spaces and Health. World Health Organization. https://www.euro.who.int/__data/assets/pdf_file/0005/321971/Urban-green-spaces-and-health-review-evidence.pdf.
World Health Organization, 2022. Children's Environmental Health. https://www.who.int/health-topics/children-environmental-health#tab=tab_1.
Yang, Y., Diez-Roux, A.V., 2012. Walking distance by trip purpose and population subgroups. Am. J. Prev. Med. 43 (1), 11–19.
Yang, B.-Y., Zhao, T., Hu, L.-X., Browning, M.H.E.M., Heinrich, J., Dharmage, S.C., Jalaludin, B., Knibbs, L.D., Liu, X.-X., Luo, Y.-N., James, P., Li, S., Huang, W.-Z., Chen, G., Zeng, X.-W., Hu, L.-W., Yu, Y., Dong, G.-H., 2021. Greenspace and human health: an umbrella review. Innovation 2 (4), 100164. https://doi.org/10.1016/J.XINN.2021.100164.
Zupancic, T., Bulthuis, M., Westmacott, C., 2015. The Impact of Green Space on Heat and Air Pollution in Urban Communities.