



Neighborhood sidewalk access and childhood obesity

Junxiang Wei^{1,2,3}  | Yang Wu^{4,5,6} | Jinge Zheng^{1,3} | Peng Nie^{7,8} |
Peng Jia^{9,10,11}  | Youfa Wang^{1,3}

¹Global Health Institute, Xi'an Jiaotong University, Xi'an, China

²Department of Physiology and Pathophysiology, School of Basic Medical Sciences, Xi'an Jiaotong University Health Science Center, Xi'an, China

³Department of Epidemiology and Biostatistics, School of Public Health, Xi'an Jiaotong University Health Science Center, Xi'an, China

⁴Department of Sociology, Jiangxi University of Finance and Economics, Nanchang, China

⁵Center for Asian & Pacific Economic & Social Development, Jiangxi University of Finance and Economics, Nanchang, Jiangxi, China

⁶Research Institute for Female Culture, Jiangxi University of Finance and Economics, Nanchang, China

⁷School of Economics and Finance, Xi'an Jiaotong University, Xi'an, China

⁸Institute for Health Care & Public Management, University of Hohenheim, Stuttgart, Germany

⁹Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hong Kong, China

¹⁰Faculty of Geo-Information Science and Earth Observation, University of Twente, Enschede, The Netherlands

¹¹International Institute of Spatial Lifecourse Epidemiology (ISLE), Hong Kong, China

Correspondence

Youfa Wang, MD, PhD, MS, Dean, Global Health Institute, Xi'an Jiaotong University Health Science Center, Xi'an, 710061 Shaanxi, China.
Email: youfawang@gmail.com

Peng Jia, PhD, Director, International Institute of Spatial Lifecourse Epidemiology (ISLE); Department of Land Surveying and Geo-Informatics, The Hong Kong Polytechnic University, Hong Kong, China.
Email: jiapengff@hotmail.com

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Summary

The lack of access to sidewalks is a barrier for physical activity (PA) and may be a risk factor for childhood obesity. However, previous studies reported mixed findings and the association between sidewalk accessibility and childhood obesity remains unclear. This study systematically examined the evidence on the association between sidewalk accessibility and childhood obesity. PubMed, Cochrane Library, and Web of Science were searched for relevant articles (published before 1 January 2019) that reported on the association between neighborhood sidewalk access and weight-related behaviors and outcomes in children. Seventeen studies conducted in five countries were included. Ten studies used objective measure of access to sidewalks, seven studies measured children's height and weight, and seven studies objectively measured the PA or sedentary behaviors. Ten studies reported on the association of better access to sidewalks with increased PA (β ranging from 0.032 to 2.159; $p < 0.05$), reduced sedentary behaviors (β ranging from -0.19 to -0.14 ; $p < 0.05$), lower body mass index (BMI) (β ranging from -0.261 to -0.144 ; $p < 0.001$), or obesity risks (OR ranging from 1.02 to 1.32; $p < 0.05$); while the remaining seven studies did not report a desirable obesity-sidewalk association. Our findings support the hypothesis that higher sidewalk accessibility is associated with higher PA levels, lower BMI, and obesity risks. Efforts in building healthy environments, including health-

Junxiang Wei and Yang Wu contributed equally to this study.

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promoting city planning, can help minimize the growing obesity epidemic and promote public health.

KEYWORDS

adolescent, built environment, child, obesity, overweight, physical activity, sidewalk

1 | INTRODUCTION

Obesity is a leading cause of morbidity and premature mortality worldwide. In 2018, an estimated 40 million children of under 5 years old were overweight. In 2016, 131 million children, 207 million adolescents, and 2 billion adults were overweight.¹ The global prevalence of obesity has increased sharply over the past four decades, from less than 1% in 1975 to 6–8% in 2016 among girls and boys, from 3% to 11% among men, and from 6% to 15% among women.² In some countries, the prevalence of overweight and obesity has reached nearly 70%, like in the United States.³ Obesity in childhood tracks strongly into adulthood and is linked with various risks for chronic conditions, such as hypertension, type 2 diabetes, heart diseases, and certain types of cancers.^{3,4}

The neighborhood environment—combined with individual characteristics—may exert an undue influence on individuals' body weight. The term “obesogenic environment” refers to an environment that could contribute to overweight and obesity.⁵ Sidewalks are one of such obesogenic neighborhood environmental factors. The access to sidewalks could have impact on one's level of routine physical activity (PA) and thus their weight status.⁶ For example, well-maintained sidewalks, an important aspect of a walkable environment with high-quality infrastructures, could promote PA. However, it remains a challenge to validate such impacts on the development of overweight and obesity.⁷ The major reasons included the difficulties and variations in assessing the access to sidewalks.⁶

This study aimed to comprehensively examine the associations between sidewalk access and weight-related behaviors and outcomes among children and adolescents. We tested the hypothesis that less access to sidewalks was associated with lower levels of PA, higher levels of sedentary behaviors, and higher obesity risk among children and adolescents. In contrast to previous reviews, this study summarized a full range of measures of sidewalk access (e.g., both subjectively and objectively measured access), weight-related behaviors (e.g., PA, sedentary behavior, and diet), and weight status. It would provide useful insights for public health professionals, urban planners, and policy makers to maximize the benefits of built environments for health promotion.

