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SUPPLEMENT ARTICLE

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State-of-the-art of measures of the obesogenic environment for children

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Summary

Various measures of the obesogenic environment have been proposed and used in childhood obesity research. The variety of measures poses methodological challenges to designing new research because methodological characteristics integral to developing the measures vary across studies. A systematic review has been conducted to examine the associations between different levels of obesogenic environmental measures (objective or perceived) and childhood obesity. The review includes all articles published in the Cochrane Library, PubMed, Web of Science and Scopus by 31 December 2018. A total of 339 associations in 101 studies have been identified from 18 countries, of which 78 are cross-sectional. Overall, null associations are predominant. Among studies with non-null associations, negative relationships between healthy food outlets in residential neighbourhoods and childhood obesity is found in seven studies; positive associations between unhealthy food outlets and childhood obesity are found in eight studies, whereas negative associations are found in three studies. Measures of recreational or physical activity facilities around the participants'

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home are also negatively correlated to childhood obesity in nine out of 15 studies. Results differ by the types of measurement, environmental indicators and geographic units used to characterize obesogenic environments in residential and school neighbourhoods. To improve the study quality and compare reported findings, a reporting standard for spatial epidemiological research should be adopted.

KEYWORDS
built environment, food environment, obesity, obesogenic environment

1 | INTRODUCTION

Obesity is a leading cause of morbidity and premature mortality worldwide.[1] It has become a severe public health concern among all populations, especially children.[2] According to the World Health Organization (WHO), over 41 million children under the age of 5 and over 340 million children and adolescents aged 5–19 had overweight or obesity as of 2016.[3] Obesity has nearly tripled worldwide since 1951. The increasing obesity rate has particularly affected upper-middle-income countries with high rates of urbanization.[3] The Centers for Disease Control and Prevention (CDC) has reported that in the United States, one out of 6 children and adolescents are suffering from obesity.[4] Childhood obesity often accompanies and leads to more serious chronic health problems, such as high blood pressure, high cholesterol, type II diabetes, asthma, sleep apnoea, fatty liver disease, gallstones, gastro-oesophageal reflux, joint problems and musculoskeletal discomfort.[5–11] Childhood obesity is also related to contingencies in mental health, such as anxiety, depression, low self-esteem, poor quality of life and may, as a result, induce social issues, such as bullying and stigma.[12–14] Children with overweight or obesity have increased risks of developing obesity-related comorbidities, including heart disease and cancer.[15]

The obesogenic environment is defined as the 'sum of the influences that the surroundings, opportunities or conditions of life have on promoting obesity in individuals and populations'.[16,17] The obesogenic environment at the neighbourhood scale may interact with personal characteristics to influence individual's weight status. Modifiable environmental factors manifest as an indirect effect on individual's diet behaviour and physical activity. First, dietary behaviours can be shaped by the community nutrition environment (generally known as the community food environment), defined as types, locations and temporality of food outlets (e.g., supermarkets, convenience stores or fast-food restaurant) in the community.[18,19] A quality community nutrition environment characterized by affordable and accessible food sources in the near proximity of the residential place is necessary for children and adolescents to procure nutritious food items and practice healthy diet behaviour.[20] Second, the proximity to a recreational or physical activity facility, such as park, playground or gym, will increase the likelihood of physical activity engagement and will decrease rates of sedentary activity, eventually mitigating risks of obesity. For example, in neighbourhoods with relatively good walkability (e.g., more sidewalks), people are more likely to engage in physical activity such as walking and cycling, while significantly reducing time spent on sedentary activity, such as watching TV, driving and sitting.[21] Third, there are contextual factors in the obesogenic environment that shape both diet behaviour and physical activity.[22] These contextual factors include the affordability of healthy food options, peer and social supports, marketing and promotion and planning policies on the sustainability of the community design.[4] In this review, we mainly focus on the physical aspect of the obesogenic environment and will not include these contextual factors.

Previous reviews have examined the associations between obesity and various measures of the obesogenic environment. Some studies argue that evaluations by these measures differ by age group and vary across countries. A recent review found that associations between the community food environment and obesity were less likely to be significant among children than adults in the United States and Canada.[23] Another review conducted an extended scope of work in four European and Oceanian countries (i.e., the United Kingdom, Ireland, Australia and New Zealand) and compared the findings with the North America.[24] Even among children, associations between the community-based obesogenic variables and obesity differed by gender, age and socio-economic status.[25] In addition to these regional comparisons, the association may also vary by the definition of the community or neighbourhood. Neighbourhood is loosely defined as a physical extent where individuals engage in communal activities with local residents.[26] This definition focused on a physical space has been further extended to the perceived neighbourhood or the geographic extent conceptualized by people as their communal space. It has been found that individuals tend to perceive their living neighbourhood as being smaller than the administrative unit (e.g., census tract and postal zone) where they reside. This means that the actual scale where the contextual factors affect individuals' health status could be very different from those derived from the administrative unit.[27] There have been no consensuses in obesity studies about the most appropriate scales and measures where obesogenic environmental factors should be employed. For example, it was noted that the majority of food environment studies were employed at the community or neighbourhood scale in terms of schools, work sites and households[23]; measures of the food environment included the availability, variety, accessibility and density of food outlets. In addition, a systematic review on green space and obesity reported that two most common measures of the physical access were distance (Euclidean or network) to near green spaces and the count of green spaces in the vicinity of the residential place.[28] Despite the accumulation of research using various environmental measures, there is still lack of consensus on how to define the obesogenic environment for children.[28,29]

This review contributes to the literature in two major aspects. First, we have systematically reviewed a full scope of literature using both objective and perceived measures of the obesogenic environment applied to childhood obesity research. Second, this review has summarized the different levels of associations between these measures and childhood obesity. This study will inform researchers about the availability, consistency and significance of these environmental measures. Furthermore, this review will shed important insights into childhood obesity research that employs a multiscale framework for intraregional and interregional comparisons.[18]

2 | METHODS

A systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews (PRISM).

