

Supplementary Materials

Greenspace exposure and children behavior: a systematic review

Mohammad Javad Zare Sakhvidi, Pablo Knobel, Mariska Bauwelinck, Carmen de Keijzer, Lilian Marie Boll, Giuseppina Spano, Monica Ubalde-Lopez, Giovanni Sanesi, Amir Houshang Mehrparvar, Bénédicte Jacquemin, Payam Dadvand

Table of contents

Table S1	Page 2
Table S2	Page 3
Table S3	Page 5
Table S4	Page 6
Table S5	Page 7
Table S6	Page 9
Table S7	Page 13
Table S8	Page 15

Table S1. PECO (population, exposure, comparison, outcome) for a systematic review on the association between greenspace exposure and behavioral problems in children.

Decision	Population	Exposure	Comparison	Outcome	Type of study
Inclusion	Human (Children)	Greenspace; urban park; agricultural lands; forest	Not applicable	Selected behavioral problems	Cross-sectional; case-control; cohort
Exclusion	Human (Adult, adolescence) Animal; Occupational cohorts	Blue space, other natural spaces	Not applicable	Cognitive outcomes, results of neuroimaging	Review articles, semi- or natural experimental studies, qualitative studies

Table S2. Search content used for systematic search on the association between exposure to greenspace and behavioral problems in children on PubMed database (updated on November 29, 2021).

Section	Search content	Number of retrieved items
Population	((((((((child[Title/Abstract] OR (children[Title/Abstract])) OR (adolescent[Title/Abstract])) OR (adolescents[Title/Abstract])) OR (teenager[Title/Abstract])) OR (teenagers[Title/Abstract])) OR (childhood[Title/Abstract])) OR ("early life"[Title/Abstract])) OR (prenatal[Title/Abstract])) OR (postnatal[Title/Abstract])) OR (("Child"[Mesh]) OR "Child, Preschool"[Mesh])	2,827,047
Exposure	((((((((((((((((("built environment"[Title/Abstract] OR ("urban environment"[Title/Abstract])) OR (urbanization[Title/Abstract])) OR (greenspace[Title/Abstract])) OR (greenspaces[Title/Abstract])) OR ("green space"[Title/Abstract])) OR ("green spaces"[Title/Abstract])) OR (greenness[Title/Abstract])) OR (greenery[Title/Abstract])) OR (ndvi[Title/Abstract])) OR (msavi[Title/Abstract])) OR (savi[Title/Abstract])) OR ("normalized difference vegetation index"[Title/Abstract])) OR (vegetation[Title/Abstract])) OR (parks[Title/Abstract])) OR (park[Title/Abstract])) OR ("park land"[Title/Abstract])) OR ("natural environments"[Title/Abstract])) OR ("land use"[Title/Abstract])) OR ("land cover"[Title/Abstract])) OR (" exposure to nature"[Title/Abstract])) OR ("nature exposure"[Title/Abstract])) OR ("proximity to nature"[Title/Abstract])) OR ("natural environment"[Title/Abstract])) OR ("nature contact"[Title/Abstract])) OR ("Parks, Recreational"[Mesh])	99,105
Outcome	((((((((((((((((((((neurodevelopment[Title/Abstract] OR (neurodevelopmental[Title/Abstract])) OR ("attention deficit"[Title/Abstract])) OR (attentiveness[Title/Abstract])) OR (inattention[Title/Abstract])) OR (inattentiveness[Title/Abstract])) OR ("behavioural problems"[Title/Abstract])) OR ("behavioral problems"[Title/Abstract])) OR ("behavioural difficulties"[Title/Abstract])) OR ("behavioral difficulties"[Title/Abstract])) OR ("emotional problems"[Title/Abstract])) OR ("emotional difficulties"[Title/Abstract])) OR ("peer relationship"[Title/Abstract])) OR ("Prosocial behavior"[Title/Abstract])) OR ("brain development"[Title/Abstract])) OR (neurobehavioural[Title/Abstract])) OR (neurobehavioral[Title/Abstract])) OR (hyperactivity[Title/Abstract])) OR (adhd[Title/Abstract])) OR ("conduct problems"[Title/Abstract])) OR ("conditional problems"[Title/Abstract])) OR ("Internalizing behaviors"[Title/Abstract])) OR ("Externalizing behaviors"[Title/Abstract])) OR (((("Child Behavior"[Mesh]) OR "Attention Deficit	316,830