2 | METHODS AND MATERIALS

A systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

2.1 | Search strategy

We searched three databases (Cochrane Library, PubMed, and Web of Science) for relevant articles, using all possible combinations of keywords from the following three categories: sidewalks, children/adolescents, and weight-related behaviors or outcomes (Data S1).

2.2 | Article screening and data abstraction

Two authors independently scanned titles and abstracts and later full texts of the identified articles, against the inclusion and exclusion criteria. The Cohen's kappa was 81%, indicating a strong interrater agreement. Discrepancies were resolved by two senior reviewers (YW and PJ). Then, the two reviewers (JW and YW) used a standardized data abstraction form to extract data from each included study. The form included information on each study's key characteristics (i.e., author name, year of publication, study design, study area, sample size, age at baseline, follow-up years, number of repeated measures, sample characteristics, and statistical model), measures (i.e., measures of the access to sidewalks, weight-related behaviors, and weight status), and key findings on the association between sidewalks and weight-related behaviors and/or outcomes. Discrepancies were resolved by two senior reviewers (YW and PJ).

2.3 | Study selection and exclusion criteria

Studies were included if they (a) were empirical studies that focused exclusively on children and adolescents under the age of 18, (b) tested the association between the access to sidewalks and weight-related behaviors (e.g., PA, sedentary behavior, diet, etc.) and/or outcomes (e.g., body mass index [BMI], BMI z-score/SD-score, overweight, and obesity status, which were determined by the BMI, waist circumference, waist-to-hip ratio, and body fat), and (c) were written in English and published in peer-reviewed journals prior to 1 January 2019.

Studies were excluded if they (a) did not report on sidewalks and weight-related behaviors and/or outcomes, (b) did not study real individuals, (c) were not written in English, or (d) were letters, editorials, research protocols, or review articles.

2.4 | Study quality assessment

Two authors used the National Institutes of Health's (NIH) Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies

(<https://www.nhlbi.nih.gov/health-topics/study-quality-assessment-tools>) to independently assess the strength of evidence for each study. They evaluated each study based on the 14 criteria listed in the assessment tool (Supporting information) and gave it a global score. The score ranged from 0 to 14, with zero indicating weak scientific evidence and 14 indicating strong scientific evidence. The inconsistencies were resolved by two other authors.

3 | RESULTS

3.1 | Study selection

The initial search yielded 551 unique articles. Among them, 27 articles were reviewed, and 17 studies were finally included (Figure 1).

3.2 | Study characteristics

As shown in Table 1, the earliest study was published in 2005,¹⁷ and the majority were published between 2010 and 2017 ($n = 12$).^{8-14,16,21-24} Most of them were conducted in the United States ($n = 13$),^{8-11,13-15,17,20-24} followed by Canada,¹² Australia,¹⁸ Portugal,¹⁶ and China¹⁹ (all $n = 1$). All but two^{21,23} used cross-sectional design. Sample sizes varied substantially from 80 to 113 767, with a median of 2690. All of the included studies focused on young children or adolescents,⁸⁻²⁴ with two studies exclusively focused on young children (aged <10)^{16,18} and eight solely on adolescents (aged 10–18).^{11-13,15,17,19,21,24} These studies used various statistical models to estimate the association between access to sidewalks and weight-related behaviors or outcomes, including mixed-effects models, generalized estimated equation models,

multinomial logistic regressions, hierarchical linear regressions, spatial simultaneous autoregressive error models, *t*-tests, and *z*-tests.

3.3 | Measures of sidewalk access and weight-related behaviors and outcomes

As shown in Table 2, over half of the studies used perceived access to sidewalks ($n = 7$).^{8,12,15,16,18,19,24} The remaining studies ($n = 10$) used objective measures of sidewalks: five used geographic information systems (GIS),^{13,14,20,21,23} and the other five used onsite observations of sidewalks.^{9-11,17,22} Among the GIS-based studies, one specifically collected GPS data by GPS-receiving units and reported the length of time spent on sidewalks,²¹ two studies used an 0.8-km road-network buffer,^{13,14} one used a 0.4-km road-network buffer,²⁰ and one used a 0.4-km straight-line buffer²³ to estimate the presence and/or quality of sidewalks.

For weight-related behaviors, half of the studies only reported on PA ($n = 8$),^{8-12,18,19,22} three reported on both PA and sedentary behavior,^{15,17,21} five did not report on any behavioral outcomes (only weight-related outcomes),^{13,14,16,20,23} while only one study examined dietary intakes in addition to PA and sedentary behavior.²⁴ To measure PA and sedentary behavior, five out of 12 studies used self-reported questionnaires (e.g., International Physical Activity Questionnaire),^{8,11,12,19,24} six used accelerometers,^{9,15,17,18,21,22} and one used direct observations.¹⁰

The majority of the studies (seven out of nine) that reported on weight-related outcomes used an objectively measured weight status,^{12,14-16,18,20,23} while the remaining two studies used either self-reported¹³ or parent-reported weight status.²⁴ Measures included weight status ($n = 6$),^{12,15,16,18,20,24} and BMI *z*-score ($n = 3$).^{13,14,23}

