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Greenspace and health, wellbeing, physical activity, and development in children and adolescents: An overview of the systematic reviews

Mohammad Javad Zare Sakhvidi[1], Amir Houshang Mehrparvar[2], Fariba Zare Sakhvidi[3] and Payam Dadvand[4,5,6]

Abstract

The evidence on the beneficial association of greenspace exposure and mental and physical health and wellbeing of children and adolescents is accumulating. We systematically searched PubMed, Scopus, and Web of Science for systematic reviews and/or meta-analyses on health, developmental, and behavioral outcomes in children and adolescents related to greenspace exposure, published until August 2022. Most of the available reviews are on mental health and behavioral outcomes. The evidence is mainly cross-sectional and conducted in high-income countries. Exposure assessment has been reported as the main methodological challenge in pooling the studies together. Outcome assessment and population characteristics are also among the reported sources of heterogeneity. Overall, reviews are suggestive of a beneficial association of greenspace with a range of outcomes (*e.g.*, birth, neurodevelopmental, cognitive, behavioral, weight-related, mental health and wellbeing, school performance, and physical and outdoor activities), except for allergic and respiratory outcomes for which the evidence is not conclusive.

Addresses

[1] Department of Occupational Health, School of Public Health, Yazd Shahid Sadoughi University of Medical Sciences
[2] Department of Occupational Medicine, School of Medicine, Shahid Sadoughi University of Medical Sciences, Yazd, Iran
[3] Liver and Pancreatobiliary Diseases Research Center, Digestive Diseases Research Institute, Tehran University of Medical Sciences, Tehran, Iran
[4] ISGlobal, Doctor Aiguader 88, 08003 Barcelona, Spain
[5] Universitat Pompeu Fabra (UPF), Doctor Aiguader 88, 08003 Barcelona, Spain
[6] CIBER Epidemiología y Salud Pública (CIBERESP), Melchor Fernández Almagro, 3-5, 28029 Madrid, Spain

Corresponding author: Dadvand, Payam (payam.dadvand@isglobal.org)

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Introduction

The ongoing urbanization has led to an increase in the number of children being born and raised in urban areas [1]. Urban living is often associated with a stressful and sedentary lifestyle, increased exposure to urban-related environmental hazards such as air pollution, noise, and heat, and limited access or exposure to natural environments, especially greenspace [2,3]. Exposure to greenspace has been suggested to improve mental and physical health, wellbeing, and development in children and adolescents [4–6]. The ability of greenspace to exert such benefits has been suggested to be through socio-behavioral factors (*e.g.*, increase in physical activity, social cohesion, and attention restoration and a decrease in stress) [7] and environmental pathways (*e.g.*, mitigating the exposure to urban-related environmental hazards such as air pollution, noise, and heat and enriching microbiota diversity) [8,9]. Evidence that children and adolescents spend less time in nature than previous generations [10] has prompted researchers to explore the connection between exposure to greenspace and health in these age groups [11]. As a result, an increasing number of studies have evaluated this association [4]. Several systematic reviews up to now have summarized the greenspace-health studies in children and adolescents. Most of the reviews highlighted the inconsistencies in the findings to different extents according to the outcomes of interest. The observed inconsistencies might arise from exposure and outcome assessment, study design, and statistical issues [12]. Yet, the findings of the reviews on the associations and inconsistencies are not synthesized and remained fragmented. We aimed to systematically review the existing synthesized evidence (*i.e.*, systematic reviews and/or meta-analyses) on the association between exposure to greenspace and health, well-being, health-related

behaviors (*i.e.*, physical activity), and development in children and adolescents to summarize the current evidence and explore the knowledge gap.

Method

We adhered to the protocol for systematic search, article selection, evaluation, and synthesis according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement [25]. We searched PubMed, Scopus, and Web of Science on August 15, 2022, for systematic reviews and/or meta-analyses that reported an association between at least one of the measures of greenspace availability, accessibility, use, or quality and at least one health, wellbeing, behavioral, or development outcome in children (up to 18 years old) and adolescents (10−19 years old) (Tables S1−S4 present study population, exposure, comparison, outcome, and type [PECOS] criteria eligibility for the review, and the search queries used for databases). Considering the importance of temporality between greenspace exposure and outcome, we also included exposure during the prenatal period in this review. Narrative reviews and expert opinions were excluded as the selection of articles, quality assessment, and risk of bias assessment usually are not done for these types of evidence. In addition to the database search, we also conducted a manual search on the references lists of retrieved articles to identify additional studies. The studies underwent title, abstract, and full-text evaluation for the assessment of the eligibility of inclusion in the review (Fig. S1).

