Received: 24 June 2020 | Accepted: 25 June 2020
DOI: 10.1111/obr.13100

SUPPLEMENT ARTICLE

OBESITY Reviews WILEY

Green space access in the neighbourhood and childhood obesity

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Funding information
National Natural Science Foundation of China,

Summary

Access to green space may influence individual physical activity (PA) and subsequently weight status, as increased exposure to green space could improve health by increasing opportunities and the actual levels of PA. However, whether such associations hold empirically remains inconclusive. This study reviewed articles that analysed the association between access to green space and weight-related behaviours/outcomes among children, published before 1 January 2019. The sample sizes ranged from 108 to 44 278. Four cohorts and 17 cross-sectional studies conducted in nine countries were identified. Overall, evidence showed a positive association between access to green space and PA and a negative association between access to green space and television-watching time, body mass index (BMI) and weight status among children. Distance to the nearest green space, measured by geographic information system (GIS) in 10 studies, was often used to represent access to the nearest green space. It still remains difficult to draw a clear conclusion on the association between access to green space and BMI. Longitudinal studies can directly estimate the strength of the association between exposure and disease, which is needed to determine the causal association between access to green space and weight status.

KEYWORDS
built environment, **child**, **green space**, **obesity**

Peng Jia and Xinxi Cao contributed equally to this work.

Grant/Award Number: 91746205; State Key Laboratory of Urban and Regional Ecology of China, Grant/Award Number: SKLURE2018-2-5

1 | INTRODUCTION

Obesity is an increasingly prevalent issue in both developed and developing countries. Estimates suggest that 3.4 million deaths per year are attributable to obesity worldwide, with around 4% in terms of years-of-life-lost and disability-adjusted life-years.[1] Despite the recent evidence showing that the long-term trends of increasing body weight are starting to slow down, overweight and obesity prevalence remain high.[2] Obesity is associated with a diminished quality of life, numerous comorbidities and a decreased life expectancy of up to 20 years.[3] In the United States, the total healthcare costs attributable to obesity/overweight are projected to double every decade to 860.7 billion to 956.9 billion US dollars by 2030, accounting for 16% to 18% of the country's total healthcare costs if the current rising incidence of obesity continues.[4] In particular, obesity has also begun to emerge as a significant health concern for the child and adolescent population, with around 23% of children in developed countries with overweight or obesity. In developing countries, the prevalence of overweight and obesity in children rose from around 5% to 13% during 1980 to 2013.[1] Increased childhood body mass index (BMI), which often tracks into adulthood, has an important influence on adult morbidity.[5] In addition, there is compelling evidence that obesity-associated cardiovascular diseases also track from early life into adulthood.[6,7] Therefore, control and prevention of childhood obesity has been, and should continue to be, an important public health issue meriting widespread attention.

There has been a growing interest in understanding the roles of neighbourhood obesogenic environments in enhancing or constraining physical activity (PA), which ultimately influence obesity.[6–16] Green space is generally considered to be one of the environmental factors that can reduce obesity and improve the community's health,[17] although it may also pose a detrimental impact on public health due to climate change.[18] It has been suggested that exposure to green space reduces the risk of several adverse health outcomes by multiple pathways, including promoting PA[19]; green spaces could reduce the risk for obesity by offering suitable spaces that encourage PA.[20] The access to green space was found to be negatively associated with the prevalence of overweight and obesity in some studies[21] but was not associated or positively associated with overweight and obesity in others.[22,23] Although there are some existing reviews of the general health impact of greenness, there has not been any review of the association between greenness and childhood obesity.

This study aimed to systematically review the association between access to green space and weight-related behaviours/outcomes. We explored all measurements of green space at multiple scales (e.g., national, state and county levels) to arrive at a comprehensive understanding of their association with children's weight-related behaviours/outcomes. Our findings will contribute to the development of effective interventions and policies to prevent childhood obesity.

2 | METHODS AND MATERIALS

A systematic review and meta-analysis were conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

2.1 | Study selection criteria

We included studies that met all of the following criteria: (a) study subject: children and adolescents aged less than 18 years; (b) study design: cross-sectional studies and longitudinal studies, including prospective and retrospective cohort studies, rather than controlled experiments conducted in manipulated rather than naturalistic settings; (c) exposure of interest: green space (e.g., the distance to the nearest green space, the number/density of green spaces); (d) study outcome: weight-related behaviours (e.g., PA, sedentary behaviours and dietary behaviours) and/or outcomes (e.g., BMI [kg/m^2], overweight and obesity, waist circumference, waist-to-hip ratio and body fat); (e) article type: peer-reviewed original research, rather than letters, editorials, study/review protocols, or review studies; (f) time of publication: from the inception of the electronic bibliographic database to 31 December 2018; and (g) language: written in English.

2.2 | Search strategy and date extraction

We conducted a systematic search on PubMed and Web of Science for related studies published before 1 January 2019. The search strategy included all possible combinations of keywords from the three groups related to access to green space, children and weight-related behaviours or outcomes (Appendix A).