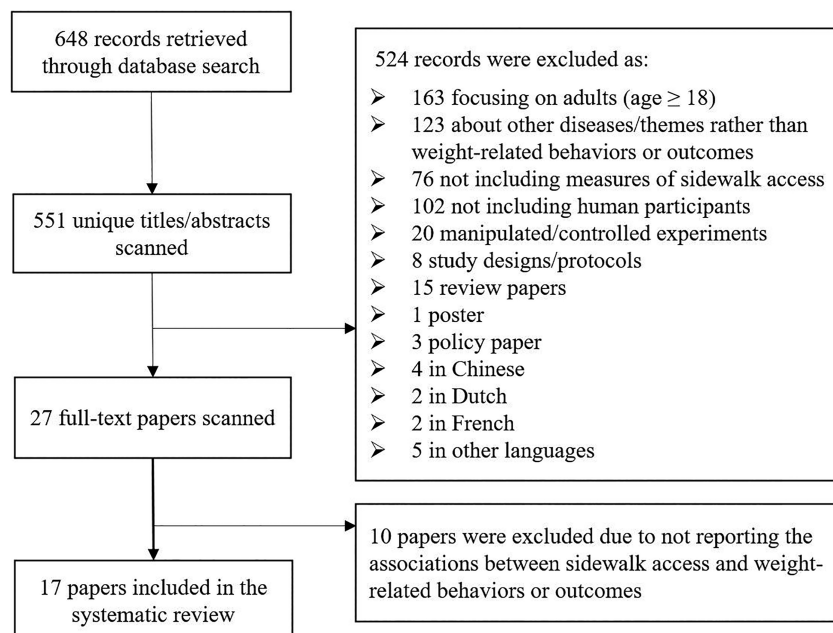


FIGURE 1 Study exclusion and inclusion flowchart

TABLE 1 Basic characteristics of 17 included studies

First author (year)	Study design ^a	Study area [scale] ^b	Sample size	Sample age (years) in the survey year	Sample characteristics	Statistical methods
An (2017) ⁸	C	USA [N]	113 767	6–17	Children and adolescents	Negative binomial regression
Cain (2014) ⁹	C	San Diego, Seattle, Baltimore, USA [S3]	3677	6–16	Children and adolescents	Mixed linear regression
Coughenour (2014) ¹⁰	C	Las Vegas, USA [S]	1421	<18	Youth	Multinomial logistic regression
Dalton (2011) ¹¹	C	Vermont, New Hampshire, USA [S2]	735	12–17	Grade 11	Hierarchical linear regression
Davidson (2010) ¹²	C	Alberta, Canada [S]	3421	10–11	Grade 5	Multi-level logistic regression
Duncan (2012) ¹³	C	Boston, USA [C]	1034	16.32 ± 1.26	Grades 9–12	Spatial simultaneous autoregressive error model
Duncan (2014) ¹⁴	C	Massachusetts, USA [S]	49 770	4–19	Children and adolescents	Multivariable regression
Evenson (2007) ¹⁵	C	Arizona, California, Louisiana, Maryland, Minnesota, South Carolina, USA [S6]	1554	11.8 (11.5–12.1)	Grade 6 girls	Hierarchical linear regression
Ferrao (2013) ¹⁶	C	Porto, Portugal [C]	2690	3–10 (6.7 ± 2.2)	Pre-school and elementary school children	Multivariate logistic regression
Jago (2005) ¹⁷	C	Houston, USA [C]	210	10–14	Adolescent males	Hierarchical linear regression
Jones (2009) ¹⁸	C	Greater Wollongong, Australia [C]	140	4.3 (0.7)	Preschoolers	Two sample t-test; z-test
Li (2006) ¹⁹	C	Xi'an, China [C]	1804	11–17	Junior high school adolescents	Multivariate regression
Oreskovic (2009) ²⁰	C	Massachusetts, USA [S]	21 008	2–18 (9.3 ± 4.8)	Children with a visit to a large integrated health care system	Multivariate logistic regression
Oreskovic (2015) ²¹	L	Boston, USA [C]	80	11–14 (12.6 ± 1.1)	Age-eligible subjects without physical impairments	Longitudinal mixed-effects model, generalized Estimation Equation model
Sallis (2015) ²²	C	USA [N]	6680	2–18	Children	Clustered logistic regression
Sandy (2013) ²³	L	Indianapolis, USA [C]	36 936	3–16 (8.26 ± 3.79)	Mainly African American children	Fixed effects model
Singh (2010) ²⁴	C	USA [N]	44 101	10–17	Children	Multivariate logistic regression

^aStudy design: C, cross-sectional study; L, longitudinal study.

^bStudy scale: [N], national; [S], state (e.g., in the United States) or equivalent unit (e.g., province in China and Canada); [Sn], *n* states or equivalent units; [CT], county or equivalent unit; [CTn], *n* counties or equivalent units; [C], city; [Cn], *n* cities.