After completion of the selection process, relevant data on study characteristics (design, location, time of the study), study population (number of included studies in the review, study designs), exposures (type of exposure, source of exposure data, exposure assessment method, exposure allocation method), outcomes, risk of bias and quality assessment (methods and scores), results (main findings, effect sizes in the case of meta-analysis), and discussed strength and limitations were extracted (Endnote software was used for screening, and reference management). We synthesized the extracted information based on the type of outcome.

Results

We found 36 systematic reviews on the association between greenspace exposure and children's and adolescent's health (Fig. S1 shows the study selection process, and Table 1 shows the general characteristics of the included reviews) [4, 12−46]. Most of the reviews were on mental health outcomes and among the retrieved reviews only eight of them were supplemented with meta-analysis (Figure 1) [13,17,20,26,30,31,39,44]. Most of the reviews were only on English evidence, and other languages were only included in a few of the reviews. The evidence quality in terms of risk of bias in most of the reviews has been reported as "fair to moderate".

Greenspace exposure

Different exposure metrics and approaches (*e.g.*, use of different greenness indicators, buffer sizes and types, locations, and time points of year) have been used across the studies. Objective and subjective approaches have been used to quantify indicators of availability, access, and use. However, the body of evidence on indicators of use and subjective perceptions is small. Heterogeneity in exposure assessment and definition has been reported as one of the most common obstacles in comparing and pooling the available evidence for meta-analysis. Until now most of the studies have used the Normalized Difference Vegetation Index (NDVI) as the greenness indicator regardless of the type of outcome. NDVI has several strengths such as ease of access at multiple time points for around four decades, which can make it easier to compare the findings across studies and different time frames. Still, NDVI is a relatively crude measure, especially when considering outcomes such as allergic responses, as it does not distinguish between types of vegetation and does not account for the quality of greenspaces. In general, there has been no defined and straightforward approach across the studies for the selection of appropriate exposure indices, approaches, and parameters for greenspace studies, and further efforts are needed to clarify the best approaches for the selection and reporting of exposure metrics across the studies based on the evaluated outcomes and hypothesized underlying mechanisms as well as the availability of data.

Outcomes

Birth outcomes

Gestational length

Five systematic reviews [26,20,29,31,39] (among them four meta-analyses [26,20,31,39]) synthesized the available evidence on greenspace exposure and gestational length (all on preterm birth, defined as delivery at <37 weeks). A meta-analysis found a 13% decrease (95% confidence interval [CI]: 0.80: 0.94) in the odds ratio (OR) of having preterm birth comparing mothers living in areas with high vs. low levels of greenspace [20]. In contrast, another meta-analysis found no significant associations between residential greenness and preterm birth [39]. Mitigation of environmental hazards, promoting physical activity, and reducing stress have been the proposed mechanisms for this beneficial association of greenspace.

Fetal growth

Six systematic reviews [13,20,26,29,31,39] (including five meta-analyses [13,20,26,31,39]) synthesized the association between greenspace exposure and different fetal growth outcomes including low birth weight (birth weight <2500g), small for gestational age (birth weight <10th percentile of the sex and gestational age), and head circumference. Five of the reviews consistently reported a positive association between exposure to

Table 1

Characteristics of the systematic reviews and/or meta-analyses on greenspace exposure and children and adolescents' health until August 2022.