Two reviewers independently conducted the title and abstract screening and identified potentially relevant articles for the full-text review. Discrepancies were screened and resolved by a third reviewer. The three reviewers jointly determined the list of articles for the full-text review through discussion. Then, two reviewers independently reviewed the full texts of all articles in the list and determined the final pool of articles included in the review.

2.3 | Data preparation

Twenty-one studies were included in the systematic analysis and meta-analysis. We used a standardized data extraction form to collect methodological and outcome variables from each selected study, including authors, year of publication, country, sampling strategy, sample size, age at baseline, follow-up years, sample characteristics, statistical model, measures of access to green space, other environmental factors adjusted for in the model, measures of weight-related behaviours, measures of weight-related outcomes and key findings on the association between access to green space and weight-related behaviours and/or outcomes. Two reviewers independently extracted data from each study, and discrepancies were resolved by the third reviewer.

2.4 | Study quality assessment

The National Institutes of Health's Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies was used to assess the quality of the included studies.[15] This assessment tool rates each included study according to 14 criteria. For each criterion, a score of one was assigned if 'yes' was the response, whereas a score of zero was assigned otherwise (i.e., an answer of 'no,' 'not applicable,' 'not reported' or 'cannot determine'). A study-specific global score ranging from zero to 14 was calculated by summing up scores across all criterion. The study quality assessment helped measure the strength of the scientific evidence but was not used to determine the inclusion of studies (Appendix B).

2.5 | Statistical analyses

A meta-analysis was performed to estimate the pooled effect size of access to green space on each weight-related behaviour or outcome. Weight-related outcomes included BMI, BMI percentile and overweight/obesity. Overweight and obesity were defined based on the standards used in the original paper, including the age-sex-specific Centers for Disease Control and Prevention (CDC) Growth Charts, the World Health Organization (WHO) growth references and the International Obesity Task Force (IOTF) recommendations. Separate meta-analyses were conducted on different measures of access to green space, including presence of green space, number of green spaces, density of green spaces and distance to the nearest green spaces. We were not able to conduct a meta-analysis on weight-related behaviours due to an insufficient number of articles with the same measures of access to green space.

Effect sizes were reported using mean differences for continuous outcomes (i.e., BMI and BMI percentile) or odds ratios for categorical variables (i.e., overweight and obesity). Heterogeneity was assessed with the Q-test. P value < 0.1 in the Q-test indicated the presence of heterogeneity across studies. The level of heterogeneity was measured by I^2 and was interpreted as modest ($I^2 \leq 25\%$), moderate ($25\% < I^2 \leq 50\%$), substantial ($50\% < I^2 \leq 75\%$) or considerable ($I^2 > 75\%$). A random-effect model was used to pool the estimates from individual studies because of the varying population and criteria used to define outcomes. All meta-analyses were conducted using the Stata 14.2 SE version (StataCorp, College Station, TX).[16] All analyses used two-sided tests, and $P < 0.05$ was considered statistically significant, except for the evaluation of heterogeneity ($P < 0.1$).

3 | RESULTS

3.1 | Study selection

Figure 1 shows the search and screening process of the study inclusion. There were 242 unique articles in total, which were extracted from 3,083 retrieved records through title and abstract screening. Furthermore, articles were excluded because they were about other diseases (n = 95), about adults (n = 20), had unclear data (n = 18), were duplications (n = 3), about study design (n = 3), were a review paper (n = 1) or lacked measures of green space or weight-related behaviours/outcomes (n = 83). The remaining 21 articles that explored the association between access to green space and children's weight-