Other environmental factors were controlled in the models but varied substantially by study. The most commonly used one was the socioeconomic environment, such as crime or neighborhood safety ($n = 3$),^{8,12,23} neighborhood economy (e.g., community socioeconomic status, and poverty rate),^{13,15,20} and demographic factors (e.g., race/ethnicity composition).¹³

3.4 | Associations of sidewalks on weighted-related behaviors and outcomes

As shown in Table 3, six out of 10 studies found a statistically significant and desirable association between access to sidewalks and weight-related behaviors (better access to sidewalks was associated

TABLE 2 Measures of access to sidewalks, weight-related behaviors and outcomes in 17 included studies

First author (year)	Measures of access to sidewalks	Other environmental factors adjusted for in the models	Measures of weight-related behaviors	Measures of weight-related outcomes
An (2017) ⁸	Perceived sidewalk availability, from parents' answers to the question "Does the neighborhood have sidewalks?"	Presence of recreation center, parks, parent-perceived neighborhood safety/crime	PA was measured by parent-reported number of physically active days (0–7), defined as 20 minutes or longer during the past week	NA
Cain (2014) ⁹	Observed sidewalk qualities along roads in a 0.4-km home road-network buffer, using the MAPS direct observation instrument	NA	Objective PA was measured with accelerometers	NA
Coughenour (2014) ¹⁰	Observed sidewalk qualities (0–3 scale) within a 0.4-km radius of 10 neighborhood parks, using the PARA protocol definition and scale	Park size, amenities, and incivilities, temperature at observation time, number of high speed streets and income	PA levels of youth by observing play and leisure activity	NA
Dalton (2011) ¹¹	Observed coverage of sidewalks along roads in a 1-km school straight-line buffer (0 = none; 1 = continuous on one side; 2 = continuous on both sides)	Distance to school, school town size	Active travel to school was measured by asking students if they walked or biked to or from school	NA
Davidson (2010) ¹²	Perceived existence of sidewalks/parks on most streets in the neighborhood, reported by parents using eight validated questions	Neighborhood satisfaction/services, Neighborhood safety, geographic residency	Validated physical activity Questionnaire for Children	Overweight and obesity categorized by the IOTF age- and sex-specific cut-off points based on measured height and weight
Duncan (2012) ¹³	<ul style="list-style-type: none"> • Sidewalk completeness was calculated using an equation: (left sidewalk length + right sidewalk length)/total road length × 100 (0 = no sidewalk and 100 = presence of sidewalks on both sides) • Average sidewalk width (in meters) in a 0.8-km road-network buffer 	Neighborhood-level % of black residents, Hispanic residents, % of households below poverty, neighborhood-level % foreign born for the 800-street network buffer	NA	<ul style="list-style-type: none"> • Age and sex-specified BMI z-score based on the 2000 CDC growth charts • Self-reported weight and height
Duncan (2014) ¹⁴	Measured sidewalk completeness within 0.8-km road-network buffers (0 = no sidewalk, 1 = sidewalk on one side, 2 = sidewalks on both sides on all road segments in buffer) using GIS	Nearest recreational open space, residential density, traffic density, average speed limit, intersection density and land use mix	NA	The age-and sex-specific BMI z-score defined by the CDC growth curves, on the basis of measured height and weight
Evenson (2007) ¹⁵	Perceived existence of sidewalks, from children's self-reports to a developed and validated questionnaire during the	Neighborhood SES, percentage on free or reduced-price lunch	<ul style="list-style-type: none"> • Minutes of metabolic equivalent weighted non-school MVPA by accelerometers 	<ul style="list-style-type: none"> • Overweight (measured BMI ≥ 95th percentile based on the 2000 CDC growth charts)

(Continues)

TABLE 2 (Continued)

First author (year)	Measures of access to sidewalks	Other environmental factors adjusted for in the models	Measures of weight-related behaviors	Measures of weight-related outcomes
	pilot phase of the TAAG Study		<ul style="list-style-type: none"> PA by an actigraph accelerometer 	<ul style="list-style-type: none"> At risks for overweight (BMI \geq 85th percentile based on the 2000 CDC growth charts)
Ferrao (2013) ¹⁶	Perceived existence and quality of sidewalks (agree vs. disagree), while parents completed the "Environmental Module" standard questionnaire of the International Physical Activity Prevalence Study	School clusters	NA	Overweight or obesity (measured BMI, based on the IOTF age- and sex-specific cut-off points)
Jago (2005) ¹⁷	Observed sidewalk characteristics within a 0.4-km radius of each participant's home address, obtained from principal component analysis on footpath type, presence of street lights, footpath material, average height of trees, and number of verge trees from the SPACES audit instrument	Walking/cycling ease, tidiness, street access and condition	<ul style="list-style-type: none"> PA was monitored by the MTI accelerometer (Manufacturing Technologies Inc., Fort Walton Beach FL) for 3 consecutive days if they possessed at least 2 days with at least 800 minutes of valid data per day. Sedentary, light or moderate to vigorous intensity activity were categorized. 	NA
Jones (2009) ¹⁸	Perceived access to footpaths (yes vs. no), as reported by parents using the Parenting Styles Questionnaire	Availability of sport/PA programs, availability of parks or open spaces	<ul style="list-style-type: none"> PA was assessed using an MTI 7164 Actigraph uniaxial accelerometer The Sirard cut-points were used to classify minutes of MVPA 	Non-overweight or overweight/obese based on the IOTF age- and sex-specific cut-off points based on measured height and weight.
Li (2006) ¹⁹	Perceived sidewalk availability around home, as reported by children using a self-administered questionnaires	NA	<ul style="list-style-type: none"> The level of PA (physical validated activity recall questionnaire) The intensity of the PA were rated with MET values 	NA
Oreskovic (2009) ²⁰	The mean amount of sidewalk space and open space (in meters squared) in a 0.4-km home road-network buffer, measured by GIS	Mean census tract household income	NA	<ul style="list-style-type: none"> Overweight (BMI \geq 85th percentile based on the CDC growth charts) Obesity (BMI \geq 95th percentile); measured height and weight
Oreskovic (2015) ²¹	Minutes spent on sidewalks, collected by GPS receiving units	NA	<ul style="list-style-type: none"> Counts of activity per minute, provided by accelerometer Whether a minute was classified as MVPA (yes/no) or sedentary (yes/no) 	NA