First author (Year)	Study type	Country	Review time span	Number of included article	Overall reported quality	Type of included studies	Population	Outcome
Dzhambov et al. (2014)	SRMA	Bulgaria	- to 2014	8	Mostly of moderate quality	Observational	Newborn	Birth weight
Gascon et al. (2015)	SR	Spain	- to 2014	4	NR	Observational	3–10 years	Emotional and behavioral problems including ADHD
de Keijzer et al. (2016)	SR	Spain	- to 2016	6	Mostly of fair quality	Observational	7–18 years	School performance, cognitive development, attention capacity, ADHD and DHD symptoms severity
Lambert et al. (2017)	SRMA	Australia	- to 2017	11	Overally with high quality	Observational	Children (up to 18)	Asthma and allergic rhinitis (asthma, wheeze, allergic rhinitis, lung function)
McCormick et al. (2017)	SR	Not clear	2012 to 2017	12	NR	No limitation	Children (up to 18)	Mental well-being
Lambert et al. (2018)	SR	Australia	- to 2018	5	Most of studies scored >70%	Observational	Children (up to 19)	Atopic sensitization to any allergen
Tillmann et al. (2018)	SR	UK	1990–2017	35	Mostly fair to good quality	No limitation (observational, qualitative, experimental)	Children (up to 18)	Mental health (emotional well-being, ADD, ADHD, self-esteem,stress, resilience, depression and health-related quality of life)
Twohig-Bennett et al. (2018)	SRMA	UK	- to 2017	6[b]	Not clear	Observational or experimental	Not clear	Preterm birth, small of gestational age, gestational age
An et al. (2019)	SR	USA	- to 2018	20	Moderate (7 out of 14)	Observational or experimental	Children (up to age 17)	Physical activity, obesity
Browning et al. (2019)	SR	USA	- to 2018	13	Majority with fair quality	Observational or experimental	8–18 years	Academic performance (test scores, grades, college preparatory exams)
Hartley et al. (2019)	SR	USA	2017 to 2019	7	NR	Observational	Children (up to 18)	Asthma
Lambert et al. (2019)	SR	Canada	- to 2019	4	Medium to high	Observational	Children (up to 18)	Time spent in outdoor play
Minch et al. (2019)	SR	Germany	- to 2019	14	Nearly all of the studies (13 out of 14) with low quality	No limitation	Children (up to 18)	Mental health, cardiovascular and sleep
Mygind et al. (2019)	SR	Denmark	2004 to 2017	36	Low quality	Observational or experimental	Children (up to 18)	Mental health, self-esteem, self-efficacy, self-concept, resilience, problem solving, academic performance, cognitive performance, mood, physical health, body mass index, psychophysiological stress, physical activity, social health, relational indicators, skill indicators, behavioral indicators

(*continued on next page*)

Table 1. (*continued*)

First author (Year)	Study type	Country	Review time span	Number of included article	Overall reported quality	Type of included studies	Population	Outcome
Akaraci et al. (2020)	SRMA	Australia	- to 2018	27	Medium to high quality	No limitation	Newborn	Birth weight, small for gestational age, low birth weight and preterm birth
Alejandre et al. (2020)	SR	UK	2010 to 2018	16	Mostly moderate and good quality	Observational or experimental	Children (up to 18)	Physical activity, body mass index, waist to hip ratio, vegetable consumption experience, eating behaviors
Dankiw et al. (2020)	SR	Australia	- to 2019	16	Significant methodological concerns reported	Observational or experimental	2–12 years	Physical activity outcomes and cognitive development (play, learning, creativity), social and emotional outcomes
Islam et al. (2020)	SR	Australia	2010 to 2020	23	NR	Prospective	Not clear	Perinatal health, physical exercise, neurodevelopmental health and respiratory health
Jia et al. (2020)	SRMA	China	- to 2018	21	Score of 10 out of 13	Observational	Children (up to <18)	Weight-related behaviors (*e.g.*, physical activity, sedentary behaviors and dietary behaviors), body mass index, overweight and obesity, waist circumference, waist-to-hip ratio and body fat
Lee et al. (2020)	SRMA	South Korea	- to 2019	10	Not clear (weak in outcome domains)	Observational	Newborn	Birth weight, low birth weight, preterm birth
Oswald et al. (2020)	SR	Australia	- to 2019	58	NR	Observational or experimental	Children (up to 18)	Mental health, cognitive function, academic achievement
Putra et al. (2020)	SR	South Korea	- to 2019	15	Mostly of fair quality	Observational or experimental	Children (up to 18)	Pro-social behavior
Roberts et al. (2020)	SR	UK	1978 to 2018	14	Most of the studies were weak	Qualitative and quantitative	Children (up to 21)	Affect and functioning, self-esteem, resilience, social resources
Zhang et al. (2020)	SR	New Zealand	2000 to 2019	14	Score of 7 out of 11	Observational	Adolescents (10–19)	Mental health outcomes (mood, stress, anxiety, depression, happiness, pleasure, emotional health, psychological health, and mental health)
Bikomeye et al. (2021)	SR	USA	- to 2020	6	NR	Experimental and Quasi-experimental	Children (up to 18)	Physical activity, physical and verbal conflict rates, pro-social behavior, mental well-being, emotionally positive interactions, play specific behaviors including antisocial behaviors, and solitary play
Daniels et al. (2021)	SR	USA	2011 to 2019	18	NR[a]	Observational and experimental	Children (up to 18)	Body mass index
Davis et al. (2021)	SR	Canada	2000–2020	45	Moderate	Observational and experimental	Children (up to 12)	Mental health and development, school achievement