	Disorder with Hyperactivity"[Mesh]) OR "Neurodevelopmental Disorders"[Mesh])	
All	1 AND 2 AND 3	399

Table S3. Search query used for systematic search on the association between exposure to greenspace and behavioral problems in children on Scopus database (updated on November 29, 2021).

Section	Search query	Number of retrieved objects
Population	TITLE-ABS (child OR children OR adolescent OR adolescents OR teenager OR teenagers OR childhood OR "early life" OR prenatal OR postnatal)	2,559,688
Exposure	TITLE-ABS ("built environment" OR "urban environment" OR "urbanization" OR greenspace OR greenspaces OR "green space" OR "green spaces" OR greenness OR greenery OR ndvi OR msavi OR savi OR "normalized difference vegetation index" OR vegetation OR parks OR park OR "park land" OR "natural environments" OR "land use" OR "land cover" OR " exposure to nature" OR "nature exposure" OR "proximity to nature" OR "natural environment" OR " nature contact")	685,046
Outcome	TITLE-ABS (neurodevelopment OR neurodevelopmental OR "attention deficit" OR attentiveness OR inattention OR inattentiveness OR "behavioural problems" OR "behavioral problems" OR "behavioural difficulties" OR "behavioral difficulties" OR "emotional problems" OR "emotional difficulties" OR "peer relationship" OR "Prosocial behavior" OR "brain development" OR neurobehavioural OR neurobehavioral OR hyperactivity OR adhd OR "conduct problems" OR "conditional problems" OR "Internalizing behaviors" OR "Externalizing behaviors")	192,465
All	1 AND 2 AND 3	208

Table S4. Sample search strategy in the Web of Science databases including WOS, KJD, RSCI, SCIELO Timespan=All years
Search language=Auto (until November 30; 2021).

Section	Search query	Number of retrieved objects
Population	TS=(child)OR TS=(children)OR TS=(adolescent)OR TS=(adolescents)OR TS=(teenager)OR TS=(teenagers)OR TS=(childhood)OR TS=(early?life)OR TS=(prenatal)OR TS=(postnatal)	5279628
Exposure	TS=(greenspace) OR TS=(greenness) OR TS=(green?space) OR TS=(green?spaces) OR TS=(greenspaces) OR TS=(land?cover) OR TS=(agriculture) OR TS=(parkland) OR TS=(ndvi) OR TS=(vegetation) OR TS=(normalized?difference?vegetation?index) OR TS=(MSAVI) OR TS=(SAVI) OR TS=(exposure?to?nature) OR TS=(nature?exposure) OR TS=(proximity?to?nature) OR TS=(natural?environment) OR TS=(nature?contact) OR TS=(greenery) OR TS=(built environment) OR TS=(urban environment) OR TS=(urbanization) OR TS=("land use") OR TS=(park) OR TS=(parks)	1918327
Outcome	TS=(neurodevelopment)OR TS=(neurodevelopmental)OR TS=(attention?deficit)OR TS=(attentiveness)OR TS=(inattention)OR TS=(inattentiveness)OR TS=(behavioural?problems)OR TS=(behavioral?problems)OR TS=(behavioural?difficulties)OR TS=(behavioral?difficulties) OR TS=(emotional?problems) OR TS=(emotional?difficulties)OR TS=(peer?relationship)OR TS=(Prosocial?behavior) OR TS=(brain?development) OR TS=(neurobehavioural) OR TS=(neurobehavioral) OR TS=(hyperactivity) OR TS=(ADHD) OR TS=(conduct?problems) OR TS=(conditional problems) OR TS=(Internalizing?behaviors) OR TS=(Externalizing?behaviors)	196566
All	1 AND 2 AND 3	622

Table S5. Modified Newcastle-Ottawa Scale (NOS) for assessing the risk of bias in the cohort, case-control, and cross-sectional studies.