TABLE 2 (Continued)

First author (year)	Measures of access to sidewalks	Other environmental factors adjusted for in the models	Measures of weight-related behaviors	Measures of weight-related outcomes
Sallis (2015) ²²	Observed presence and quality of sidewalks, buffers between streets and sidewalks in a 0.4-km home buffer, using the MAPS-mini	Streetscape characteristics, aesthetics, crossing/intersections, town	<ul style="list-style-type: none"> Objective PA by the Actigraph accelerometer MVPA for children by accelerometer data 	NA
Sandy (2013) ²³	Length of any trails (per 0.1 km) in a 0.4-km home straight-line buffer from city data	Crime	NA	<ul style="list-style-type: none"> Height and weight were obtained from the record of measurements of pediatric clinic visits BMI z-score based on the 2000 CDC growth charts
Singh (2010) ²⁴	Parent-perceived neighborhood access to sidewalks and walking paths (yes vs. no) in the neighborhood	NA	PA, sedentary behavior (television viewing time, recreational computer use), and dietary factors	<ul style="list-style-type: none"> Overweight (parental reports of weight and height to obtain BMI \geq 85th percentile based on CDC growth charts) Obesity (parental reports of weight and height to obtain BMI \geq 95th percentile based on CDC growth charts)

Abbreviations: BMI, body mass index; CDC, Center for Disease Control and Prevention; GIS, geographic information systems; IOTF, the International Obesity Task Force; MVPA, moderate-to-vigorous physical activity; MAPS, Microscale Audit of Pedestrian Streetscapes; MET, metabolic equivalent; NA, not available; PA, physical activity; PARA, Physical Activity Resource Assessment; SES, socioeconomic status; SPACES, Systematic Pedestrian and Cycling Environmental Scan; TAAG, Trial of Activity in Adolescent Girls.

with increased PA or decreased sedentary behavior),^{9,11,12,17,19,21} two found a statistically significant and undesirable association (better access to sidewalk was associated with decreased PA or increased sedentary behavior),^{8,10} and two failed to find any significant association.^{15,22}

Five out of nine studies showed a statistically significant and desirable association between access to sidewalks and weight-related outcomes (better access to sidewalks was associated with a decreased BMI z-score or likelihood of overweight/obesity),^{12,14,16,23,24} two found a statistically significant and undesirable association (better access to sidewalks was associated with an increased BMI z-score or odds of overweight/obesity),^{13,18} and two found no association between sidewalk access and weight outcomes.^{15,20}

3.5 | Study quality assessment

As shown in Table 4, the included studies scored 8.47 on average out of a full study quality score of 14, ranging from five to 10. All included studies clearly stated the research question or objective and used clearly defined, valid, and reliable exposure and outcome measures, which were implemented consistently across all study participants. Moreover, the studies did not blind outcome assessors to the

exposure status of participants and did not have a loss to follow-up rate of 20% or less after baseline (mostly cross-sectional). Other criteria usually unmet by the included 17 studies were as follows: having a sufficient time frame so that one could reasonably expect to see an association between exposure and outcome if it existed ($n = 15$); having measured the exposures of interest prior to the outcomes ($n = 15$); having assessed the exposures more than once over time ($n = 13$); and having examined different levels of the exposure associated with the outcome (e.g., continuous or categorical measures of exposure) ($n = 13$).

4 | DISCUSSION

The hypothesis that sidewalk accessibility was associated with weight-related behaviors or outcomes in children and adolescents was supported by the majority of our included studies (14 out of 17), which were conducted in five countries, although it was inconclusive. Up to 59% ($n = 10$) of the included studies showed that better access to sidewalks was significantly associated with increased levels of PA, reduced sedentary behavior, or lower odds of obesity. Associations between sidewalk access and children's weight status or weight-related behaviors were quite mixed in the United States, but

TABLE 3 Associations of sidewalks on weight-related behaviors and outcomes in 17 included studies