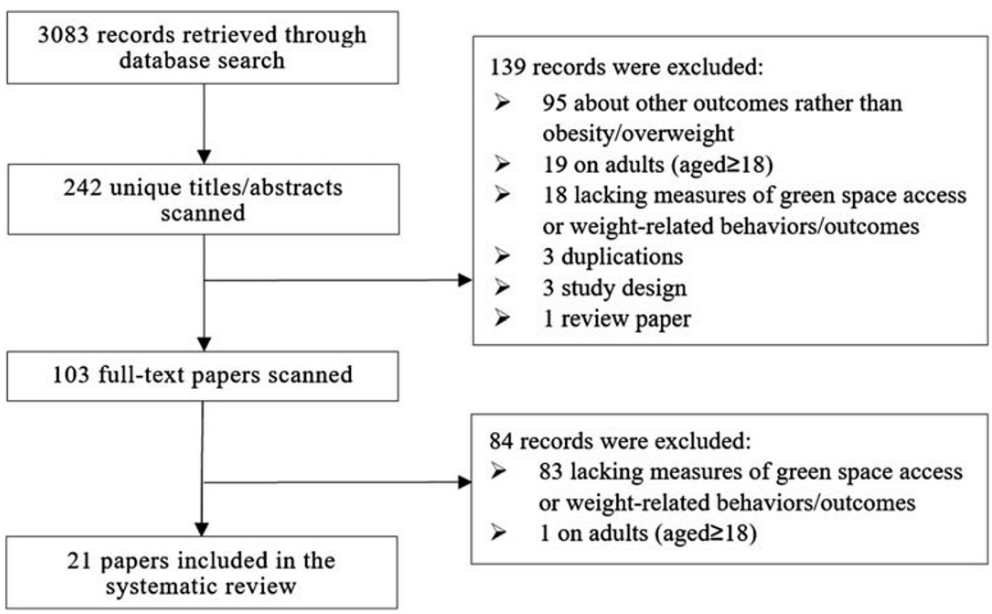

FIGURE 1 Study exclusions and inclusions

related behaviours/outcomes were included in the full-text review. According to the study quality assessment, the included studies scored 9.95 on average, ranging from 7 to 13 (Table S1).

3.2 | Study characteristics

We summarized the basic characteristics of the 21 included studies, which were published from 2008 to 2018, and consisted of four cohort studies and 17 cross-sectional studies (Table 1). Nearly half of the studies were conducted in the United States (n = 9); the remaining studies were conducted in the United Kingdom (n = 3), Canada (n = 3), New Zealand (n = 1), Brazil (n = 1), Germany (n = 1), the Netherlands (n = 1), Norway (n = 1) and Spain (n = 1). Seven of these studies were conducted at national level, seven studies were conducted in one state (i.e., subnational) and seven studies were conducted at county level. Of the 21 studies, the samples of 10 studies were school students; samples were from family or community surveys in six studies and from the national surveys or other projects in five studies. The sample size in these studies ranged widely, from 108 to 44 278, including one study that regarded school district as the study unit and used the Geographically Weighted Regression model to explore the association.

3.3 | Measures of access to green space

Various measures of access to green space were used in the included studies (Table 2). Specifically, the number (n = 6), proportion (n = 6), area (n = 4) or density (n = 3) of green spaces, the distance to the nearest green space (n = 4), the Normalized Difference Vegetation Index (NDVI) derived from satellites (n = 2), the land use mix entropy (n = 1), time spent in green spaces (n = 1), presence or use of green space (n = 4) and a score calculated by using the Community Park Audit Tool (n = 2). The included studies used one of these indicators or a combination of two or more indicators. Most of the indicators in the 18 studies were measured by geographic information systems (GIS) or remote sensing (RS). Additionally, two studies interviewed parents or children to measure the access to green space by questionnaire. In total, distance to green space is the most frequent indicator and is mainly calculated by using the road-network or the straight-line distance around the centroid of children's residence or school. Furthermore, the number, proportion, area or density of green spaces and the NDVI are often measured within the buffer zone of children's homes or schools, whose radii ranged from 100 to 5000 m.

3.4 | Measures of other environmental factors

Twelve studies examined the association between green space and weight-related behaviours, which were usually measured by PA (n = 9), food consumption-related behaviours (n = 5), sleeping-related behaviours (n = 2) and television screen time (n = 4) (more than one behaviour). Eleven studies objectively measured children's weight-related behaviours via questionnaires, self-reporting and parents' estimation, while only one study requested participants to wear an accelerometer.

Weight-related outcomes were used in all 21 studies, and measures included BMI (n = 16), BMI z-score (n = 3) and BMI percentile (n = 9). The BMI reference used included the US CDC growth charts (n = 6), Cole's international age and sex specific cut-offs (n = 5) and the international BMI classification for children (n = 1). Most of the studies objectively measured weight and height (n = 16), while some used self- or parent-reported weight and height (n = 5).

3.5 | Associations between green space access and weight-related behaviours and outcomes

Five out of 12 studies that measured overall access to green space reported that there was positive or negative association with PA and moderate-to-vigorous physical activity (MVPA) or television-watching time or frequency of food consumption, respectively (Table S2), while there was one study that reported that green space was negatively associated with PA frequency.[40]

Thirteen studies reported that there was a negative association between access to green space and weight-related outcomes. One study showed that greater access could reduce the likelihood of obesity.[36] Six studies reported no association between access to green space and weight-related behaviours. One study showed that the percentage of inconvenient green areas in rural areas was positively correlated with BMI (Table S2).

3.6 | Meta-analysis of weight-related status

The results of our meta-analysis showed that there was no significant association between green space access and children's BMI z-score and BMI, with pooled estimates of −0.01 (95% CI: −0.04-0.02; I^2 = 0.00%, τ^2 = 0.000) and −0.05 (95% CI: −0.025-0.14; I^2 = 17.3%, τ^2 = 0.013) (Figure 2), respectively. Better access to green space was significantly associated with lower risk of overweight/obesity (OR: 0.91, 95% CI: 0.88-0.95; I^2 = 56.2%, τ^2 = 0.0025). The associations remained significant in the subgroup analyses by study design, with OR of 0.91 (95% CI: 0.85-0.97; I^2 = 49.6%, τ^2 = 0.002) in cohort studies and 0.91 (95% CI: 0.87-0.96; I^2 = 60.4%, τ^2 = 0.003) in cross-sectional studies (Figure 3).