Fleckney et al. (2021)	SR	Australia	2005 to 2020	19	NR	Observational	Adolescents (10–19)	Maternal health outcomes including depression or depressive symptoms, anxiety and stress
Fyfe-Johnson et al. (2021)	SR	USA	-to 2021	140	Moderate to high	Observational and experimental	Children (up to 18)	Physical activity, cognitive, behavioral, mental health, asthma and allergy-related conditions
Hu et al. (2021)	SRMA	China	- to 2020	29	Moderate to good quality	Observational	Newborn	Preterm birth, small of gestation age, low birth weight, birth weight, birth length, head circumference
Pitt et al. (2021)	SCR	Canada	- to 2021	32	NR	Observational	Children (up to 18)	Adiposity, mental health, respiratory outcomes, injury, mortality, allergic responses, health related quality of life,
Luque-García et al. (2022)	SR	Spain	- to 2021	34	Most with high, or probably high risk of bias	Observational	Children (6–12)	Brain volume, attention, visual and working memory, Intelligence, cognitive development, academic performance, self-discipline, mental health outcomes, well-being, ADHD symptoms, behavior
Sprague et al. (2022)	SR	USA	- to 2020	28	For most of outcomes it was moderate. For Allergy and weight related outcomes it was low.	Observational; Experimental; Quasi-experimental	Children (2–18)	Cognitive and brain development, mental health and wellbeing, attention and behavior, allergy and respiratory, and obesity and weight
Vella-Brodrick et al. (2022)	SR	Australia	- to 2021	12	Mostly of strong quality (83%)	Experimental and Quasi-experimental	Children (5–18)	Enhanced cognitive functioning
Ye et al. (2022)	SRMA	Australia	- to 2022	140	None of them had low quality	Observational	Children (up to 18)	Mental health, nutritional status, allergic and respiratory, circulatory health, general health, other.
Zare Sakhvidi et al. (2022)	SR	Iran	- to 2021	29	Fair	Observational	Children (up to 18)	Children behavior (total behavioral difficulties, ADHD symptoms and severity, ADHD diagnosis, conduct problems, pro-social behavior, emotional symptoms,peer-relationship problems, externalizing disorders, internalizing disorders)

SR: systematic review; SRMA: systematic review and meta-analysis; ADHD: Attention deficit hyperactivity disorder.