2.1 | Study selection criteria

Our study inclusion criteria were as follows: (1) the study included at least one measure of the obesogenic environment, (2) the study outcome was obesity (including overweight) instead of other health outcomes, (3) the study was focused on the association with obesity rather than the obesogenic environment (e.g., food environments) per se or obesity-related behaviours (e.g., diet behaviour and physical activity) per se, (4) the study was focused on the obesity of children aged younger than 18 years and (5) the study was an original research article published in English.

2.2 | Search strategy

A keyword search was performed in four electronic bibliographic databases: Cochrane Library, PubMed, Web of Science and Scopus. The search strategy included all possible combinations of keywords, including the obesogenic environment (mainly built environment and food environment), children and adolescents and weight-related outcomes (Appendix A). To increase the coverage of the literature, we manually searched the reference lists in a snowball approach and cited relevant articles with an end search date of 31 December 2018.

Titles and abstracts of the articles identified through the keyword search were screened against the study selection criteria. The full text of potentially relevant articles was retrieved for scrutiny and integration. Two reviewers independently conducted the title and abstract screening and identified potentially relevant articles for the full-text review. Discrepancies were screened by a third reviewer. The three reviewers jointly determined the list of articles for the full-text review through several rounds of discussion. Two reviewers then 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 extraction

For each selected study, we adopted a standardized data extraction process to collect methodological and outcome variables, including authors, year of publication, study area, country, study year, sample size, age range/age at baseline, sample characteristics (including follow-up years), number of repeated measures, attrition rate (if applicable), statistical model, measures of the obesogenic environment (objective or perceived; residential neighbourhood or school), measures of body-weight status and key findings on the association between obesogenic environments and weight-related outcomes. Two reviewers independently extracted data from each study included in the review, and discrepancies were resolved by the third reviewer.

3 | RESULTS

3.1 | Study selection

Figure 1 shows the study selection flow chart. We identified a total of 4629 articles through the keyword search process. The search underwent title and abstract screening, by which 1697 articles were excluded. The full texts of the remaining 106 articles were reviewed against the study selection criteria. Of these full-text articles, five articles were excluded. The remaining 101 studies that examined the relationship between the obesogenic environment and weight-related outcomes were included in this review.

3.2 | Study characteristics

The main characteristics of the 101 included articles were presented in Table 1. All studies were published after 2004. The age of participants ranged from 2 to 18, with 76 cross-sectional studies, 23 longitudinal studies, and two repeated cross-sectional studies. These 101 studies covered 18 countries: 65 studies were conducted in North America, with 53 studies from the United States and 12 studies from Canada; 11 studies were from the United Kingdom; 16 were from Australia, Germany and China, with four studies from each country; two were from Brazil; and the rest were from France, Ireland, Lithuania, Malaysia, Mexico, Netherland, Portugal, South Korea, Spain, Sweden and Ukraine, with one study per country.

The geographic scales of these studies varied from country to county, while the number of participants ranged from 78 to 3 003 288. These studies were conducted at different geographic scales, including nationwide (n = 11), provincial (n = 17), multistate

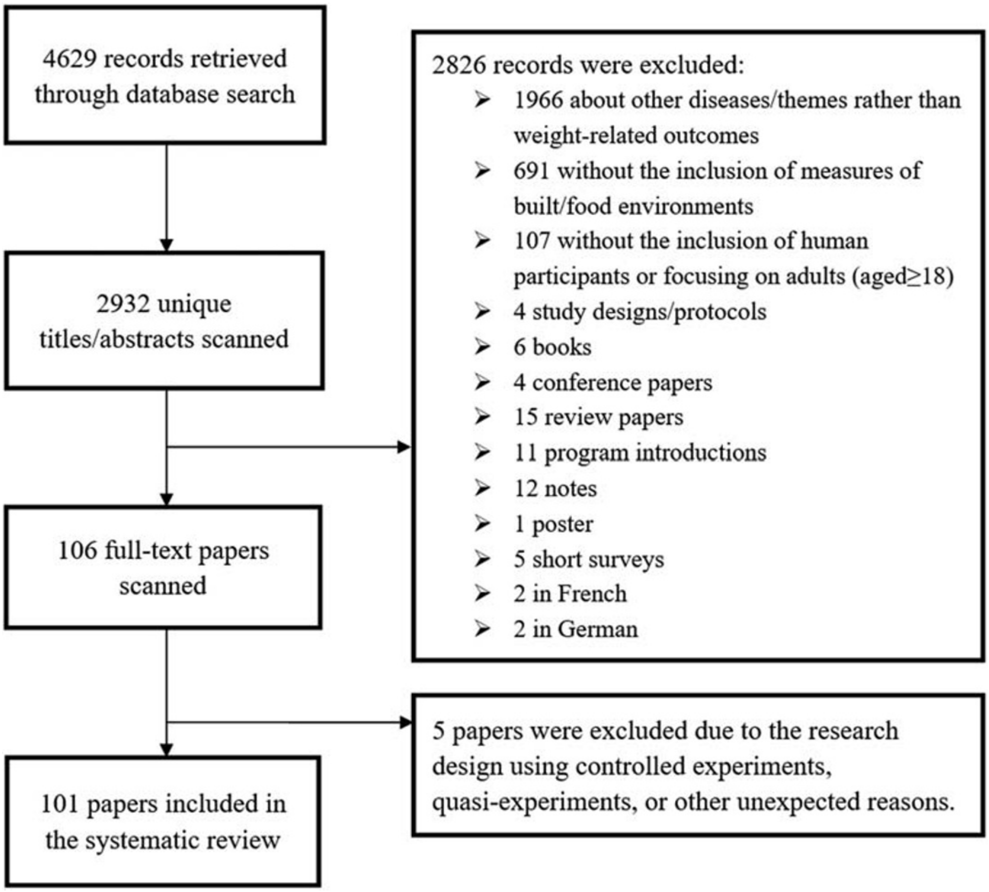

FIGURE 1 Study exclusion and inclusion flowchart

(*n* = 1), multicity (*n* = 3), single city (*n* = 13), multicounty (*n* = 1) and single county (*n* = 7). Most of the studies accounted for multilevel data and applied multivariable regression models for data analysis (*n* = 86, 85%), including linear regression model (*n* = 27, 27%) and logistic regression model (*n* = 38, 38%). Other methods, such as the correlation analysis (*n* = 2) and the multilevel grows curve model (*n* = 3), were also employed. Study outcomes included the absolute value of the body mass index (BMI), BMI percentile or *z* score, rate of obesity or overweight and change in BMI or weight.