4 | DISCUSSION

In this review, we selected 21 studies that explored the association between green space and childhood weight-related behaviours or outcomes. The included studies varied in design, including four cohort studies and 17 cross-sectional studies; study locations were in nine different countries, and study levels included the national level, state

TABLE 1 Basic characteristics of the included studies

First author (year)	Study area [scale][a]	Sample size	Sample age (years, range and/or mean ± SD)[b]	Sample characteristics (follow-up status for longitudinal studies)	Statistical model
Cohort studies					
Bell (2008)[8]	Indianapolis, US [C]	3831	3–16	School children	Multiple linear regression
Bloemsma (2018)[24]	The Netherlands [N]	3680	3–17	School children (followed up from 2004 to 2007 with two repeated measures)	Generalized linear mixed models
Schalkwijk (2017)[10]	UK [N]	6467	5–7	Singleton infants (followed up at ages 3, 5, and 7)	Logistic regression
Zwaard (2018)[25]	UK [N]	6001	3–11	Singleton children (followed up at ages 3, 5, 7 and 11 years)	Linear regression fixed effects analyses
Cross-sectional studies					
Alexander (2012)[16]	US [N]	44 278	6–17	Children from the National Survey of Children	Logistic regression
Dadvand (2014)[26]	Sabadell, Spain [C]	2848	9-12 (10.9 ± 1.6)	School children at Grades 4–6 in primary schools (aged 9–12 years)	Logistic regression
Jenkin (2015)[27]	New Zealand [N]	4175	2–14	Children with primary caregivers	Separate logistic regression models
Lovasi (2011)[28]	New York, US [S]	428	4 ± 0.5	Children participating in Head Start (home visits conducted 6 months after initial enrollment)	Generalized estimating equation models
Lovasi (2013)[29]	New York, US [S]	11 562	3–5	Children enrolled in a large means-tested preschool programme	Poisson regression models
McCarthy (2017)[30]	Southeastern, US [S]	13 469	9.7 ± 0.99	Youth at Grades 3 and 5	Multilevel logistic regression
Nesbit (2014)[13]	US [N]	39 542	11–17	People aged <18 in the household	Logistic regression
Ohri-Vachaspati (2013)[31]	New Jersey, US [S]	702	3–18	Children living in four low-income cities between 2009 and 2010	Multivariate regression models
Oreskovic (2009)[15]	Massachusetts, US [S]	21 008	9.3 ± 4.8	Outpatient patients between 1 January and 31 December 2006	Multivariate logistic regression
Potestio (2009)[32]	Calgary, Canada [C]	6772	4.95	Children presented to a public health clinic for vaccination between January 2005 and January 2006	Multivariate multilevel analysis
Potwarka (2008)[33]	Ontario, Canada [C]	108	2–17	Children living in four neighbourhoods during August 2006	Logistic regression
Rossi (2018)[34]	Florianópolis, Brazil [C]	2506	7–14	School children enrolled at public or private schools	Logistic regression
Schüle (2016)[35]	Munich, Germany [C]	2613	5–7	School children (from three surveys between 2004 and 2007 from 18 school enrolment zones)	Multivariate logistic regression
Veugelers (2008)[36]	Nova Scotia, Canada [S]	5471	Grades 5 in 2003	Grade 5 students and their parents	Multivariate multilevel linear regression
Ward (2016)[37]	Auckland, New Zealand [C]	108	11–14	Intermediate school children	Generalized linear mixed models
Wasserman (2014)[38]	Kansas, US [S]	12 118	4–12	Schoolchildren in the academic year 2008-2009	Multi-level analysis
Wilhelmsen (2017)[39]	Norway [N]	10 527	14–17	Schoolchildren measured in 2001–2004	Logistic regression

[a]Study area: [N], national; [S], state (e.g., in the United States) or equivalent unit (e.g., province in China and Canada); [C], city.
[b]Sample age: age in baseline year for cohort studies or mean age in survey year for cross-sectional studies.

