Epidemiologic Reviews
Vol. 29, 2007
DOI: 10.1093/epirev/mxm009
Advance Access publication May 28, 2007

The Built Environment and Obesity

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Accepted for publication April 16, 2007.

Obesity results from a complex interaction between diet, physical activity, and the environment. The built environment encompasses a range of physical and social elements that make up the structure of a community and may influence obesity. This review summarizes existing empirical research relating the built environment to obesity. The Medline, PsychInfo, and Web of Science databases were searched using the keywords "obesity" or "overweight" and "neighborhood" or "built environment" or "environment." The search was restricted to English-language articles conducted in human populations between 1966 and 2007. To meet inclusion criteria, articles had to 1) have a direct measure of body weight and 2) have an objective measure of the built environment. A total of 1,506 abstracts were obtained, and 20 articles met the inclusion criteria. Most articles (84%) reported a statistically significant positive association between some aspect of the built environment and obesity. Several methodological issues were of concern, including the inconsistency of measurements of the built environment across studies, the cross-sectional design of most investigations, and the focus on aspects of either diet or physical activity but not both. Given the importance of the physical and social contexts of individual behavior and the limited success of individual-based interventions in long-term obesity prevention, more research on the impact of the built environment on obesity is needed.

environment design; obesity; residence characteristics; social environment

Abbreviations: BMI, body mass index; CI, confidence interval; PR, prevalence ratio.

INTRODUCTION

Obesity is a serious public health problem with negative physical, social, and mental health consequences (1–13). Rates have been rising rapidly over the past two decades among both children and adults (14–20). Given the detrimental health consequences of obesity and the rapidly rising rates, successful prevention efforts are urgently needed. Fundamentally, obesity results from an energy imbalance that occurs when energy consumption exceeds energy expenditure. The factors that influence increases in energy consumption and decreases in energy expenditure are complex and are currently the focus of much research (21, 22).

Recent discussions regarding the obesity epidemic have focused on the role the environment plays in increasing energy consumption and decreasing energy expenditure (23–26). The built environment, in particular, has been thought to play an important role in influencing obesity by creating a climate that promotes increased energy consumption and a reduction in energy expenditure (27). As broadly defined in the health literature, the environment can be thought of as "all that is external to the individual" (28),

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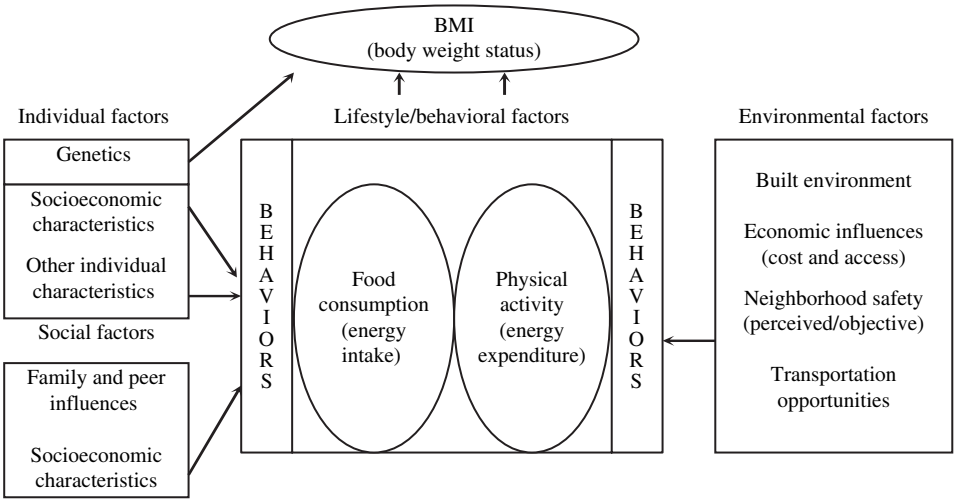

FIGURE 1. Ecologic model relating the built environment to physical activity, diet, and body weight. BMI, body mass index. Reproduced with the permission of Lisa Powell et al., ImpacTeen Program Office, Institute for Health Research and Policy, University of Illinois at Chicago, Chicago, Illinois (www.impacteen.org).

with the term ''built environment'' encompassing aspects of a person's surroundings which are human-made or modified, as compared with naturally occurring aspects of the environment. The many ways in which the built environment influences health include not only ''direct pathological impacts of various chemical, physical, and biologic agents, but also... factors in the broad physical and social environments, which include housing, urban development, land use, transportation, industry, and agriculture'' (28). Understanding the impact of the built environment on obesity may provide information necessary to develop successful community-based prevention efforts (29).