First author (year)	Estimated effects of sidewalks		Main findings of study	
	Weight-related behaviors	Weight-related outcomes	Weight-related behaviors	Weight-related outcomes
An (2017) ⁸	Neighborhood availability of sidewalks was associated with a reduction in weekly physically active days by 0.21 (95% CI [0.00, 0.42]).	NA	Provision of adequate amenities in residential neighborhood could be essential in promoting PA among children/adolescents with special health care need.	NA
Cain (2014) ⁹	Sidewalk quality was found to be significantly associated with leisure/neighborhood PA (adjusted $\beta = 1.864$, $p > 0.05$ for children; $\beta = -1.433$, $p > 0.05$ for adolescents) and MVPA (adjusted $\beta = 2.159$, $p < 0.05$ for children in neighborhood; $\beta = -0.324$, $p > 0.05$ for children non-school time; $\beta = 1.903$, $p > 0.05$ for adolescents non-school time) in children.	NA	Microscale environment attributes are related to PA.	NA
Coughenour (2014) ¹⁰	<ul style="list-style-type: none"> Better sidewalk condition was associated with decreased odds of observing vigorous PA (OR = 0.34, 95% CI [0.12, 0.98]). Males were more likely to be observed walking (OR = 1.42) and vigorous (OR = 2.21) when compared with sedentary. 	NA	A great number of amenities were associated with greater odds of vigorous activity.	NA
Dalton (2011) ¹¹	<ul style="list-style-type: none"> Students were more likely to actively travel to schools located in neighborhoods with sidewalks (OR = 1.63, 95% CI [1.11, 2.38]). 	NA	Adolescents who attended schools in highly dense residential neighborhoods with sidewalks were most likely to be active travelers.	NA
Davidson (2010) ¹²	Existence of neighborhood sidewalks/parks had a statistically significant positive association with student PA ($\beta = 0.032$; 95% CI [0.01, 0.05], $p < 0.01$).	Existence of neighborhood sidewalks/parks had a statistically significant negative association with body weight ($\beta = -0.261$; 95% CI [-0.421, -0.101], $p < 0.01$).	The study identified neighborhood sidewalks and parks as determinants of PA. Self-efficacy exhibited a positive effect on PA.	The independent associations of neighborhood characteristics with body weight; self-efficacy exhibited a negative effect on body weight.
Duncan (2012) ¹³	NA	<ul style="list-style-type: none"> Sidewalk completeness was significantly associated with a higher BMI z-score for the total sample ($\beta = 0.010$, SE = 0.004, $p < 0.05$). No significant findings for the interactions for race/ethnicity. 	NA	<ul style="list-style-type: none"> Density of bus stops was associated with a higher BMI z-score among Whites ($\beta = 0.029$, $p < 0.05$). The interaction term for Asians in the association between retail destinations and BMI

TABLE 3 (Continued)

First author (year)	Estimated effects of sidewalks		Main findings of study	
	Weight-related behaviors	Weight-related outcomes	Weight-related behaviors	Weight-related outcomes
		<ul style="list-style-type: none"> Average sidewalk width was marginally associated with a higher BMI z-score for the total sample ($\beta = 0.267$, $SE = 0.145$, $p < 0.10$). 		<p>z-score was statistically significant and indicated an inverse association.</p> <ul style="list-style-type: none"> These significant associations were found for the 800-m buffer.
Duncan (2014) ¹⁴	NA	Children living in areas with the least amount of sidewalk completeness was associated with an increase in BMI z-score over time (adjusted $\beta = 0.04$, 95% CI [0.02, 0.06]), $p < 0.05$) when compared with the highest quartiles.	NA	<ul style="list-style-type: none"> Built environment characteristics such as sidewalks completeness that may increase walkability were associated with lower BMI z-score in children. Modifying existing built environment to make them more walkable may reduce childhood obesity.
Evenson (2007) ¹⁵	<ul style="list-style-type: none"> Having neighborhood sidewalks on most of the street was positively associated with non-school MVPA (mean difference = 28.9, $p = 0.05$). Not significantly associated with non-school sedentary behavior (mean difference = -12.3 min, $p = 0.54$). 	Having neighborhood sidewalks was not significantly associated with BMI (mean difference = -0.3, $p = 0.07$), at risks for overweight (OR = 0.9, 95% CI [0.7, 1.2]) and overweight (OR = 0.8, 95% CI [0.6, 1.1]).	Having well-lit streets at night, having a lot of traffic in the neighborhood, having bicycle or walking trails in the neighborhood, and access to PA facilities were associated with higher MVPA. Girls with ≥ 9 places to go for PA had 14.0% higher non-school MW-MVPA than girls with ≤ 4 places	Seeing walkers and bikers on neighborhood streets, not having a lot of crime in the neighborhood, seeing other children playing outdoors, having bicycle or walking trails in the neighborhood, and access to PA facilities were associated with lower BMI.
Ferrao (2013) ¹⁶	NA	The odds of children being overweight/obesity were lower if their parents perceived that the local sidewalks were well maintained and unobstructed (OR = 1.18; 95% CI [1.01, 1.40]).	NA	Parental perceptions of neighborhood safety and the quality of local sidewalks are significantly associated with obesity values.
Jago (2005) ¹⁷	<ul style="list-style-type: none"> Sidewalk characteristics were significantly negatively associated (standard $\beta = -0.19$, $p = 0.005$) with sedentary activity. Sidewalk characteristics were significantly positively associated (standard $\beta = 0.20$, $p = 0.003$) with minutes of light-intensity PA. 	NA	Environmental factors were interrelated with each other, but only sidewalks characteristics were associated with sedentary behavior and light intensity PA.	NA
Jones (2009) ¹⁸	NA	Overweight children had greater access to footpaths compared with non-overweight children ($p = 0.046$), with 34% non-overweight children	NA	There is little difference between overweight and non-overweight children in relation to a variety of child, parent and community variables.