Domain	Item	Description (for gaining the star)	Attainable score
Cohort studies			
Population selection	Representativeness (P1)	Participants form the general population with random sampling or close to the general population (not in specific regions such as only urban participants or specific age group)	One star
	Non-exposed selection (P2)	Drawn from the same community as the exposed cohort	One star
	Ascertainment of exposure (P3)	Using residential address at the individual level	One star
	No outcome at the start (P4)	Demonstrated that outcome of interest was not present at the start of the study	One star
Comparability	Comparability (C 1, C2)	A) Adjustment for at least minimal cut set variables determined by the DAG (and not inclusion of mediators or over adjustment) AND B) Additional model with the inclusion of possible mediators	A) One star AND B) One star
Outcome	Outcome assessment (O1)	Independent blind assessment or record linkage (national or local registrations)	One star
	Length of follow-up (O2)	At least 1 year of follow-up	One star
	Adequacy of follow up (O3)	Less than 20% loss to follow-up and that the loss to follow-up is not associated with bias in the estimates.	One star
Case-control studies			
Population selection	Representativeness (P1)	Representative of the disease of interest	One star
	Case definition (P1)	With independent validation (record linkage, hospital registration)	One star
	Control selection (P1)	Community control	One star
	Control definition (P1)	No history of outcome	One star
Comparability	Comparability (C1, C2)	A) Adjustment for at least minimal cut set variables determined by the DAG (and not inclusion of mediators or over adjustment) AND B) Additional model with the inclusion of possible mediators	A) One star AND B) One star
Outcome	Exposure assessment (O1)	Personal level interview	One star
	Exposure ascertainment (O2)	Using residential address at individual level	One star
	Non-Response rate (O3)	Below 20%	One star
Cross-sectional studies			

Population selection	Representativeness (P1)	Truly or somewhat representative of the source population (random sampling), or not from a specific group, region, or ethnicity	One star
	Sample size (P2)	Unit of study be at the individual level and not area-level outcome data.	One star
	Non-respondent (P3)	Comparability between respondent and non-respondents, and given participation rate	One star
	Ascertainment of exposure (P4)	The individual-level at home address	One star
Comparability	Comparability (C1, C2)	A) Adjustment for at least minimal cut set variables determined by the DAG (and not inclusion of mediators or over adjustment) AND B) Additional model with the inclusion of possible mediators	A) One star AND B) One star
Outcome	Outcome assessment (O1)	National or local registration, medically diagnosed (not self-report) OR Self-report	Two stars OR One star
	Statistical tests (O2)	Give data on point estimate and confidence interval	One star

Table S6: The list of excluded studies at full-text assessment step and reasons for the exclusion.