3.3 | Diversity of measurements

The most common types of the obesogenic environment under examination were residential neighbourhoods (*n* = 96) (Table S1) and school neighbourhoods (*n* = 23) (Table S2). The investigation approaches included objective measures by Geographic Information Systems (GIS) tools (*n* = 85) or neighbourhood perceptions self-reported by the participants, their parents or the school directors (*n* = 17). Both the objective measures and the perceived measures included four environmental indicators, including availability (e.g., presence or not), count (e.g., total number), density (e.g., count/population, count/area) and proximity (e.g., straight-line/network distance). Among the 101 studies examining these indicators, count was the most common measure (*n* = 72), followed by availability (*n* = 36). More complex spatial measures such as the kernel density that weighs outlets near participants' school (*n* = 6) or moderates the distance to the nearest retail outlet (*n* = 2) were less likely to be employed.

Studies also differed by the geographic units used to assess exposure to the obesogenic environment in residential neighbourhoods or school neighbourhoods. For instance, 22 studies measured the exposure to supermarkets in 20 different ways, and 26 studies assessed the exposure to fast-food restaurants in 17 different ways. Sixteen studies used administrative units, including census tracts (*n* = 12), postal zones (*n* = 2) and predefined grids (*n* = 4; i.e., Middle Super Output Area,[29] Street Segments,[53] Small Area Market Statistics[16] and Lower Super Output Area[115]). Residential or school addresses were also used for assessing environmental exposure, buffered by a radius (and was measured either along the road network or by a set distance) (Tables S3 and S4). Buffers ranged in sizes from 0.4 to 6 km. A 1.6-km road-network buffer was the most commonly used criterion (*n* = 13), followed by a 1-km buffer (*n* = 11). Many studies performed sensitivity analyses with buffers of multiple sizes.

3.4 | Association between food environment and obesity

Sixty-five studies examined weight-related outcomes in relation to food environment measures in residential neighbourhoods (*n* = 164) (Table S1) or school neighbourhoods (*n* = 72) (Table S2). Although a high percentage (*n* = 146, 62%) of these associations were null, there

TABLE 1 Basic characteristics of the included studies

First author (year)	Study area [scale][a]	Study design[b]	Sample size	Age at baseline (years)[c]	Sample characteristics	Statistical models	Outcome variables
Baek (2016)[30]	California, USA [S]	C	601 847	10–15 in 2009	FitnessGram test	Distributed lag model	BMI *z* score
Barrera (2016)[31]	Cuernavaca and Guadalajara, Mexico [C2]	C	725	9–11 in 2012–2013	Elementary school children	Multiple linear regression	BMI *z* score
Bell (2008)[32]	Indianapolis, USA [C]	L	3831	3–16 in 1996–2002	Cohort in primary care clinic network, followed up for 2 years with two repeated measurements	Multiple linear regression	BMI *z* score
Berge (2014)[33]	Minneapolis/St. Paul, USA [C]	C	2682	14–16 in 2009	Eating and Activity in Teens (EAT) survey	Multiple linear regression	BMI *z* score
Carroll-Scott (2013)[34]	New Haven, USA [C]	C	1048	10–11 in 2009	Community interventions for health chronic disease prevention study	Linear regression	BMI
Carter (2012)[35]	Quebec, Canada [S]	L	2120	4–10 in 1997–1998	Quebec Longitudinal Study of Child Development cohort, followed up for 7 years with five repeated measurements and attrition rate of 26.1%	Linear regression	BMI *z* score
Casey (2012)[36]	Bas-Rhin, France [S]	C	3327	11–13 in 2001	France middle school students	Mixed logistic regression	Weight, BMI
Cetateanu (2014)[29]	UK [N]	C	3 003 288	4–5 and 10–11 in 2007–2010	National Child Measurement Program (NCMP) dataset	Stepwise linear regression	Overweight/obesity
Chaparro (2014)[37]	Los Angeles, USA [CT]	L	32 172	2–5 in 2005–2008	Women, Infants and Children (WIC) study, followed up for 4 years with three repeated measurements	Linear regression, multilevel linear growth model	WHZ
Cheah (2012)[38]	Kuching, Malaysia [C]	C	316	14–16	Secondary schools students	Univariate data analysis	BMI
Chen (2016)[39]	USA [N]	L	7090	11 in 2004–2007	Early Childhood Longitudinal Study-Kindergarten (ECLS-K) cohort, followed up for 4 years with two repeated measurements	Fixed-effect regression	BMI, obesity
Chiang (2017)[40]	Taiwan, China [S]	C	1458	11–16 in 2010	Nutrition and Health Survey in Taiwan	Multiple linear regression	Height *z* score, weight *z* score, BMI score, WC *z* score, WC/height ratio, WC/hip ratio, TSF *z* score, MAMC *z* score
Correa (2018)[41]	Florianópolis, Brazil [C]	C	2195	7–14 in 2012–2013	Public and private school children	Logistic regression	BMI *z* score, overweight/obesity
Crawford (2010)[42]	Melbourne, Australia [C]	L	926	10–12 in 2001	Children's Leisure Activities Study (CLAN), followed up for 5 years with three repeated	Generalized estimating equation	BMI *z* score, MVPA