(Continues)

TABLE 3 (Continued)

First author (year)	Estimated effects of sidewalks		Main findings of study	
	Weight-related behaviors	Weight-related outcomes	Weight-related behaviors	Weight-related outcomes
		(n = 74) having access to footpaths, and 57% in overweight/obese children (n = 21).		
Li (2006) ¹⁹	Adolescents living in neighborhood without sidewalks were 1.3 times more likely to be inactive (95% CI [1.0, 1.6]).	NA	<ul style="list-style-type: none"> Adolescents aged 14 years were 30% less likely to be inactive compared with those younger than 13 years (95% CI [0.5, 0.9]). Paternal education was inversely associated with inactivity (OR = 0.6; 95% CI [0.4, 0.9]). 	NA
Oreskovic (2009) ²⁰	NA	In bivariate analysis, overweight and obesity were positively associated with the mean amount of sidewalk space ($p < 0.0001$), but not hold in the adjusted analysis (overweight: OR = 0.93; 95% CI [0.39, 2.22]; obesity: OR = 0.95; 95% CI [0.33, 2.73]).	NA	Controlling for socioeconomic factors, only distance to the nearest subway station was inversely associated with overweight (OR = 0.87; 95% CI [0.81, 0.94]) and obesity (OR = 0.90; 95% CI [0.82, 0.99]) among Massachusetts children.
Oreskovic (2015) ²¹	Streets and sidewalks use was associated with greater PA levels ($\beta = 147$ counts per minute of activity, $SE = 2$, $p < 0.0001$) and higher odds of being in MVPA (OR = 6.75; 95% CI [4.72, 9.64]), lower odds of engaging in sedentary behavior (OR = 1.82; 95% CI [1.61, 2.05]).	NA	Adolescents were more likely to engage in MVPA, and achieve their highest PA levels when using built environments located outdoors. Playground use was associated with the highest PA level ($\beta = 172$ activity counts per minute, $SE = 4$, $p < 0.0001$) and greatest odds of being in MVPA (OR = 8.3; 95% CI [4.8, 14.2]).	NA
Sallis (2015) ²²	Presence of sidewalk in neighborhood was associated with MVPA, but did not reach statistical significance ($t = 1.97$, -0.56 , 1.05 ; $p > 0.05$ for children's MVPA in neighborhood, children non-school time MVPA, and adolescents' MVPA in neighborhood, respectively).	NA	NA	Sidewalk presence, curb cuts, street lights, benches and buffer between street and sidewalk were significantly related to active transportation in children.
Sandy (2013) ²³	NA	Length of recreational trails can have beneficial effects on children's BMI ($\beta = -0.144$, robust $SE = 0.05$, $p < 0.001$) and obesity (log	NA	A addition of 100 m of trails next to a child's home in areas without crime would lead to a reduction of 1 pound of weight among older children.

TABLE 3 (Continued)

First author (year)	Estimated effects of sidewalks		Main findings of study	
	Weight-related behaviors	Weight-related outcomes	Weight-related behaviors	Weight-related outcomes
		OR = -0.0152, SE = 0.00, $p < 0.001$). This effect is primarily among boys and older children, and children who live in high-income neighborhoods.		
Singh (2010) ²⁴	NA	Children living in neighborhoods with no access to sidewalks or walking paths had 32% higher adjusted odds of obesity than children in neighborhoods with access to such amenities (OR = 1.32; 95% CI: 1.14–1.53). Not significant for overweight (OR = 1.09; 95% CI: 0.98–1.22).	NA	Odds of obese or overweight were 20–60% higher among children in neighborhoods with unsafe surroundings, poor housing, no access to sidewalks, parks, and recreation centers than among children not facing such conditions.

Abbreviations: BMI, body mass index; CI, confidence interval; MVPA, moderate-to-vigorous physical activity; NA, not available; MW-MVPA, metabolic equivalent weighted moderate-to-vigorous physical activity; OR, odds ratio; PA, physical activity.

TABLE 4 Study quality assessment of 17 included studies (see 14 questions in Supporting information)

First Author (year) ^[ref]	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total score
An (2017) ⁸	Y	Y	Y	Y	Y	N	N	N	Y	N	Y	N	N	Y	9
Cain (2014) ⁹	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	N	Y	9
Coughenour (2014) ¹⁰	Y	N	N	N	Y	N	N	Y	Y	N	Y	N	N	N	5
Dalton (2011) ¹¹	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	N	Y	9
Davidson (2010) ¹²	Y	Y	Y	Y	Y	N	N	Y	Y	N	Y	N	N	Y	9
Duncan (2012) ¹³	Y	Y	Y	Y	Y	N	N	N	Y	N	Y	N	N	Y	8
Duncan (2014) ¹⁴	Y	Y	Y	Y	Y	N	N	Y	Y	N	Y	N	N	Y	9
Evenson (2007) ¹⁵	Y	Y	Y	Y	Y	N	Y	N	Y	Y	Y	N	N	Y	10
Ferrao (2013) ¹⁶	Y	Y	Y	Y	Y	N	N	N	Y	N	Y	N	N	Y	8
Jago (2005) ¹⁷	Y	Y	Y	Y	Y	N	N	N	Y	N	Y	N	N	Y	8
Jones (2009) ¹⁸	Y	Y	Y	Y	Y	N	N	N	Y	N	Y	N	N	N	8
Li (2006) ¹⁹	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y	N	N	Y	9
Oreskovic (2009) ²⁰	Y	Y	Y	Y	Y	N	N	N	Y	N	Y	N	N	Y	8
Oreskovic (2015) ²¹	Y	Y	Y	Y	Y	Y	N	N	Y	N	Y	N	N	Y	9
Sallis (2015) ²²	Y	Y	Y	Y	N	N	N	N	Y	N	Y	N	N	Y	7
Sandy (2013) ²³	Y	Y	Y	Y	Y	Y	Y	N	Y	N	Y	N	N	Y	10
Singh (2010) ²⁴	Y	Y	Y	Y	Y	N	N	Y	Y	N	Y	N	N	Y	9

significantly positive in Canada, Portugal, and China. This was not only because of the heterogeneity of demographic characteristics of the study population and small sample sizes in a certain countries but also because of the variously defined measures of access to sidewalks. After reviewing the existing studies, our study showed that the

evidence from the developing countries was limited, as their urban planning is still at an early stage.