No	Citation	Reason
1	Baroni A, Castellanos FX. 2019. Emerging insights into the association between nature exposure and healthy neuronal development. <i>JAMA network open</i> 2:e1917880.	Commentary paper on Yang et al. (2019) paper.
2	Bates CR, Bohnert AM, Gerstein DE. 2018. Green schoolyards in low-income urban neighborhoods: Natural spaces for positive youth development outcomes. <i>Frontiers in psychology</i> 9:805.	No relevant exposure (exposure was school renovation)
3	Binter AC, Bernard JY, Mon-Williams M, Andiarena A, González-Safont L, Vafeiadi M, et al. 2022. Urban environment and cognitive and motor function in children from four european birth cohorts. <i>Environment international</i> 158.	No relevant outcome (cognitive outcome)
4	Cederblad M, Rahim SI. 1986. Effects of rapid urbanization on child behaviour and health in a part of khartoum, sudan--i. Socio-economic changes 1965-1980. <i>Social science & medicine</i> (1982) 22:713-721.	No relevant outcome (wellbeing outcome)
5	Dadvand P, Tischer C, Estarlich M, Llop S, Dalmau-Bueno A, López-Vicente M, et al. 2017. Lifelong residential exposure to green space and attention: A population-based prospective study. <i>Environmental health perspectives</i> 125:097016.	No relevant outcome (cognitive outcome)
6	Di Carmine F, Berto R. 2021. Contact with nature can help adhd children to cope with their symptoms. The state of the evidence and future directions for research. <i>Visions for Sustainability</i> 2021:24-34.	Review article
7	Evans BE, van der Ende J, Greaves-Lord K, Huizink AC, Beijers R, de Weerth C. 2020. Urbanicity, hypothalamic-pituitary-adrenal axis functioning, and behavioral and emotional problems in children: A path analysis. <i>BMC psychology</i> 8:12.	No relevant exposure (exposure was urbanization)
8	Julvez J, López-Vicente M, Warembourg C, Maitre L, Philippat C, Gützkow KB, et al. 2021. Early life multiple exposures and child cognitive function: A multi-centric birth cohort study in six european countries. <i>Environmental</i>	No relevant outcome (cognitive outcome)

	pollution (Barking, Essex : 1987) 284:117404.	outcome)
9	Katapally TR, Muhajarine N. 2015. Capturing the interrelationship between objectively measured physical activity and sedentary behaviour in children in the context of diverse environmental exposures. <i>International journal of environmental research and public health</i> 12:10995-11011.	No relevant outcome (sedentary behavior)
10	Kuo FE, Taylor AF. 2004. A potential natural treatment for attention-deficit/hyperactivity disorder: Evidence from a national study. <i>American journal of public health</i> 94:1580-1586.	No relevant exposure (exposure to outdoor nature versus indoor classroom)
11	Largo-Wight E, Guardino C, Wludyka PS, Hall KW, Wight JT, Merten JW. 2018. Nature contact at school: The impact of an outdoor classroom on children's well-being. <i>International journal of environmental health research</i> 28:653-666.	No relevant exposure (exposure to outdoor nature versus indoor classroom)
12	Liao J, Zhang B, Xia W, Cao Z, Zhang Y, Liang S, et al. 2019. Residential exposure to green space and early childhood neurodevelopment. <i>Environment international</i> 128:70-76.	No relevant outcome (neurodevelopmental outcomes by BSID)
13	Mennis J, Mason M, Ambrus A. 2018. Urban greenspace is associated with reduced psychological stress among adolescents: A geographic ecological momentary assessment (gema) analysis of activity space. <i>Landscape and Urban Planning</i> 174:1-9.	No relevant outcome (stress)
14	Merrill BM, Raiker JS, Evans SW, Gnagy EM, Pelham WE, Jr. 2021. Cognitive mechanisms of methylphenidate in adhd: Do improvements in sustained attention mediate behavioral improvements in the natural environment? <i>Child neuropsychology : a journal on normal and abnormal development in childhood and adolescence</i> 27:425-446.	No relevant exposure (nature)
15	Nagata M, Liehr P. 2021. Urban children's well-being factors and qualities of being and doing in natural space: Nature immersion. <i>Journal of holistic nursing : official journal of the American Holistic Nurses' Association</i> 39:174-184.	No relevant outcome (positive affect and satisfaction)
16	Poulain T, Sobek C, Ludwig J, Igel U, Grande G, Ott V, et al. 2020. Associations of green spaces and streets in the living environment with outdoor activity, media use, overweight/obesity and emotional wellbeing in children and adolescents.	No relevant outcome (used two