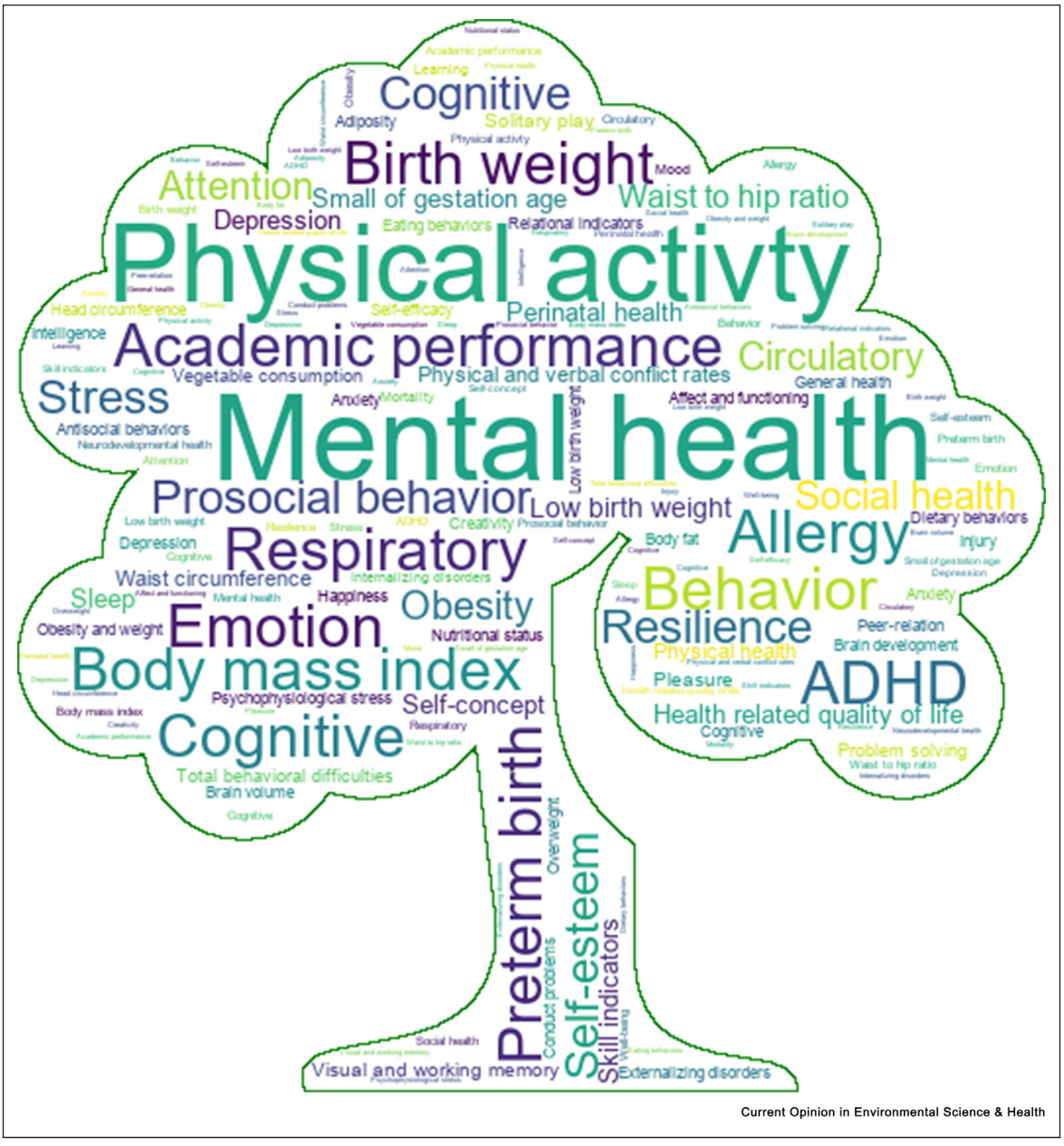
"-" in the "review time-span" column stands for from inception.

NR in the "overall reported quality" stands for not reported.

[a] All scored high according to the selected quality check list. And the authors concluded that their check list was not sensitive enough to detect low qualities.

[b] Review is on all age range. And the number of studies extracted from the children outcome with most retrieved studies (preterm birth).

Figure 1



Words cloud representation of the reported outcomes in the systematic reviews.

higher levels of greenspace and birth weight. Additionally, three of the reviews reported a negative association between greenspace exposure and the risk of low birth weight, but only one of them found significant associations [39]. The findings on small for gestational age were also suggestive of a beneficial role of greenspace [20,26,29,39]. One of the meta-analyses reported significant beneficial associations (pooled OR: 0.95; 95% CI: 0.92:0.97 for 0.1 unit increase in NDVI at 250−300m buffer size) [26]. Similar findings have been reported in another meta-analysis (pooled OR: 0.81; 95% CI: 0.76: 0.86 when compared highest with lowest exposure category); however, such a significant association was not observed on continuous outcome scales (pooled mean difference: -0.01: 95% CI: −0.05: 0.05 when compared highest exposure category with lowest exposure category) [20]. Dichotomizing the continuous variables could lead to false positive results, reducing power, concealing possible non-linearity, and uneven distribution of variables in each group. These could be a

possible explanation for the inconsistency between the continuous and dichotomous findings. Among the proposed mechanisms for beneficial associations, the most reported was stress reduction. Prenatal stress is a predictor of increased risks of low birth weight and preterm births. However, the role of mediating factors such as maternal physical activity and reduced exposure to air pollution should not be neglected. Pregnant women with higher deprivation (*e.g.*, lower education) were also suggested to benefit more from greenspace, probably because they have more free time and have increased opportunities to benefit from greenspace [47]. Therefore, socioeconomic factors could be responsible for reported heterogeneity across the reviews [39].