Evidence regarding the mechanisms through which the built environment may influence obesity (i.e., through dietary consumption or physical inactivity) is just beginning to emerge (30–32). The many theoretical pathways between the built environment and obesity have necessarily resulted in a diverse range of influences' being conceptualized and measured (see figure 1). Nevertheless, certain methodological issues are common across areas of inquiry.

Researchers need to consider all the many different built environments to which humans are exposed across their lives. This includes consideration of both residential space and activity space, as well as the connection between these spheres. For children, this might include both school and recreational space. For adults, environments of interest might include residential space, work space, and characteristics of the travel environment between work, shopping, and personal business, social, and recreational activities and the residence. For example, the amount of time spent daily in commuting between home and work, as well as the quality of a person's daily commute, is drawing attention for its potential impact on health.

Travel is thought to be an outgrowth of activities, where in-home and outside activities are both substitutes for and complements of each other. A growing interest in activity modeling, through the use of activity diaries and assessment of activity spaces and patterns, has also raised important methodological concerns. For example, the size of a person's activity space and the mechanism by which a characteristic exerts its putative influence are conceptually important. Environments such as residential neighborhoods may be thought of as being of a certain geographic size, may be determined by locally specific history or culture, or may have natural or human-made boundaries, such as highways, parks, or transitions in land use.

In studies carried out across large areas, creating metrics equally appropriate to rural, urban, and suburban areas is challenging. Similarly, because it is the interaction of the individual with his or her environment that influences health, measures and concepts may differ for men and women, for families as compared with the elderly or children, and for persons or groups with relatively fewer or greater social or economic resources. Poor persons, for example, are thought to be more affected by their built environments because their activity spaces are smaller and they are more constrained by lack of transportation and opportunities for mobility. Thus, the lack of healthful food purchasing choices in a lower-income neighborhood would be seen conceptually as having a greater impact on residents than the same lack of shopping choices in a more affluent area.

Within this area of research, spatial attributes are often measured as surrogates for actual influences. For example, distance and travel time to a resource such as a hospital are often of interest, because they capture one dimension of access to health care. The availability of certain types of food choices—one aspect of the food environment—can be measured by means of food pricing, quality, and variety. Proximity may serve as a surrogate measure of influence, with aspects of the built environment closest to a residence

being seen as having a stronger influence than those farther away. However, for many environmental influences, other attributes, such as density, may be more important than distance. For example, a neighborhood's identity as an ethnic enclave may be determined by the existence of certain key commercial or residential characteristics, by the population composition, or by its identification as such by either insiders or outsiders.

This review examines the published empirical evidence for the influence of the built environment on the risk of obesity. Inclusion criteria for articles in this review were: 1) a direct measure of body weight (e.g., body mass index (BMI)) and 2) at least one objective measure of the built environment.

METHODS

A Medline search was conducted using the keywords "obesity" or "overweight" and "neighborhood" or "community." A second search was conducted using the keywords "obesity" or "overweight" and "built environment" or "environment." The search was restricted to English-language articles conducted in human populations between January 1, 1966, and February 1, 2007. Medline was used as the primary search engine, given its wide accessibility and common use in public health research. In the first search, 285 abstracts were obtained, and in the second search, 62 abstracts were found. Four articles overlapped between the two searches, leaving a total of 343 unique abstracts. Only those studies with a direct measure of body weight (such as BMI) and an objective measure of the built environment were included in this review. This restriction produced 15 empirical studies of the built environment and obesity. Excluded articles that examined neighborhood characteristics and obesity ($n = 310$) focused primarily on socioeconomic or social characteristics of neighborhoods, including income, education, race/ethnicity, and social cohesion. The reference sections of 18 discussion/review articles, as well as of the 15 empirical papers, were examined for additional studies of the built environment and obesity. Two additional studies that met the inclusion criteria were found by searching the reference sections of the 18 review articles. This resulted in a total of 17 articles (33–49).