	International journal of environmental research and public health 17.	specific questions of SDQ and defined as emotional problem)
17	Putra IGNE, Astell-Burt T, Cliff DP, Vella SA, Feng X. 2021b. Association between caregiver perceived green space quality and the development of prosocial behaviour from childhood to adolescence: Latent class trajectory and multilevel longitudinal analyses of australian children over 10 years. Journal of Environmental Psychology 74.	Repeated item (see Putra et al. (2021) in the list of selected papers)
28	Putra IGNE, Astell-Burt T, Cliff DP, Vella SA, Feng X. 2021a. Do physical activity, social interaction, and mental health mediate the association between green space quality and child prosocial behaviour? Urban Forestry and Urban Greening 64.	Repeated item (see Putra et al. (2021) in the list of selected papers)
19	Rahim SI, Cederblad M. 1986. Effects of rapid urbanization on child behaviour and health in a part of khartoum, sudan--ii. Psycho-social influences on behaviour. Social science & medicine (1982) 22:723-730.	No relevant exposure and outcome
20	Reuben A, Rutherford GW, James J, Razani N. 2020. Association of neighborhood parks with child health in the united states. Preventive medicine 141:106265.	No appropriate outcome assessment (ADHD outcome was part of the overall outcome named "child health")
21	Rucklidge JJ. 2019. Exposure to green spaces as a modifiable risk factor in attention-deficit hyperactivity disorder. The Lancet Planetary health 3:e200-e201.	Commentary paper on the Donovan et al. (2019) paper
22	Sellers R, Harold GT, Smith AF, Neiderhiser JM, Reiss D, Shaw D, et al. 2021. Disentangling nature from nurture in examining the interplay between parent-child relationships, adhd, and early academic attainment. Psychological medicine 51:645-652.	No relevant exposure
23	Sharp W, Mangalmurti A, Hall C, Choudhury S, Shaw P. 2021. Associations between neighborhood, family factors and symptom change in childhood attention deficit hyperactivity disorder. Social science & medicine (1982) 271:112203.	No relevant exposure
24	Stevenson MP, McEwan J, Bentsen P, Schilhab T, Glue P, Trani P, et al. 2021. Nature walks versus medication: A pre-registered randomized-controlled trial in children with attention deficit/hyperactivity disorder. Journal of Environmental Psychology 77.	No appropriate outcome (used greenspace access in a specific scale with other characteristics)

		and named in as "access to health promoting activities")
25	Taylor AF, Kuo FE. 2009. Children with attention deficits concentrate better after walk in the park. <i>Journal of attention disorders</i> 12:402-409.	No relevant outcome (concentration)
26	van den Berg AE, van den Berg CG. 2011. A comparison of children with adhd in a natural and built setting. <i>Child: care, health and development</i> 37:430-439.	No relevant exposure (used nature definition in general)
27	Whitten T, Stevens R, Ructtinger L, Tzoumakis S, Green MJ, Laurens KR, et al. 2018. Connection to the natural environment and well-being in middle childhood. <i>Ecopsychology</i> 10:270-279.	No appropriate exposure index (defined as connection to nature scale)
28	Younan D, Tuvblad C, Li L, Wu J, Lurmann F, Franklin M, et al. 2016. Environmental determinants of aggression in adolescents: Role of urban neighborhood greenspace. <i>Journal of the American Academy of Child and Adolescent Psychiatry</i> 55:591-601.	No relevant outcome

Table S7. Details on different green spaces definitions and buffer sizes used by the included studies in the review.

Study	Green space type	Buffer size
Amoly et al., 2014	Major green spaces (not defined by type)	100, 250, 500 m
Andrusaityte, et al., 2020	City parks (excluding Small-scale green spaces (such as street trees, green roadsides, or plain forests with no infrastructure), agricultural green places, or nature conservation areas, and part of city forests)	100, 300, 500 m
Balseviciene et al., 2014	City parks (excluding Small-scale green spaces (such as street trees, green roadsides, or plain forests with no infrastructure), agricultural green places, or nature conservation areas, and part of city forests)	300 m
Baumgardner et al., 2010	Park	--
Bijnens et al., 2020	Semi-natural, forested, and urban green areas	50, 100, 300, 500, 1000, 2000 m
Butler et al., 2012	Park or playground area	--
Donovan et al., 2019	Surrounding greenness	Unclear
Feng et al., 2017a	Parks	--
Feng et al., 2017b	Parks	--
Flouri et al., 2014	Unclear (just specified that excluded domestic gardens)	--
Jimenez et al., 2021	Surrounding greenness	90, 270, 1230 m
Lee et al., 2019	Surrounding greenness	1600 m
Liao et al., 2019	Surrounding greenness	100 m
Madzei et al., 2019	Surrounding greenness	200, 400, 800 m
Maes et al., 2021	Surrounding greenness	50, 100, 250 m
Markevych et al., 2014	Cemetery, garden, park, plant nursery	500 m
Markevych et al., 2018	Surrounding greenness	Area level
McEachan et al., 2018	Major green spaces (not clear type)	100, 300, 500 m
Meidenbauer et al., 2019	Unclear (nearby nature)	--