Neurodevelopmental outcomes

Fifteen systematic reviews (including one meta-analysis [44]) reported an association between greenspace exposure and different neurodevelopmental outcomes [11,14,15,25,28,29,32,34,36,38,41–45]. Here, we presented the available evidence in two broad groups of cognitive and behavioral outcomes.

Cognitive outcomes

Different cognitive neurodevelopmental outcomes such as cognitive performance and language, motor, and social abilities have been reviewed in 11 systematic reviews [15,25,28,29,32,36,38,41–44]. The reviews consistently reported a positive association between greenspace exposure and cognitive development in children. A review on cognitive and brain development found a significant positive association in half of the studies for working memory, cognitive performance, and white and gray matter volume in different regions of the brain [42]. However, the percentage of positive or significant findings across the reviews was different according to the review characteristics such as the year of conduction of the review, and the number and type of the included studies.

Behavioral outcomes

We found 11 reviews that reported results of behavioral outcomes [11,12,14,25,28,29,34,38,41,42,45]. Reported outcomes were mainly problematic behaviors (emotional symptoms, conduct problems, hyperactivity/inattention, peer relation problems, and attention deficit-hyperactivity disorder (ADHD)), pro-social behavior, self-determination, and self-regulation. A review of eight studies found a beneficial role of greenspace on behavioral outcomes in most of the included studies (seven out of eight) [42]. Another review on pro-social behaviors in children and adolescents found that about 70% of the reported associations were beneficial, of which around 30% were statistically significant [12]. The findings were reported to be similar, regardless of the socioeconomic status of children [29,34]. However, the findings on some of the outcomes were heterogeneous. For example, a review of children's behaviors found no supportive evidence for a beneficial association of greenspace on conduct problems in children [45]. Different mechanisms have been proposed for the neurodevelopmental benefits of greenspace including stress reduction, cognitive restoration, higher levels of physical activity, enhanced social interactions, and decreased exposure to air and noise pollution [43]. Available reviews highlighted the need for more studies in the low- and middle-income countries (LMICs) as most of the evidence is coming from high-income Northern American and western European countries, which could limit the generalizability of the results [42]. Also, there is a need for future mechanistic studies to explore possible pathways [41]. The available studies on neuroanatomical and neuroimaging outcomes such as brain anatomy and function are very limited and need further studies to replicate the previous findings on different populations, types, and quality of greenspace, and other neuro-cognitive outcomes. Additionally, whether greenspace exposure could lead to structural change and development of the brain needs to be further developed in the future.

Mental health and wellbeing

Mental health-related outcomes are reported in 14 systematic reviews [4,19,24,25,32–34,36–38,40–42,44] (including one meta-analysis [44]). A recent review found that more than 40% of original studies on greenspace and children's health were on mental health-related outcomes [44]. The reported outcomes were depression, anxiety, psychological distress, and psychological wellbeing. Most of the evidence (around 70%) are coming from cross-sectional studies [38], and only 30% of them were from cohort studies [44]. In general, most of the studies found a protective association for at least one mental health outcome (around 80%) [38]. A review of immersive nature experiences found nearly 60% of the included studies in the review reported an improvement in mental health outcomes following immersive nature experiences [25]. The number of experimental and randomized clinical trials in this area is still limited. However, a review found all the available randomized controlled trials reported a positive effect of greenspace on mental health outcomes in children [38]. The availability of studies with adverse effects (*e.g.*, anxiety and violence) has also been reported in a few reviews [44]. The proposed mechanisms for a protective role of greenspace on mental health-related outcomes in children focused on three pathways including environmental pollution mitigation (reducing harms from environmental hazards such as air pollution, traffic noise, and extreme heat), facilitating physical activities and social interactions, and inducing restorative experiences and stress reduction. Other mechanisms such as a buildup of microbiome diversity have been proposed to describe the positive influence of greenspace on children's mental health.