In order to explore how comprehensive the Medline search was, additional searches of the PsychINFO and Web of Science databases were conducted using the same keywords. The PsychINFO search produced 53 abstracts; five met the eligibility criteria, with five out of five overlapping with the Medline search. The Web of Science search produced 1,110 abstracts; 22 met the eligibility criteria, with 19 out of 22 overlapping with the Medline search. The three additional articles from the Web of Science database (50–52) were included as part of this review, resulting in a total of 20 articles (figure 2). These articles demonstrate the recent interest in examining environmental influences of obesity risk and document a fruitful area of research. Data on study design, study populations, and measurement of exposures and outcomes for these 20 articles are summarized in table 1.

RESULTS

Study characteristics

The relevant articles were evaluated with regard to study design, population studied (i.e., age range, racial/ethnic composition), exposure measurement, and outcome measurement. Of the 20 articles, 17 reported a statistically significant positive association between some aspect of the built environment and BMI. The majority of studies (18/20) were cross-sectional, limiting the ability to infer directionality in the association between the built environment and obesity. Two longitudinal studies were conducted, with one (41) finding a significant positive association between lower fruit and vegetable prices and lesser gains in BMI over a 3-year period and the other (49) finding no association between county-level urban sprawl and 7-year change in BMI. Studies were conducted within both child and adult populations in the United States, Australia, and Europe, allowing for cross-national comparisons of the associations under investigation. Sixteen of the 20 studies included both group-level and individual-level factors in assessing the relation between the built environment and obesity, with 10 of these 16 studies (41, 43–49, 51, 52) using multilevel modeling strategies to account for the correlations between observations within defined areas. Objective measures of the built environment were collected across all studies, with density measures of either recreational facilities or food sources being the most commonly used metric assessing availability. All of the studies used BMI (weight (kg)/height $(m)^2$), computed by means of either self-reported or measured weight and height data, to define obesity. Standard definitions were used across adult populations. Four of the five studies carried out in children (36, 44, 47, 49) used the age- and sex-specific percentile values for BMI recommended by the Centers for Disease Control and Prevention (53) to classify overweight for persons under 21 years of age. These characteristics are considered in more detail below.

Study design

Of the 18 cross-sectional investigations, three were ecologic studies with measures of both the built environment and obesity collected at the area level. The level of aggregation differed between these three ecologic studies and included a state-level analysis (38), two county-level analyses (42, 43), and a city/metropolitan area-level analysis (43). Although ecologic studies may be useful in examining the effect of a group-level variable, such as county-level sprawl, as a predictor of group-level variability in obesity rates, they are unable to investigate the contribution of individual-level factors, such as physical inactivity, to between-group differences. On the other hand, traditional individual-level studies, such as those examining physical inactivity and risk of overweight, are unable to investigate the role of group-level factors, such as the availability of recreational facilities within residential neighborhoods, in explaining variability in overweight between individuals (54). Directionality is difficult to establish within cross-sectional investigations; for example, persons who are obese may be less likely to prioritize access to physical activity