(Continues)

TABLE 1 (Continued)

First author (year)	Study area [scale][a]	Study design[b]	Sample size	Age at baseline (years)[c]	Sample characteristics	Statistical models	Outcome variables
					measurements and attrition rate of 66%		
Datar (2015)[43]	Ft. Lewis, Ft. Carson, Ft. Drum, Ft. Bragg, Ft. Benning, Ft. Bliss, Ft. Campbell, Ft. Hood, Ft. Polk, Ft. Stewart, Ft. sill, Ft. Riley, USA [C12]	C	903	12–13 in 2013	Military Teenagers Environment, Exercise, and Nutrition Study	Multivariate regression	PA, BMI
Davis (2009)[44]	California, USA [S]	C	529 367	≤19 in 2002–2005	California Healthy Kids Survey	Ordinary least squares regression, logistic regression	Overweight, obesity, BMI
Duncan (2012)[45]	Boston, USA [C]	C	1034	15–18 in 2007–2008	Boston Youth Survey	Spatial regression, ordinary least squares regression	BMI
Duncan (2012)[46]	Coventry, UK [C]	C	405	14–15	Pupils	Pearson's product moment correlations	PA, BMI
Duncan (2015)[47]	Massachusetts, USA [S]	L	49 770	4–12 in 2011–2012	Pediatric practices of Harvard Vanguard Medical Associates, followed up for 1.5 years with two repeated measurements	Multivariable model	BMI *z* score
Dwicaksono (2017)[48]	New York, USA [S]	C	680	In 2010–2012	Student Weight Status Category Reporting System dataset	Ordinary least squares regression, geographically weighted regression	Obesity rate
Edwards (2010)[49]	Leeds, UK [C]	C	33 594	3–13 in 2004–2005	Leeds primary care trusts record and trends study in Leeds	Geographically weighted regression	BMI
Epstein (2012)[50]	Erie, USA [CT]	L	191	8–12 in 1997–2005	Four randomized, controlled outcome studies, followed up for 2 years with two repeated measurements	Hierarchical mixed model analyses of covariance	BMI, BMI *z* score
Fiechtner (2016)[51]	Massachusetts, USA [S]	L	498	6–12 in 2011–2013	Study of Technology to Accelerate Research trail, followed up for 3 years with two repeated measurements and attrition rate of 9%	Generalized linear mixed effects regression	BMI *z* score
Friedman (2009)[52]	Kyiv, Dniprodzerzhynsk and Mariupo, Ukraine [C3]	C	883	3 in 1993–1996	European Longitudinal Study of Pregnancy and Childhood (ELSPAC) cohort	Multivariable logistic regression	Overweight, obesity
Ghenadenik (2018)[53]	Quebec, Canada [S]	L	506	8–10 in 2005–2008	Quebec Adipose and Lifestyle Investigation in Youth cohort, followed up for 2 years with two repeated measurements and attrition rate of 19.3%	Multivariable linear regression	BMI *z* score, WHR

TABLE 1 (Continued)

First author (year)	Study area [scale][a]	Study design[b]	Sample size	Age at baseline (years)[c]	Sample characteristics	Statistical models	Outcome variables
Gilliland (2012)[54]	London, UK [C]	C	1048	10–14	28 elementary school	Multilevel structural equation	BMI *z* score
Gordon-Larsen (2006)[55]	USA [N]	C	20 745	Grades 7–12 in 1994–1995	Add Health wave I	Logistic regression	Overweight
Gose (2013)[56]	Kiel, Germany [C]	L	485	6 in 2006–2012	Kiel Obesity Prevention Study (KOPS), followed up for 4 years with two repeated measurements and attrition rate of 72.6%	Generalized estimating equation	BMI standard deviation score
Grafova (2008)[57]	USA [N]	C	2482	5–18 in 2002–2003	Child Development Supplement survey	Logistic regression	BMI
Green (2018)[58]	Leeds, UK [C]	L	746	11–12 in 2005–2010	Rugby League and Athletics Development Scheme (RADS), followed up for 5 years with three repeated measurements	Multilevel linear regression	Overweight, obesity
Fiechtner (2013)[59]	Massachusetts, USA [S]	C	438	2–7 in 2006–2009	High Five for Kids (HFK) study	Multivariable linear regression	BMI
Griffiths (2014)[60]	Leeds, UK [C]	C	13 291	11 in 2005–2007	RADS	Multiple linear and logistic regression	BMI
Guedes (2011)[61]	Minas Gerais, Brazil [S]	C	5100	6–18 in 2007	School children	Binary logistic regression	BMI
Hamano (2017)[16]	Sweden [N]	C	944 487	0–14 in 2005–2010	Swedish nationwide population and health care dataset	Multilevel logistic regression	Obesity
Harris (2011)[62]	Maine, USA [S]	C	552	Grades 9–12	Students at 11 Maine high schools	Logistic regression	BMI
Harrison (2011)[63]	Norfolk, UK [CT]	C	1724	9–10 in 2007	Sport, Physical Activity and Eating Behaviour: Environmental Determinants in Young People (SPEEDY) study	Multilevel and multivariable hierarchical regression	FMI
Howard (2011)[64]	California, USA [S]	C	879	Grade 9 in 2007	FitnessGram test	Linear regression	BMI
Hoyt (2014)[65]	California, USA [S]	L	174	8–10 in 2007–2012	Cohort Study of Young Girls' Nutrition, Environment, and Transitions (CYGNET), followed up for 4 years with at least two repeated measurements and attrition rate of 19.1%	Logistic regression	BMI, obesity
Morgan Hughey (2017)[66]	USA [CT]	L	13 469	3–5 in 2013	Children in county school district	Multilevel linear regression	BMI
Jennings (2011)[67]	Norfolk, UK [CT]	C	1669	9–10 in 2007	SPEEDY study	Poisson regression	BMI, weight, BMI *z* score, WC, % of body fat