Our findings were consistent with previous literature.⁵ The presence and quality of sidewalks or trails, as part of the built environment, could make a great contribution to the neighborhood

walkability.²⁵ If sidewalks around one's residence are either unavailable or unsafe to utilize, one is more likely to be physically inactive, which could lead to an elevated possibility of having obesity.^{5,26} However, seven included studies indicated null or even counterintuitive findings. This may be attributable to the failure to control for some crucial confounders and effect modifiers. For example, neighborhood safety and crime rate are potential effect modifiers in the relationship between access to sidewalks and weight outcomes. Although six of the included studies have accounted for neighborhood safety or crime rate in their regression models, only one study conducted a stratified analysis by crime, which indeed showed that nearby violent crime modified the association between sidewalk accessibility and children's weight.²³ Although sidewalks had a beneficial effect on weight outcomes of children living in safe neighborhoods, they may have an opposite effect on those living in unsafe neighborhoods, as sidewalks could represent limited bounds and more potential threats.²³

We found several major research gaps in this field, which pointed to several interesting avenues for future research. First, the current studies varied considerably in the measures of sidewalk accessibility, making it difficult to compare across studies and conduct the high-quality meta-analyses. The majority of studies used subjective rather than objective methods; some studies did not report the specific indicators, for example, lack of reporting of specific questions to assess perceived sidewalk accessibility^{18,19} and spatial methods used for delineating residential neighborhoods in which sidewalk accessibility was measured (straight-line or road-network buffers).¹⁷ The measures that might be used in future studies should be supported by measures in existing high-quality studies and reported in a standard way, so they can be repeated and validated in other studies.²⁷ Also, because it has not yet been well understood how actual and perceived access to sidewalks may correlate with each other and affect weight-related behaviors and outcomes, we suggest including both measures in future studies. Moreover, sidewalks, compared with other built environmental characteristics (e.g., roads, buildings, and greenspace),²⁸⁻³¹ are generally not well measured in previous studies. They are mostly small in size in one dimension and are sometimes covered by tree canopies or shaded by buildings. This could make them even more difficult to be extracted from satellite images by advanced spatial technologies such as remote sensing.^{32,33} More specialized skills (e.g., machine learning) are needed to extract such items from very high-resolution satellite images or street view photos.^{34,35} Therefore, multidisciplinary collaboration is necessary to facilitate this research area, which is at the intersection of public health and spatial science.^{36,37}

Second, nearly all of the included studies were cross-sectional in design, thereby rendering a causal relationship impossible. Although it is much easier to consider how access to sidewalks could contribute to one's PA and weight, reverse causality may also exist; for instance, normal-weight children may follow their parents' walking habits to

move to walkable neighborhoods with good access to sidewalks. Sidewalk features extracted from historical street view images at multiple points in time by machine learning methods could be better matched to multiple measurements of individuals' weight status in longitudinal studies on the basis of existing cohort data, thus investigating how the changes in the access to sidewalks may affect weight status of those without residential changes during that period. Also, our included studies were predominated by developed countries and could not provide a comprehensive understanding of the association between sidewalk accessibility and weight-related behaviors and/or outcomes all over the world.

Third, future studies should take some potential confounders and moderators into consideration, such as neighborhood safety, which could be measured by the crime rate. Also, because diet and PA are two primary transmitters of obesity, we shall take both dietary intakes and PA into account. This can be done by introducing a food frequency questionnaire, 24-h dietary recalls, or other validated measures of energy intake. Moreover, subgroup analyses were insufficiently conducted in previous studies, thereby hindering our understanding of the varying health effects of sidewalk accessibility across subpopulations, and of the effectiveness of relevant interventions and policies targeting specific subpopulations. For example, one included study showed that access to sidewalks was inversely related to the BMI of older children (≥ 8 years old) but not of younger ones (< 8 years old).²³ However, this is inconclusive primarily due to the small number of such studies. Thus, conducting subgroup analyses by, for example, age, sex, and socioeconomic status, is another important research direction.

5 | CONCLUSIONS

A growing body of studies from five countries shows that access to sidewalks could affect obesity-related behaviors and outcomes. However, results remain mixed. Most of the included studies that had a cross-sectional design were conducted in the United States and used questionnaires to measure access to sidewalks and PA. Both subjective measures and objective measures of access to sidewalks and PA should be used in a standardized way in future longitudinal studies designed in broader regions, to explore the causal relationships between sidewalk accessibility and children's behaviors and weight status.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

ORCID

Junxiang Wei  <https://orcid.org/0000-0002-1026-673X>

Peng Jia  <https://orcid.org/0000-0003-0110-3637>

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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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