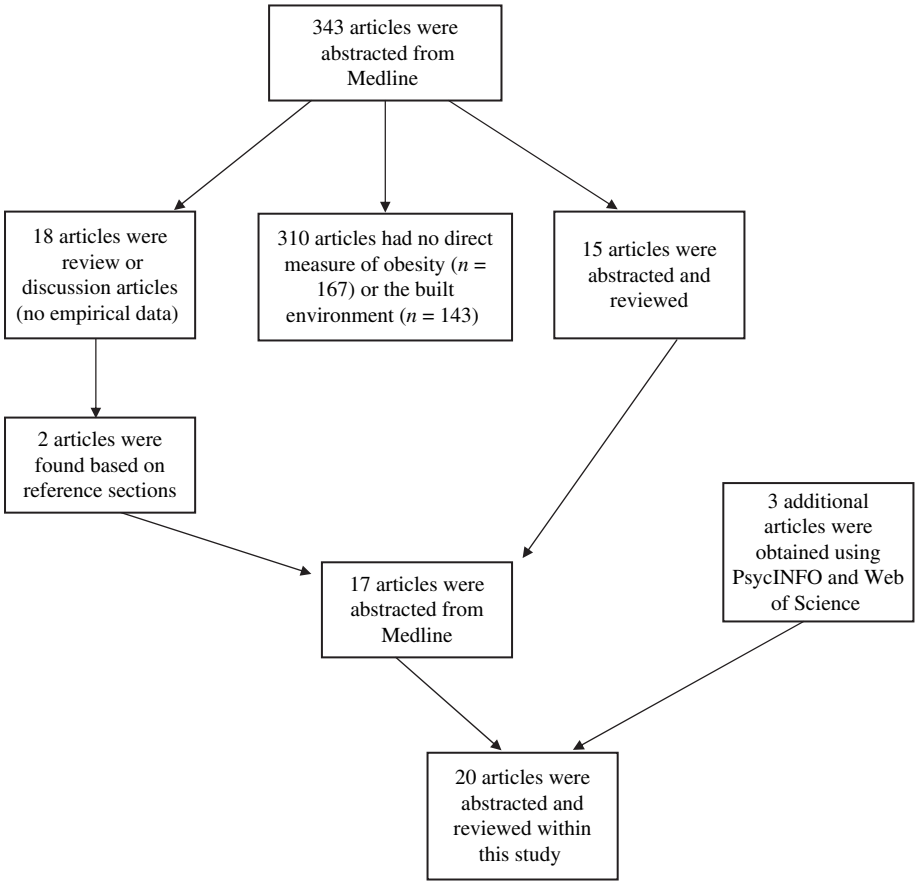

FIGURE 2. Schematic of article abstraction from a Medline search for a review of obesity and the built environment.

and healthy foods in comparison with nonobese persons when selecting residential locations. Only two of the studies published were longitudinal cohort studies (41, 49); one found a statistically significant association between the built environment and obesity (41) and the other found no association (49), raising questions as to self-selection and directionality of effect.

Study populations

Age. One of the major differences between the 17 articles (34, 35, 37–50, 52) that documented a positive statistically significant association and the three (33, 36, 51) that did not was the age of the study population. Only one of the three studies conducted in populations of children (41) found a statistically significant positive association between the built environment and BMI, whereas 16 of the 17 studies conducted in adolescent and adult populations found a statistically significant positive association between some aspect of the built environment and BMI. None of the studies included both child and adult populations. While the study by Liu et al. (33) incorporated young children as well as adolescents, the results were shown for all age groups combined.

Race/ethnicity. Examining racial/ethnic differences in the relation between the built environment and overweight may aid in the development of culturally specific community-level interventions. Seventeen of the 20 studies were either conducted in predominantly non-Hispanic White populations or did not include comparisons by race/ethnicity. The majority of these studies simply adjusted for race/ethnicity within their analytical models. Only one of the 20 studies examined differences in the built environment-obesity association by race/ethnicity (37). In this investigation, both the inverse association between increased mixed land use and odds of obesity and the positive association between increased time spent in a car and increased odds of obesity were stronger among non-Hispanic Whites than among African Americans. One study (40) specifically investigated the built environment-obesity relation only within a minority population. Rutt and Coleman (40) examined the association between neighborhood measures of access to physical activity and BMI in a predominantly Hispanic adult community, a population with extremely high rates of obesity (55). Within this community, land-use mix was statistically significantly associated with BMI. Land-use mix is the degree to which residential, commercial, and institutional parcels of land are located close together (43). It was

hypothesized that the greater the level of mixed land use, the more ''walkable'' the community would be and thus the lower the risk of obesity. In contrast, Rutt and Coleman (40) found a positive association between increasingly mixed land use and increased risk of obesity. This is inconsistent with two other studies investigating the influence of land-use mix on BMI in non-Hispanic White populations (35, 37). The differential impact of land-use mix on risk of obesity within non-Hispanic White communities versus Hispanic communities warrants further investigation.

Exposure measurement: the built environment

Of the 20 studies reviewed, measurement of the built environment varied, with little overlap across studies (see table 2 for a list of measures). The most frequently used measure was the density of play space or recreational facilities, with five out of 20 studies using this measure to quantify the availability of opportunities for physical activity. Typically, studies examined either access to physical activity opportunities (i.e., proximity to play space, sidewalk availability, neighborhood walkability) ($n = 14$) (34, 35, 37–40, 42–44, 47–51) or access to food outlets (i.e., availability of fast-food restaurants, number of food stores) ($n = 4$) (38, 41, 45, 52); two studies (36, 46) incorporated measures of access to both foods and physical activity within the same investigation.