(Continues)

TABLE 1 (Continued)

First author (year)	Study area [scale][a]	Study design[b]	Sample size	Age at baseline (years)[c]	Sample characteristics	Statistical models	Outcome variables
Jerrett (2010)[68]	California, USA [S]	L	3318	9–10 in 1993 and 1996	Children's Health Study (CHS) cohort, followed up for 8 years with two repeated measurements and attrition rate of 12.9%	Multilevel growth curve model	BMI
Jerrett (2014)[69]	California, USA [S]	L	4550	5–7 in 2002–2003	A cohort of children attending kindergarten and first grade, followed up for 4 years with four repeated measurements and attrition rate of 6.4%	Multilevel linear regression	BMI
Koleilat (2012)[70]	Los Angeles, USA [CT]	C	266	3–4 in 2008	WIC study	Simple linear regression	Weight
Lakes (2016)[71]	Berlin, Germany [C]	C	28 159	5–6 in 2012	Berlin children survey	Multivariate regression	% of overweight/obesity
Lange (2011)[72]	Kiel, Germany [C]	C	3440	13–15 in 2004–2008	KOPS	Logistic regression	BMI
Larsen (2014)[73]	Toronto, Canada [C]	C	943	2–20 in 2010–2011	BEAT	Logistic regression	BMI
Laska (2010)[74]	Minneapolis/St. Paul, USA [C]	C	349	10–17 in 2006–2007	Identifying Determinants of Eating and Activity Study	Multilevel regression	BMI
Leatherdale (2011)[75]	Ontario, Canada [S]	C	2449	10–13 in 2007–2008	Play-Ontario (PLAY-ON) study	Multilevel logistic regression	BMI
Leatherdale (2013)[76]	Ontario, Canada [S]	C	2331	6–9 in 2007–2008	PLAY-ON study	Multilevel logistic regression	Overweight, obesity
Leung (2011)[77]	California, USA [S]	L	444	6–7 in 2005–2008	CYGNET cohort, followed up for 3 years with two repeated measurements and attrition rate of 20.5%	Generalized linear and logistic regression	BMI *z* score
Li (2015)[78]	A rural BBR, USA [CT]	C	613	4–13 in 2013	School children	Multilevel models	BMI percentile
Lovasi (2013)[79]	New York, USA [C]	C	11 562	3–5 in 2004	Preschool programme	Linear and Poisson regression	BMI *z* score, obesity
Miller (2011)[80]	USA [N]	L	11 400	6–12 in 1998–2004	ECLS-K cohort, followed up for 7 years with two repeated measurements	Three-level growth curve model	BMI
Miller (2014)[81]	Perth, Australia [C]	C	1850	5–15 in 2005–2010	Western Australian Health and Wellbeing Surveillance System database	Multivariate logistic regression	BMI
Minaker (2011)[82]	Alberta, Canada [S]	C	4936	11–17 in 2005	Web-Survey of Physical Activity and Nutrition study	Multinomial logistic and ordinal regressions	BMI
Molina-García (2017)[83]	Valencia, Spain [C]	C	325	14–18 in 2013–2015	International Physical Activity and the Environment Network adolescent study	Mixed regression	BMI, % of body fat
Nelson (2009)[84]	Ireland [N]	C	4587	15–17 in 2003–2005	Take PART study	Logistic regression	Overweight, obesity

TABLE 1 (Continued)

First author (year)	Study area [scale][a]	Study design[b]	Sample size	Age at baseline (years)[c]	Sample characteristics	Statistical models	Outcome variables
Nesbit (2014)[85]	USA [N]	C	39 542	11–17 in 2007	National Survey of Children's Health (NSCH)	Logistic regression	BMI, obesity
Ness (2012)[86]	USA [N]	C	5342	10–19 in 2007	NSCH	Pooled and race-stratified logistic regression	BMI
Nogueira (2013)[87]	Coimbra, Portugal [CT]	C	1885	3–10 in 2009	Private and public school children	Logistic regression	BMI
Norman (2006)[88]	San Diego, USA [CT]	C	799	11–15	Health promotion intervention trial	Multiple linear regression	BMI
Ohri-Vachaspati (2013)[89]	Camden, New Brunswick, Newark and Trenton, USA [C4]	C	702	3–18 in 2009–2010	Random-digit-dial survey	Logistic regression	Overweight, obesity
Oreskovic (2009)[90]	Massachusetts, USA [S]	C	6680	2–18 in 2006	Partners HealthCare	Clustered logistic regression	Overweight/obesity
Oreskovic (2009)[91]	Massachusetts, USA [S]	C	21 008	2–18 in 2006	Partners HealthCare	Multilevel logistic regression	Overweight/obesity
Park (2013)[92]	Seoul, South Korea [C]	C	1342	10–13 in 2011	Elementary and middle school children	Generalized estimating equation	BMI, weight status
Pearce (2017)[93]	South Gloucestershire, UK [S]	L	1577	7 in 2006–2012	NCMP dataset, followed up for 6 years with two repeated measurements	Multiple logistic regression	BMI, WC
Petraviciene (2018)[94]	Kaunas, Lithuania [C]	C	1498	4–6 in 2012–2013	Positive Health Effects of the Natural Outdoor Environment in Typical Populations in Different Regions in Europe project	Logistic regression	BMI *z* score
Pitts (2013)[95]	Greene and Pitt, USA [CT2]	C	296	11–13 in 2008–2010	Middle school children	Linear regression	BMI percentile
Poole (2017)[96]	Southampton, UK [C]	C	1748	4–5 in 2012–2013	NCMP dataset	Multilevel logistic regression	BMI percentile
Potestio (2009)[97]	Calgary, Canada [C]	C	6772	5 in 2005–2006	Public health clinics for preschool vaccinations	Two-level, random-intercept logistic regression	BMI
Rossen (2013)[98]	Baltimore, USA [C]	L	319	8–10 in 2007	Multiple Opportunities to Reach Excellence project cohort, followed up for 1 year with two repeated measurements and attrition rate of 26%	Multilevel model	BMI change, WC change
Gorski Findling (2018)[99]	USA [N]	C	3748	2–18 in 2012–2013	Food Acquisition and Purchase Survey	Logistic regression	Overweight, obesity
Sánchez (2012)[100]	California, USA [S]	C	926 018	2007	FitnessGram test	Log-binomial regression	BMI
Schmidt (2015)[101]	Netherlands [N]	L	1887	4–5 in 2000–2002			BMI *z* score