Putra et al., 2021	Availability of good parks, playgrounds, and play space	--
Razani et al., 2015	Park or playground area	--
Reyes et al., 2013	Parks	--
Richardson et al., 2017	Parks	--
Saez et al., 2018	Agricultural, forest, fruit trees and berries, wooden and grasslands	--
Taylor et al., 2011	Green play setting	--
Thygesen et al., 2020	Surrounding greenness	210, 330, 570, 930 m (quadratic area)
Van Aart et al., 2018	Semi-natural and forested, agricultural	100, 500 m
Yang et al., 2019	Surrounding greenness	100, 500, 1000 m
Zach et al., 2016	Public parks or greenspace	--

Table S8: Temporality of exposure-outcome assessment in the retrieved studies in the review.

Study, Year (Country)	Temporality between exposure and outcome
Amoly et al., 2014 (Spain)	Same time with outcome assessment
Andrusaityte, et al., 2020 (Lithuania)	Same time with outcome assessment
Balseviciene et al., 2014 (Lithuania)	Same time with outcome assessment
Baumgardner et al.2010 (USA)	Same time with outcome assessment
Bijnens et al., 2020 (Belgium)	Greenspace during pregnancy and childhood with childhood IQ (both significant)
Butler et al.2012 (USA)	Same time with outcome assessment
Donovan et al.2019 (New Zealand)	Exposure from gestation onward to the time of outcome.
Feng et al., 2017a (Australia)	Same time with outcome assessment
Feng et al., 2017b (Australia)	Longitudinally from the first wave of data gathering (age 4 years) to 18 years.
Flouri et al., 2014 (UK)	Longitudinally from the first wave of data gathering (age 3 years) to 7 years.
Lee et al.2019 (South Korea)	Same time with outcome assessment
Liao et al., 2019 (China)	Same time with outcome assessment (home and kindergarten)
Madzia et al., 2019 (USA)	Longitudinally from the first wave of data gathering (age 7 years) to 12 years.

Study, Year (Country)	Temporality between exposure and outcome
Markevych et al., 2014 (Germany)	Same time with outcome assessment
Markevych et al.2018 (Germany)	Included children who were born between 2000 and 2004; then diagnosed one time between 2005 and 2014, and exposure was the 10-year average level of NDVI for the years 2005 to 2014
McEachan et al., 2018 (UK)	Unclear (probably the same time as the last visit)
Meidenbauer et al., 2019 (USA)	Same time with outcome assessment (experimental)
Razani et al.2015 (USA)	Same time with outcome assessment
Reyes et al.2013 (USA)	Same time with outcome assessment
Richardson et al., 2017 (Scotland)	Exposure at baseline and outcome at both cross-sectional and trajectory
Saez et al.2018 (Spain)	Exposure after outcome (at the last recorded address)
Taylor et al.2011 (USA)	Same time with outcome assessment
Thygesen et al.2020 (Denmark)	Averaged exposure from birth to the time of diagnosis (age of 5)
Van Aart et al., 2018 (Belgium)	Both cross-sectional and longitudinal
Yang et al.2019 (China)	Same time with outcome assessment (considering 2 years residing in the same location)
Zach et al., 2016 (Germany)	Same time with outcome assessment