Diet. Studies that used measures of access to food included either a measure of distance to the nearest fast-food restaurant (36) or grocery store (52) or a measure of the density of food outlets within a defined area (38, 41, 45, 46), but not both. For studies that examined the density of food outlets, area measurements differed. Maddock (38) examined the number of square miles per fast-food restaurant and the number of people per fast-food restaurant within a state; Sturm and Datar (41) and Mobley et al. (46) investigated the number of food outlets (grocery stores, convenience stores, fast-food restaurants, and full-service restaurants) per 1,000 people in each study participant's ZIP code; and Morland et al. (45) created a dichotomous variable indicating the presence or absence of each type of food store (supermarkets, grocery stores, convenience stores, fast-food establishments, full-service restaurants, and limited-service restaurants) within census tracts where people resided.

Besides the physical availability of food outlets, Sturm and Datar (41) additionally examined the cost of foods within metropolitan areas where children resided. They examined four variables, including average area prices for meats, dairy products, fruits and vegetables, and fast food. Three (38, 41, 45) of the four studies that examined density or food prices found positive associations with BMI. The number of residents per fast-food restaurant and the number of square miles per fast-food restaurant were significantly ($p < 0.05$) associated with the prevalence of obesity at the statewide level ($\beta = -0.23$ (standard error, 0.001) and $\beta = -0.24$ (standard error, 0.001), respectively) (38). Lower area prices for fruits and vegetables were also associated with decreases in BMI over a 3-year period for children aged 4 and 5 years ($\beta = 0.114$ (standard error, 0.033); $p < 0.001$) (41). The presence of supermarkets was statistically significantly associated with lower prevalences of obesity (prevalence ratio (PR) = 0.83, 95 percent confidence interval (CI): 0.75, 0.92) and overweight (PR = 0.94, 95 percent CI: 0.90, 0.98), whereas the presence of convenience stores was statistically significantly associated with higher prevalences of obesity (PR = 1.16, 95 percent CI: 1.05, 1.27) and overweight (PR = 1.06, 95 percent CI: 1.02, 1.10) (45). These results held after adjustment for socioeconomic characteristics. The density of food establishments per 1,000 residents in each ZIP code was not associated with BMI for adult study participants in the WISEWOMAN Study (β coefficients were -0.37, 0.09, 1.19, and -0.25 for grocery stores, fast-food restaurants, regular restaurants, and minimarts, respectively) (46). Distances to fast-food restaurants were not associated with risk of overweight for children aged 3 and 4 years (the mean distance was 0.70 miles (1.1 km) (standard deviation, 0.40) for overweight children as compared with 0.69 miles (1.1 km) (standard deviation, 0.38) for nonoverweight children) (41). For adults, distance to the grocery store where they usually shopped was associated with obesity; in comparison with persons whose grocery store was within their census tract, persons who shopped more than 1.8 miles (2.9 km) away had greater BMIs ($\beta = 0.78$, $p < 0.05$) (52).

Physical activity. Access to physical activity facilities was the most common measure of the built environment, with seven of the 20 studies including some measure of access to facilities (33, 34, 36, 40, 44, 46, 47). Distance measures were employed within three studies (33, 34, 36), measures of density were used in three studies (44, 46, 47), and one study included measures of both distance and density (40). The two studies that investigated this issue within child populations (33, 36) computed the distance from the child's residence to the nearest playground. Both of these studies found no association. Two studies in adults (34, 40) computed the distance from study participants' homes to the nearest recreational facility, with one (34) demonstrating a positive association between distance to the nearest facility and increased risk of overweight. The two studies investigating this issue in adolescent study populations, on the other hand, measured the number of recreational facilities within census block groups (47) or used the number of facilities within a multivariable model classifying neighborhood types (44). Both of these studies found positive associations between the number of recreational facilities and the likelihood of being overweight. Using a measure of density (number of fitness facilities per 1,000 residents, within ZIP codes), Mobley et al. (46) found a statistically significant negative association with BMI ($\beta = -1.39$).