TABLE 2 Measures of green space access and weight-related behaviours and outcomes in the included studies

First author (year)	Measures of access to green space	Other environmental factors adjusted for in the model	Measures of weight-related behaviour	Detailed measures of weight-related outcomes
Cohort study				
Bell (2008)[8]	• Mean NDVI in a 1-km home straight-line/road-network buffers	• Racial/ethnic group, gender, race/ethnicity X gender interaction; age at baseline; and health insurance status as a proxy for individual SEP	• Measured BMI *z*-scores (height and weight)	• Higher greenness was associated with lower odds of increasing BMI *z*-scores
Bloemsma (2018)[24]	• Mean NDVI in 0.3- and 3-km home straight-line buffers • % of total green space, and urban, agricultural and natural green space (separately) in 0.3- and 3-km home straight-line buffers • GIS-based distance to the nearest park entrance	• Age, sex, maternal and paternal level of education, maternal smoking during pregnancy, parental smoking in the child's home • Region, the other types of green space in the same buffer size	• Measured BMI (according to the age and sex-specific International Obesity Task Force cutoffs)	• The odds of being overweight from age 3 to 17 years decreased with an increasing average NDVI and total percentage of green space in a buffer of 3,000 m • Children living in an urban area and living further away from a park was associated with lower odds of being overweight
Schalkwijk (2017)[10]	• Concentration of green space in each LSOA on the basis of the 2001 Generalized Land Use Database • Perceived access to a garden by interviewing children's mothers • Sum score of 10 green space-related questions by interviewing children's mothers	• Parenting determinants comprising: food consumption, PA, rules, regularity and SEP	• Measured BMI (based on the Cole's international age and sex-specific cut-offs)	• Children without access to a garden had a higher likelihood of overweight or obesity
Zwaard (2018)[25]	• Categories of the amount of green space, garden areas and other types of land use in LSOA ('1' denotes the least green spaces and '10' denotes the greenest spaces)	• Age-related changes in weight, children's sex and education level of the main carers	• Measured BMI	• Statistically significant associations were found between environmental measures of both more gardens and lower levels of crime and lower BMI
Cross-sectional study				
Alexander (2012)[16]	• Perceived expose of children to a park, playground area, recreation centre, community centre or boys'/girls' club by interviewing parents	• Age, race/ethnicity, maternal and paternal education, socioeconomic status, geographic location and living status	• Measured BMI • Overweight/obesity: BMI ≥ 85th percentile	• Results were not statistically significant • In non-Hispanic black children, the result was statistically significant
Dadvand (2014)[26]	• Mean NDVI in 0.1-, 0.25-, 0.5-, and 1-km home straight-line buffers • Whether to live within a 0.3-km buffer from a park or forest on the basis of the Urban Atlas	• Child's sex and age, exposure to environmental tobacco smoke at home, having older siblings, type of school, parental education and parental history of asthma, sport activity	• Measured BMI • Transform BMI into *z*-scores according to age and sex (based on the World Health Organization's reference values)	• An increase in greenness was associated with lower relative prevalence of overweight/obesity
Jenkin (2015)[27]	• % of green space in neighbourhood	Individual-level confounders and the other environmental characteristics	• Measured height and weight • Overweight/obesity (all defined using the international BMI classification for children)	• Access to green space was not found to be statistically significantly related to overweight/obesity
Lovasi (2011)[28]			• Measured BMI *z*-scores	

TABLE 2 (Continued)

First author (year)	Measures of access to green space	Other environmental factors adjusted for in the model	Measures of weight-related behaviour	Detailed measures of weight-related outcomes
	• Density of street trees in a 0.5-km pill or circle buffer around the straight line between home and school • % of areas covered by parks in a 0.5-km pill or circle buffer around the straight line between home and school • % of areas covered by playground in a 0.5-km pill or circle buffer around the straight line between home and school	• Age, race/ethnicity, maternal and paternal education, socioeconomic status, geographic location and living status	• Overweight (85th to 94th percentile) • Obesity (95th percentile and above)	• Access to green space was not found to be statistically significantly related to overweight/obesity
Lovasi (2013)[29]	• Density of street trees in a 0.4-km home straight-line buffer • % of areas covered by small parks, and large park (separately) in a 0.4-km home straight-line buffer	• Sex, race/ethnicity, age in months and all neighbourhood characteristics shown	• Measured height and weight Calculated BMI *z*-score (based on a comparison to CDC growth charts for children of the same age and sex)	• Street tree density was associated with lower obesity prevalence
McCarthy (2017)[30]	• Number of publicly accessible parks in a 0.8-km home road-network buffer	• Age, gender, race/ethnicity, socioeconomic status and total population in block group	• Measured BMI percentiles (based on standardized protocols for youth from the CDC)	• There were no significant associations for playground access/quality and weight status after adjusting for sociodemographic variables
Nesbit (2014)[13]	• Presence of parks and playgrounds	• NA	• BMI ≥ 95th percentile based on gender and age specific growth charts (based on the CDC)	• Unfavourable conditions of the neighbourhood built environment have been shown to have a positive relationship with a higher BMI
Ohri-Vachaspati (2013)[31]	• Distance to the nearest park • Presence of parks in 0.4-, 0.8- and 1.6-km home straight-line buffers	• Age, sex, race/ethnicity, household poverty status, parental nativity, mother's education level, household language status, parental BMI, median income in the block group of children's residences and racial/ethnic composition in the block group of children's residences	• Measured BMI • Overweight and obesity were defined using the international BMI cut-off points established for children and youth	• Children living within 0.8 km of a large park were less than half as likely to have overweight or obesity as those who did not
Oreskovic (2009)[15]	• Density of open spaces in a 0.4-km buffer	• Age, gender, race and income	• Measured BMI (based on the CDC) • Overweight: BMI ≥ 85th percentile; • Obesity: BMI ≥ 95th percentile	• Found that the amount of open space was associated with BMI
Potestio (2009)[32]	• Number of parks and green spaces per 10,000 residents • % of parks and green spaces in the community (defined by the 2001 Canadian census) • Distance to the nearest park or green space % of park/green space service area in a community (defined by the 2001 Canadian census)	• Sex, income, education and visible minority	• Measured BMI • Overweight/obesity based on the international BMI cut-off points established by Cole et al (2000)	• Spatial access to parks/green space has a limited direct association with childhood overweight/obesity