(Continues)

TABLE 1 (Continued)

First author (year)	Study area [scale][a]	Study design[b]	Sample size	Age at baseline (years)[c]	Sample characteristics	Statistical models	Outcome variables
					KOALA Birth Cohort, followed up for 4 years with five repeated measurements	Linear regression, generalized estimating equations	
Schüle (2016)[102]	Munich, Germany [C]	C	3499	5–7 in 2004–2007	Gesundheits-Monitoring-Einheiten survey	Hierarchical logistic regression	BMI, overweight, obesity
Seliske (2009)[103]	Canada [N]	C	9672	Grades 6–10 in 2005–2006	Health Behaviour in School-Aged Children survey	Multilevel regression	BMI
Seliske (2012)[104]	Canada [N]	C	7017	12–19 in 2007–2008	Canadian Community Health Survey	Multilevel logistic regressions	MVPA, BMI
Singh (2010)[105]	USA [N]	C	44 101	10–17 in 2007–2008	NSCH	Logistic regression	BMI
Slater (2013)[106]	USA [N]	C	11 041	Grades 8, 10 and 12 in 2010	Monitoring the Future (MTF) survey	Multivariable logistic regression	Overweight, obesity
Spence (2008)[107]	Edmonton, Canada [C]	C	501	4–6 in 2004	Preschool immunization	Logistic regression	BMI
Tang (2014)[108]	Camden, New Brunswick, Newark and Trenton, USA [C4]	C	12 954	10–17 in 2008–2009	New Jersey Childhood Obesity study	Random-effects model	BMI *z* score, overweight, obesity
Taylor (2014)[109]	13 block groups in Southeastern USA [C]	C	911	5–15	Environmental audits and a cross-sectional prevalence study of cardiovascular risk factors	Correlation analysis	Obesity, overweight, WC, WHR
Timperio (2010)[110]	Melbourne, Australia [C]	L	409	5–6 and 10–12 in 2001–2004	CLAN, followed up for 3 years with two repeated measurements and attrition rate of 30.7%	Univariate and multivariable linear regression	BMI *z* score, BMI
Torres (2014)[111]	San Juan, USA [C]	C	114	12 in 2012–2013	Public school children	Spearman's correlation	BMI percentile
Veugelers (2008)[112]	Nova Scotia, Canada [S]	C	5471	10–11 in 2003	Children's Lifestyle and School-Performance Study	Multilevel linear regression	Overweight, obesity
Wall (2012)[113]	Minneapolis/St. Paul, USA [C]	C	2682	12–16 in 2009–2010	EAT survey	Multiple linear regression	BMI *z* score
Wasserman (2014)[114]	Kansas, USA [C]	C	12 118	4–12 in 2008–2009	School children	Hierarchical linear	BMI percentile
Williams (2015)[115]	UK [N]	C	16 956	4–6 and 10–11 in 2010–2011	NCMP dataset	Multilevel	BMI
Wolch (2011)[116]	California, USA [S]	L	3173	9–10 in 1993–1996	CHS cohort, followed up for 8 years with eight repeated measurements	Multilevel growth curve model	BMI change
Xu (2010)[117]	Nanjing, China [C]	C	2375	14 in 2004	Nanjing High School Students' Health Survey	Mixed-effect logistic regression	BMI
Yang (2018)[118]		C	41 283		Children in SCS	Multilevel logistic regression	BMI

TABLE 1 (Continued)

First author (year)	Study area [scale][a]	Study design[b]	Sample size	Age at baseline (years)[c]	Sample characteristics	Statistical models	Outcome variables
	Shelby Count, Memphis, USA [CT]			Grades pre-K, K, 2, 4, 6, 8 and 9 in 2014–2015			
Zhang (2016)[119]	China [N]	C	348	8–12 in 2009–2011	China Health and Nutrition Survey	Generalized estimating equation	BMI
Sallis (2018)[21]	Maryland and King County, Washington regions, USA [S2]	C	928	12–16 in 2009–2011	Teen Environment and Neighborhood study	Mixed model linear and logistic regression	BMI percentile
Li (2014)[120]	Guangzhou and Hechi, China [C2]	C	497	8–10 in 2009–2010	Schools for routine (every 5 years) student health monitoring by local health bureau	Multiple logistic regression and linear regression	Overweight/obesity
Kepper (2016)[121]	Louisiana, USA [S]	C	78	2–5	A randomized controlled trial	Multiple regression analysis	BMI *z* score
Crawford (2015)[122]	Victoria, Australia [S]	L	200	5–12 in 2007–2011	A survey on weight children in socio-economically disadvantaged neighbourhoods, followed up for 3 years with two repeated measurements and attrition rate of 41.3%	Linear and logistic regression	BMI *z* score, unhealthy weight gain
Powell (2007)[123]	USA [N]	C	73 079	13–15 in 1997–2003	MTF survey	Reduced form models	BMI, overweight
Burdette (2004)[124]	Cincinnati, USA [C]	C	7020	3–5 in 1998–2001	WIC study	Logistic regression	BMI percentile
Sturm (2005)[125]	USA [N]	L	6918	Grades K, 1 and 3 in 1998–1999	ECLS-K cohort, followed up for 4 years with two repeated measurements	Least squares and quantile regression	BMI change
Potwarka (2008)[126]	Mid-sized city in Ontario, Canada [C]	C	108	2–17 in 2006	Randomly selected	Logistic regression	Healthy weight
Galvez (2009)[127]	New York, USA [C]	C	323	6–8 in 2004	Mount Sinai Pediatrics Practice, East Harlem community health centres, community-based organizations and East Harlem schools children	Logistic regression	BMI in top tertile

Abbreviations: BMI, body mass index; FMI, fat mass index; MAMC, mid-arm muscle circumference; PA, physical activity; TSF, triceps skinfold thickness; WC, waist circumference; WHR, waist-height ratio; WHZ, weight-for-height *z* score.