School performance

Nine systematic reviews [4,15,19,22,25,32,36,41,44] (including one meta-analysis [44]) reported an association between greenspace exposure and academic performance. In general, the literature on greenspace and academic performance is small, showing mixed findings, and most are based on observational, school-level study designs. A review of the 13 studies, found that around one-third of the reported associations were significantly beneficial, whereas less than 10 percent were significant and detrimental. Most of the evidence (around 60%) was non-significant [22]. It seems that greenspace is not effective same for all the school achievement outcomes. For example, Browning and Rigolon [22] found that end-of-semester grades and college preparatory exams showed greater shares of positive associations for math or reading test scores, whereas most findings regarding writing test scores were non-significant. The hypothesis behind the possible association between greenspace exposure and school achievements is that it can foster performance and help reduce stress and distractions. Different mechanisms including attention restoration, better mental health, more outdoor time, more physical activity, and better physical health have been proposed for these beneficial associations. Several confounding and moderating factors may affect the relationships including parental characteristics, school and environmental factors, socioeconomic status, gender, and urbanization. Additionally, a considerable share of the studies on school performance had an ecological design that can be affected by the ecologic fallacy problem.

Physical activity and time spent outdoor

Nine systematic reviews [16,21,25,27,28,29,30,34,38] (including one meta-analysis [30]) reviewed the available studies for the association between greenspace and physical activity in children and adolescents. Across the reviewed studies, physical activity has been measured and reported in different methods such as percentage of time spent in moderate to vigorous physical activity (MVPA), time spent in sedentary and light physical activity, percentages or the number of children observed in different activities in green spaces, physical activity frequency and distance, and use of a pedometer and accelerometer data. Available reviews found a positive association between greenspace (residential or schoolyard [34]) and physical activity or time spent outdoor [16,25,27,30,34,38]. However, the reviews reported few sporadic studies that reported a negative or null association between greenspace and physical activity or time spent outdoor [30,48–50]. In a review of seven studies on the effect of nature play intervention on physical activity three of the studies found no significant role of nature play intervention/exposure relative to traditional play settings [28]. One review concluded stronger benefits for boys and the associations were also stronger with an increase in age [29]. The beneficial influence of greenspace on children's physical activity could be associated with quality characteristics of green spaces (*e.g.*, density, foliage, proximity), activity type (*e.g.*, formal vs. informal plays and activities), demographic characteristics of children (*e.g.*, sex, ethnicity, and parent-children relationship) [27].

Weight-related outcomes

Different weight-related measures including body mass index (BMI), waist-to-hip ratio, BMI trajectory, skinfold thickness, body fat, overweight/obesity, and insulin resistance have been used across eight systematic reviews [21,25,27,30,35,40,42,44] (among them two meta-analyses [30,44]). The reported associations were mixed, but most of the reviews concluded a potential beneficial role of greenspace at least on one of the aforementioned attributes. A recent meta-analysis of five studies investigating the association of residential surrounding greenness (measured by NDVI) with obesity/overweight found lower odds of obesity/overweight in children (OR: 0.91, 95%CI: 0.84 to 0.98 per 0.1 unit increase in NDVI) [44]. A review of immersive nature experience studies found BMI decreased after a 16-week adventure therapy program; however, the risk of bias in the studies was high due to not including control [25]. In addition to children's characteristics such as sex and socioeconomic status (SES), greenspace characteristics such as type (*e.g.*, park, forest) and location (*e.g.*, home, school) could be responsible for the variations in the observed associations [27].