(Continues)

TABLE 2 (Continued)

First author (year)	Measures of access to green space	Other environmental factors adjusted for in the model	Measures of weight-related behaviour	Detailed measures of weight-related outcomes
Potwarka (2008)[33]	• Number of parks in a 1-km home straight-line buffer • Total area of all parks in a 1-km home straight-line buffer	• Gender, age, neighbourhood of residence and parent's BMI	• Measured BMI • Overweight/obesity: BMI ≥ 85th percentile (based on CDC sex-specific BMI-for-age growth charts)	• Proximity to park space was not associated with a healthy weight status among children
Rossi (2018)[34]	Schoolchildren and their families self-report data about frequency of use and perceived distance from home to a list of facilities	• Age, sex and food intake variables	• Measured height and weight • Overweight: BMI *z*-score ≥ +1 and <+2 Obesity: BMI *z*-score ≥ + 2	• An increase in greenness was associated with a lower relative prevalence of overweight/obesity
Schüle (2016)[35]	• Per capita amount of available playground space (m^2) for children aged <11 years (in categorized of high, middle, low)	• Sex, income, education and visible minority	• Measured BMI • Overweight/obese: based on the International Obesity Task Force (IOTF) cut-off values	• Public playground space and park availability were not independently associated with overweight in preschool aged children
Veugelers (2008)[36]	• Perceived access to playgrounds and parks by interviewing parents (on a scale of 1 to 5)	• Child gender, parental education and household income	• Measured weight and height • Overweight/obesity: BMI ≥ 85th percentile (based on the 2000 CDC Growth Charts)	• Children in neighbourhoods with good access to playgrounds, parks and recreational facilities are more actively engaged in structured sports, less likely to spend time in front of a computer or TV screen and less likely to be overweight or obese
Ward (2016)[37]	• Time spent in green space, measured by GPS receiver and wearing wrist belt	• MVPA	• Measured BMI	• No associations were detected between BMI and green space exposure
Wasserman (2014)[38]	• Number of parks in a 1.6-km school straight-line buffer	• NA	• Measured BMIp (based on the CDC)	• Population change along with the number of parks and fitness centres were inversely associated with BMIp
Wilhelmsen (2017)[39]	• Distance to the nearest green space • Degree of greenness (on a scale of 1 to 5)	• Age, gender, ethnicity, physical activity, transportation mode, use of nature, social support from friends and family, family situation, diet, smoking habits, county, moving history and climatic variables	• Measured BMI (based on the Cole and colleagues' age- and sex-specific BMI-classification)	The odds for being overweight was 1.38 times higher for participants living in the greenest surroundings compared to participants living in the least green surroundings

Abbreviations: BMI, body mass index; CDC, Centers for Disease Control and Prevention; GIS, geographic information systems; LSOA, lower-level super output area; MVPA, moderate-to-vigorous physical activity; NDVI, normalized difference vegetation index; PA, physical activity; SEP, socio-economic position.