[a][N], national; [S], state (United States) or equivalent unit (e.g., province in China); [S*n*], *n* states or equivalent units; [CT], county or equivalent unit; [CT*n*], *n* counties or equivalent units; [C], city; [C*n*], *n* cities.

[b]C, cross-sectional study; L, longitudinal study.

[c]Age in baseline year for longitudinal study and age in survey year for cross-sectional study.

were some notable findings. For example, most of the findings (seven out of nine associations in five studies for residential neighbourhoods) on healthy food outlets (e.g., supermarkets) and obesity suggested a negative association between the two, and the association was more apparent for availability, count and density measures than for distance measures. Similarly, the availability of[39,52,108,123] and the proximity to[51,59,73] supermarkets were inversely related to obesity. In contrast, the availability of unhealthy food outlets (e.g., convenience stores and fast-food restaurants) was positively associated with obesity in several studies (eight out of 20 associations in 15 studies for residential neighbourhood; three out of 13 associations in 11 studies for school neighbourhoods). For associations between convenience stores and obesity, seven out of 23 associations for residential neighbourhoods and six out of 11 associations for school neighbourhoods were positive. Results for fast-food restaurants were equivocal: although positive associations between fast-food availability and obesity outnumbered negative ones (seven positive vs. three negative), the majority of the associations (n = 23, 70%) were null. Evidence for associations with grocery stores (five positive, two negative and 15 null) and full-service restaurants (one negative, one positive and 8 null) was relatively weak.

3.5 | Association between built environment and obesity

Overall, 35 studies examined 85 associations between built environmental measures and weight-related outcomes in residential neighbourhoods (Table S1) and 18 associations in schools (Table S2). Regardless of the type of measurement, null associations were predominant. For studies examining all recreational or physical activity facilities around the participants' residential place, negative associations with obesity were reported (n = 9, 60%). Similar patterns emerged with built environment measures calculated for gyms and fitness centres in or around schools (three negative out of four studies). However, the results for parks were mixed. Both positive correlations and negative correlations between the availability of parks (including green spaces and playgrounds) and obesity were identified (three positive vs. six negative for residential neighbourhoods; two positive vs. two negative for school neighbourhoods). Some studies reported that travel-related built environment measures, such as dense traffic roads,[56,63,68,69,102,110] intersections,[48] transit stations[45,49] and traffic signs,[113] had a positive correlation with obesity, whereas others found the correlations to be negative for dense traffic roads[47,63,91] and intersections.[47,107,110]

3.6 | Impact of geographic units on associations

The spatial delineation of geographic units affected the results to some extent. In residential neighbourhoods, there were negative associations with healthy food outlets with measures in all buffer sizes for residential neighbourhood (Table S3). On the other hand, the positive association was dominant between the availability of unhealthy food outlets and obesity within most of geographic units (n = 8, 40%) especially administrative unit (n = 4, 80%); however, unhealthy food outlets yielded negative associations in 0.8- and 3-km road-network buffers. Some studies also identified mixed results using different geographic units, such as number of grocery store in 0.4-km straight-line buffer[108] and 0.4-km road-network buffer,[77] and others had even yielded opposite results using same geographic units, such as number of supermarket in postal zone.[39,70]

To investigate the influence of geographic units on associations, 15 studies used more than one geographic unit, and they reported that the correlation between food outlet and obesity tended to be more significant when analyses were performed using smaller buffer sizes.[54,81]

4 | DISCUSSION

This systematic review identified 101 studies that examined the associations between obesogenic environmental factors and childhood obesity. Several important findings were identified. First, there was a high degree of heterogeneity in quantifying the obesogenic environment for children. Notably, an obesogenic environment was commonly measured as either objective measures, perceived measures or both. Among the studies that employed both objective and perceived measures, the perceived measures were more likely to yield statistical significance than the objective measures. However, the effect sizes of the perceived measures were relatively small, providing only weak evidence to support a relationship between environmental factors and obesity in children.[128]

Second, the majority of the studies that examined food environment and childhood obesity reported more consistent associations. Among these studies, the most commonly used objective measures were count and availability, and the results varied by the type of food outlet. Fast-food outlets and convenience stores showed more positive associations with childhood obesity. This finding resonates with the widespread concern that the frequent patronization of fast-food outlets and convenience stores has health-damaging effects.[129] This statistical linkage calls for more rigorous studies to establish the causal pathway to childhood obesity. Likewise, the proximity to supermarkets and farmers' markets showed negative associations with childhood obesity,[39,50,60,84,88,128] and this effect could be attributed to the higher likelihood of fruit and/or vegetable intake when healthy food access is adequate. However, several studies investigating the effect of supermarkets on obesity did not reveal a significant association,[51,59,73] implying that the association between supermarket access and obesity could be influenced by other contextual factors, such as shopping preferences, available modes of transportation and the presence of alternative food outlets.