Allergy and respiratory

Association between greenspace exposure and different allergy and respiratory outcomes (asthma, allergic rhinitis, respiratory sinus arrhythmia, allergic rhinitis, eczema, atopic sensitization, wheezing, pneumonia, bronchitis, lung function, and other respiratory conditions) in children and adolescents has been reported in six reviews [17,18,23,42,44,29]. Current evidence on the association of greenspace exposure with allergic and respiratory health and diseases is inconsistent, both in terms of direction and strength [44]. Two meta-analyses found no significant association between greenspace and asthma [17,44]. A review concluded that certain plant species increase asthmatic symptoms indicating that the type of plant is an important determinant in the heterogeneity of the findings [29]. The evidence on lung function is very limited (five studies reported in one review), and in general, are suggestive of the beneficial role of greenspace exposure for lung function in children and adolescents. The protective studies postulated the mitigating role of greenspace on the environmental pollutants and enhancing physical activity, and more diverse microbial exposure as the mechanisms for a potential protective role of greenspace on allergy and respiratory outcomes [44]. On the other hand, increasing pollen exposure is proposed as a mechanism for the observed detrimental associations.

Cardiovascular and circulatory outcomes

Two studies reviewed the evidence on the association between greenspace exposure and different cardiocirculatory outcomes such as systolic and diastolic blood pressure, arterial pressure, risk of hypertension, blood lipids profile, combined cardiometabolic score, allostatic-based index, retinal vessel diameter, and heart rate variability in children [24,44,]. Most of the evidence (80%) was from the cross-sectional studies [44], and blood pressure is the most commonly reported outcome. Most of the findings for blood pressure outcomes were suggestive of the beneficial (inverse) association of greenspace exposure with blood pressure in children and adolescents. The positive role of greenspace on children and adolescent health can be postulated through the mitigation of cardiovascular risk factors such as air and noise pollution, stress reduction, and increasing physical activity.

Discussion

Most of the reviews generally reported a beneficial role of greenspace on children's and adolescent's health. However, for a part of the outcomes (*e.g.*, allergy, respiratory outcomes, or conduct problems), the available evidence is not conclusive. Different mechanisms such as reducing stress, mitigation of urban-related environmental hazards, increasing physical activity, social interactions, microbial diversity, and cognitive restoration could be expected for the observed beneficial associations. Considering the role of mediators and modifiers is important in the interpretation of the findings and also draw a conclusion about the possible mechanism(s). Available reviews have mainly overlooked these issues and therefore these topics could be considered as open questions in future reviews. Included reviews attributed the observed heterogeneity mainly to exposure assessment and claimed that the diverse findings across the studies are probably due to the use of inappropriate greenspace indices. Part of the heterogeneity could be due to the different susceptibility of the population to the effects of greenspace (*e.g.*, different socioeconomic status). Mediation and modification of the associations by different factors (*e.g.*, mediation by physical activity, or modification by personal traits) are among the topics that have not been considered systematically in the available reviews. Outcome assessment was also claimed as another important source of heterogeneity that should be considered in future studies. For example, for mental health, weight status, and asthma and allergic outcomes, reliance on guardian or teacher reports for kids' health indicators may have resulted in the misclassification of outcomes [17,44,]. Additionally, the diversity of the populations in terms of socioeconomic status, gender, age, personal preferences, and perception of nature was discussed as the source of variation across the studies [13]. Several other methodological issues such as considering the role of possible mediators, and the window of susceptibility (especially for birth outcomes) are among the highlighted shortcoming of available studies and should be considered in future research [13]. In conclusion, the body of evidence on the association between greenspace exposure and children's health is diverse in terms of direction and magnitude, mostly inclined towards a beneficial role of greenspace for children and adolescents' health, wellbeing, and development. The evidence is stronger on mental health and behavioral outcomes, and the studies on outcomes such as respiratory, circulatory and brain functions are limited, and highlight the needs for further research. Future longitudinal studies, especially in LMICs, are needed that include different measures of greenspace exposure (*e.g.*, use of green space, visual access to greenspace, and indoor plants in addition to surrounding greenspace and access to green spaces) and repeated characterization of outcomes and relevant covariates/confounders and modifiers, which also shed light on potential mechanisms underlying such associations. The association of the greenspace exposure with improved health, well-being, development, and behaviors could differ in terms of its relevance and the underlying mechanisms in different age groups (developmental, childhood, etc.). Therefore, future reviews need to do evidence synthesis based on the age groups of participants. Additionally, systematic reviews on the health effects of greenspace on children and adolescents are highly suggested to compare and provide recommendations based on different type of greenspace, greenspace exposure measures, and exposure assessment methods.

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

No data was used for the research described in the article.

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Appendix A. Supplementary data

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** of outstanding interest

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