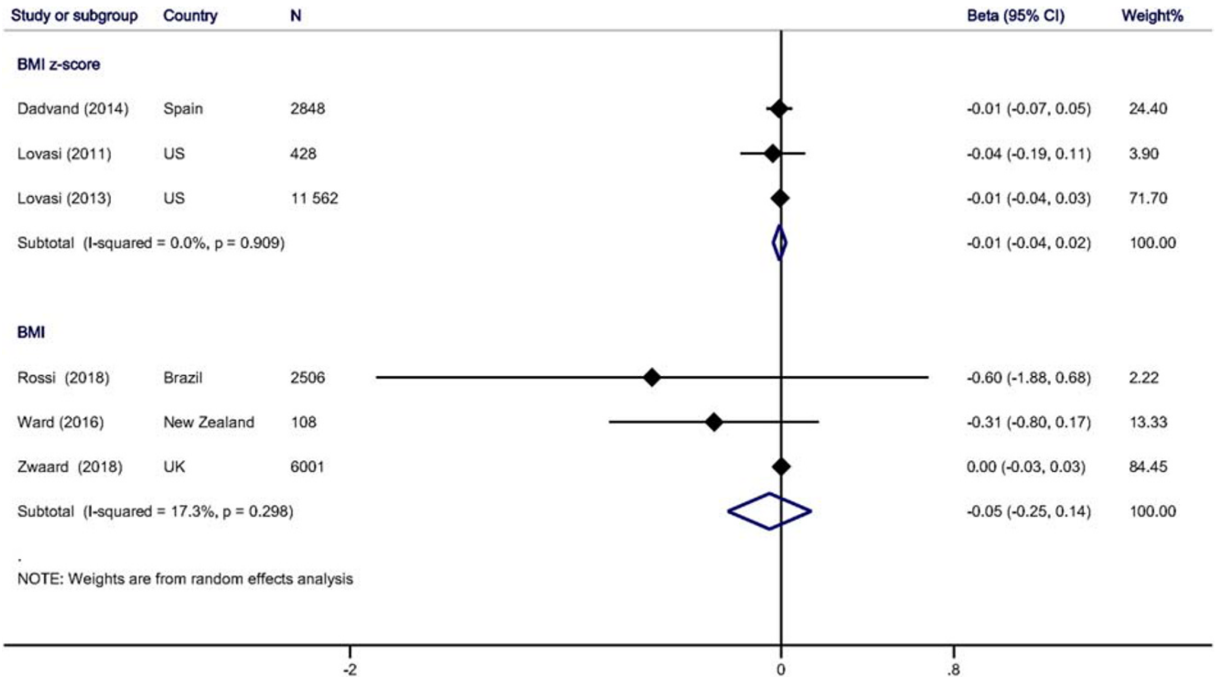

FIGURE 2 Forest plot of the associations between green space access and body mass index

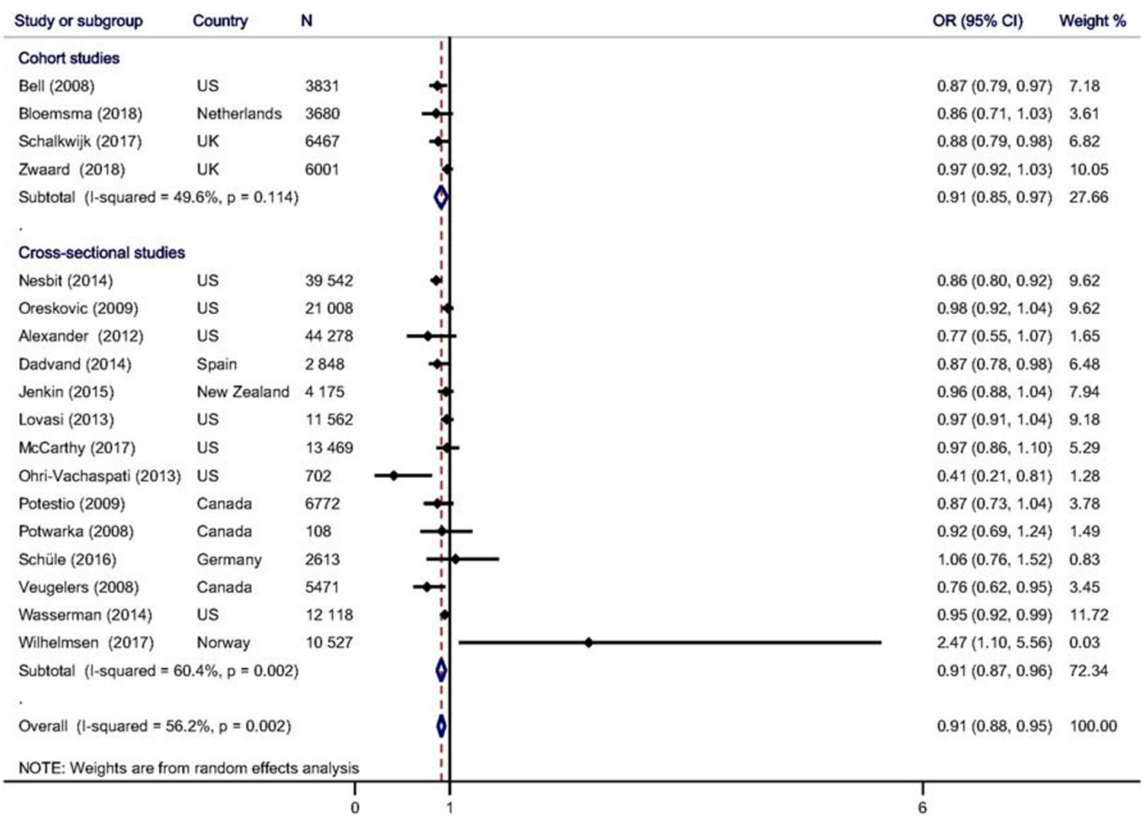

FIGURE 3 Forest plot of the associations between green space access and overweight/obesity

level and county level. Weight-related behaviours and outcomes were used to determine the association in 12 of 21 studies. Mixed results were observed for the association between green space and childhood weight-related behaviours or outcomes among the included studies. Although access to green space was negatively associated with weight-related behaviours and outcomes in most of the included studies, other studies reported either opposite or null associations.