Third, other factors of the built environment in shaping childhood obesity were rather inconclusive. Several studies recognized physical activity as an important factor in linking the obesogenic environment and childhood obesity, highlighting the health-promoting role of recreational or physical activity facilities.[84,88,130] Several other studies also examine the differences in transport-related environments (e.g., sidewalk, intersection and traffic) in explaining the disparity in children's physical activity and obesity.[*] However, mixed results in terms of travel-related environmental factors were found in the literature.[†] A recent systematic review indicated that school transport interventions, such as the 'Safe Routes to School' programme in the United States, could be effective in increasing children's physical activity; however, overall quality of evidence was weak, largely due to inconsistencies across study design and short study periods.[132] Isolating the influence of the travel-related environment on children's physical activity and obesity would be difficult because of possible interactions with other psychometric factors, such as safety perception.[131] Also, some studies may be subject to residential self-selection bias[133] or selective daily mobility bias,[134] wherein preference or knowledge of healthy lifestyle could influence subjects' residential choice and travel patterns. The extent to which these biases also present in identifying modifiable risk factors in the built environment associated with childhood obesity remains relatively unknown, calling for further work.[135]

Lastly, a large number of studies reported null associations between the obesogenic environment and childhood obesity, possibly due to the confounding effect on the individual level. Associations between environmental factors and childhood obesity could be modified by individual characteristics, such as gender, race, age, education attainment, family income and marital status. The same environment may have markedly different effects on different population groups. For example, the density of farmers' markets around the residential place was negatively associated with obesity among elementary students; the association, however, was not significant among middle/high school students.[48] For the two groups of students in the same study, the associations with the density of fast-food restaurants were the opposite. In another study, the environmental effects of supermarkets on obesity were different by gender group—girls were more likely to be affected by supermarket access than boys.[39] This gender difference, although being subtler in children than in adults, could be explained by the different levels of exposure and vulnerability to the obesogenic environment between genders. It originates from the physiological difference between genders in terms of body composition, hormone biology, patterns of weight gain, levels of resting energy expenditure and energy requirements, ability to engage in physical activity, levels of self-regulation in early childhood, and the susceptibility to social norms, cultures and ethnic backgrounds.[136] Likewise, socio-economic inequities in early childhood development allow children to have different opportunities of physical activity and diet quality, eventually leading to different levels of weight gain.[137,138] Moreover, low-income families tend to be less vigilant about children's weight gain and therefore are less likely to seek appropriate interventions.[139,140] As such, individual characteristics, notably gender difference and socio-economic positioning, may strengthen or weaken environmental factors that contribute to childhood obesity.

This study has several limitations. First, the majority of the studies included in the review are cross-sectional. Although cross-sectional evidence is useful to test research hypotheses, further investigations using a longitudinal design will help to establish a more robust evidence base. Although prospective cohort studies are preferable, they are subject to high costs and the difficulty in capturing critical exposure over a prolonged time period or even the life course. One approach to overcome the limitation is to conduct retrospective studies linking existing administrative health records with historical geospatial data available on a global scale.[141] Second, most of the studies in the review are focused on developed countries and do not reflect the reality of the growing obesity epidemic facing underdeveloped and developing countries.[142] Especially in developing countries, rapid urbanization coupled with changing dietary patterns will likely exacerbate childhood obesity.[143] Failure to account for the obesogenic environment in underdeveloped and developing countries will lead to the omission of health risk factors posed for regions in need of obesity prevention and health intervention. Third, questionnaire-based survey methods as reviewed in this paper may have led to unreliable measurements, especially for the perceived measures. This is a common issue in survey research targeting children, as children's perception of the obesogenic environment tends to be inadvertently misrepresented in both the recruitment procedure and the survey question design.[144] It is thus recommended that future studies employ new technologies in a hybrid approach to offset the subjectivity in the research design.[145-147] Also, active engagement of and the coproduction with children in the generation of knowledge can help minimize potential measurement biases.[148] Finally, the reporting quality of and comparability among future studies should be improved. The Spatial Lifecourse Epidemiology Reporting Standards (ISLE-ReSt) statement should be adopted by scientific journals in public health, geography and other relevant disciplines to increase reporting quality of such environmental health research.[149,150]

5 | CONCLUSIONS

This systematic review reveals more significant associations of food rather than built environmental factors with weight status among children and adolescents. Heterogeneous measures in obesogenic environments for children and differences in controlling for confounding effects among studies may partly accounted for those null and inconclusive associations between some factors and weight status. This study comprehensively summarizes all existing evidence in this field and would serve as an important reference to multiple stakeholders, from new scholars in multiple relevant fields to policy makers.

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CONFLICT OF INTEREST

No conflict of interest was declared.

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SUPPORTING INFORMATION

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

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APPENDIX A.: SEARCH STRATEGY

The search strategy includes all possible combinations of keywords in the title/abstract from the following three groups:

1. 'built environment*', 'food environment*', 'obesogenic environment*','built environment factor*', 'food environment factor*', 'obesogenic environment factor*', 'built environmental factor*', 'food environmental factor*', 'obesogenic environmental factor*', 'built environment variable*', 'food environment variable*', 'obesogenic environment variable*', 'built environmental variable*', 'food environmental variable*', 'obesogenic environmental variable*', 'built environment indicator*', 'food environment indicator*', 'obesogenic environment indicator*', 'built environmental indicator*', 'food environmental indicator*', 'obesogenic environmental indicator*';
2. 'child*', 'juvenile*', 'pubescent*', 'pubert*', 'adolescen*', 'youth*', 'teen*', 'kid*', 'young*', 'youngster*', 'minor*', 'student*', 'pupil*', 'pediatric*', 'preschooler*','pre-schooler*', 'schoolchild*', 'school-child*', 'school child*', 'schoolage*', 'school-age*', 'school age*';
3. 'energy balance', 'calorie*', 'body mass index', 'BMI', 'weight', 'weight status', 'weight-related health', 'overweight', 'obese', 'obesity', 'adiposity', 'abdominal overweight', 'abdominal obesity', 'central overweight', 'central obesity', 'central adiposity', 'waist circumference', 'waist to hip', 'waist-to-hip', 'waist to height', 'waist-to-height', 'waist to stature', 'waist-to-stature', 'fatness', 'body fat', 'excess fat', 'excess weight', 'overnutrition', 'over-nutrition', 'over nutrition'.