Our findings on the association between green space and childhood weight-related behaviours or outcomes were consistent with another systematic review,[41] where the reported distance to the nearest green space measured by GIS seemed to promote PA and influence obesity, although this association had mixed results due to the differing socioeconomic positions of individuals and the sizes of green spaces. Furthermore, distance to the nearest green space was most commonly measured in these studies, and most of the studies reported that better access to green space could predict higher levels of PA and lower levels of television-watching time. This is likely due to better access to green space, which allows children to visit green spaces more easily and safely. Moreover, green spaces could provide a safe, convenient and attractive place to conduct PA.[42] Some studies found that there were negative associations between green space and childhood PA, which may be due to different measurements of green space. For example, the derived NDVI from remotely sensed images includes croplands, forests, lakes and marshes, which are not necessarily recreational spaces and therefore not suitable for children's PA.[39]

BMI and obesity classification or weight status were the main weight-related outcomes analysed in all included studies. Although most studies found that green space was negatively associated with BMI or weight status, we still cannot arrive at a clear conclusion partly because of the limited number of studies. There were several probable reasons that could help explain the null findings for the association with BMI. For example, the shelter caused by the high-density trees in green spaces provided an opportunity for crowd-base crime, which is unsafe for children's—and especially girls'—outdoor activity.[43–45] On the other hand, the different socioeconomic positions of individuals could influence the correlations between green space and walkability or PA.[44,46] Lovasi et al found that there was a very weak correlation between green space and walkability, especially in low-income communities.[29,43] Additionally, park disamenities could be one of the confounding factors, which may directly influence the use and interest of people, and therefore indirectly influence people's PA.[29] The neighbourhood-built environment, such as a fast-food restaurants on the way to green spaces, may also shape an individual's behaviour. Additionally, the effect of green spaces in different regions on overweight or obesity may vary. For example, Wilhelmsen et al believed that the percentage of adolescents with overweight and obesity increased significantly with the percentage of inconvenient rural green areas.[39]

This review also had limitations that need to be acknowledged and suggestions for future research directions with respect to the association between green spaces and chronic diseases and their risk factors including obesity. First, the measurement of access to green space occurred at only one scale in some studies, or at multiple scales defined differently across studies, making it difficult to compare the included studies. Second, most of the included studies were cross-sectional, with only a few longitudinal studies. The increasing use of advanced earth observation and geo-spatial big data approaches will enable more accurate measurements of the built environment for longitudinal study designs and the combination of follow-up health survey data.[47–50] Longitudinal studies should strengthen the testing of the statistical power to improve the scientific evidence of sampling.[51] Moreover, multiple measurements (ground observations and satellites) of green space will be required to enhance the accuracy of the exposure measurements. Third, the different confounding factors should be controlled for in all studies, which may have an impact on the obtained results. Fourth, access to green space, such as the distance to the nearest green space and presence of green spaces, has been measured by traditional questionnaires or interviews, which reflect the perception of parents and may not accurately reflect children's actual activities. There is a need to use new technologies and approaches, such as volunteered GIS, public participant GIS, crowd-sourced data engineer projects, street view images and eye-tracking technology to measure children's perception.[52] Finally, the definitions of green space and weight-related behaviours and outcomes varied across the studies. Differences in these studies leads to heterogeneity, which we found in our subgroup analyses (except for MVPA) and may also be from other potential sources (e.g., differences in study design and populations and methods of data collection). The Spatial Lifecourse Epidemiology Reporting Standards (ISLE-ReSt), which is a reporting standard for spatial data and methods used in epidemiological research, could be used to address this problem.[53]

5 | CONCLUSION

This systematic review reported mixed findings, although the majority of the included studies found a positive association between access to green space and PA, and a negative association between access to green space and childhood weight-related behaviours/outcomes. Methods of defining and measuring green space access must be improved to accurately estimate individuals' exposure to green space. Future research should incorporate more longitudinal studies to establish the causality of the association and to find the pathways from green space to childhood obesity, which would also allow multiple stakeholders to design effective interventions and policies for the prevention and control of childhood obesity.

ACKNOWLEDGEMENTS

This study is supported by the State Key Laboratory of Urban and Regional Ecology of China (SKLURE2018-2-5), the National Natural Science Foundation of China (91746205), and the International Institute of Spatial Lifecourse Epidemiology (ISLE).

CONFLICT OF INTERESTS

We declare no conflict of interests.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Jia P, Cao X, Yang H, et al. Green space access in the neighbourhood and childhood obesity. *Obesity Reviews*. 2020;1–12. https://doi.org/10.1111/obr.13100