Additional measures of access to physical activity incorporated some aspect of community design using publicly available data sources such as the US Census or land-use mix as measured by county tax assessors. Across all 20 studies, there were five measures of community design used, including connectivity, net residential density, land-use mix, street accessibility, and provision of sidewalks. Nine studies incorporated at least one of these measures (34, 35, 37, 40, 43, 46, 49–51). Ewing et al. (43) used these measures to construct an overall index of sprawl that was later used in three other studies (49–51); Sturm and Datar (41) and Doyle

TABLE 1. Summary of the evidence for an association between the built environment and risk of obesity, by type of exposure measurement

Study author(s) and year (ref. no.)	Study population, design, and size	Exposure assessment	Outcome assessment	Study findings
		Access to/availability of physical activity		
Liu et al., 2002 (33)	Cross-sectional survey of a random sample of 2,554 children aged 4–18 years drawn from a medical record system in Indiana	Proximity to the nearest public play space, measured as the distance (m) from a child's home address to the nearest YMCA,* city park, city trail, or after-school program with physical education curricular components	BMI*,† was computed from heights and weights abstracted from medical charts; children were classified as normal (BMI < 25), overweight (BMI ≥ 25), or obese (BMI ≥ 30).	No differences found in the average distance to a play space by BMI status (mean distances for obese and nonobese children were 567 m and 571 m, respectively).
Giles-Corti et al., 2003 (34)	Cross-sectional survey of 1,803 healthy sedentary workers and homemakers aged 18–59 years living in areas within the top and bottom quintiles of social disadvantage in Perth, Australia	Three objectively measured variables, including the type of street the resident lived on (cul-de-sac, highway, or other), whether there were sidewalks (none or on one or both sides of the road), and a measure of poor spatial access to recreational facilities	Self-reported height and weight data were used to compute BMI; adults were classified as overweight (BMI ≥ 25) or obese (BMI ≥ 30).	Overweight/obesity was associated with living on a highway, living on a street with no sidewalks or with sidewalks on one side only, and having poor access to four or more recreational facilities.
Saelens et al., 2003 (35)	Cross-sectional survey of 107 residents aged 18–65 years recruited from high-walkability (n = 54) and low-walkability (n = 53) neighborhoods in San Diego, California	A neighborhood walkability scale was developed using measures of residential density, mixed land use, and street connectivity.	Self-reported height and weight data were used to compute BMI; adults were classified as overweight (BMI > 25) or nonoverweight (BMI ≤ 25).	Residents of low-walkability neighborhoods had higher BMIs (27.4 vs. 25.3) and were more likely to be classified as overweight (60.4% vs. 35.2%) than residents of high-walkability neighborhoods.
Ewing et al., 2003 (43)	Cross-sectional survey using the BRFSS,* which consisted of 206,992 respondents from 448 US counties and 175,609 respondents from 83 US metropolitan areas over the years 1998–2000	A metropolitan sprawl index was created that incorporated dimensions of residential density, land-use mix, degree of centering (extent to which development is focused on region's core or regional subcenters), and street accessibility (length and size of blocks).	Self-reported height and weight data were used to compute BMI; adults were classified as obese (BMI ≥ 30) or nonobese (BMI < 30).	The county-level, but not metropolitan-level, sprawl index was associated with BMI and risk of obesity. The association between sprawl index and BMI was partially mediated through the number of minutes walked in the past month.
Frank et al., 2004 (37)	Cross-sectional survey of 10,878 study participants aged 16–100 years residing in the 13-county Atlanta, Georgia, region	Environmental measures assessed were connectivity (number of intersections within a 1-km household radius), net residential density, and land-use mix. Transportation-related activity was measured by daily time spent in a car and distance walked as collected through 2-day travel diaries.	Self-reported height and weight were used to compute BMI, and obesity was defined as BMI ≥ 30.	Increased mixed land use and daily distance walked were associated with reduced obesity; increased time spent in a car was associated with increased obesity. Relations were stronger among Whites than among Blacks.
Lopez, 2004 (50)	Cross-sectional US study using data from the 2000 BRFSS on 104,084 adults who resided in metropolitan areas	An urban sprawl index, with values ranging from 0 to 100, was developed for each of 330 US metropolitan areas. The index was based on the population density within census tracts that made up each metropolitan area. Lower scores indicated less sprawl.	Self-reported height and weight were used to compute BMI; overweight was defined as BMI > 25, and obesity was defined as BMI ≥ 30.	After adjustment for sex, age, race/ethnicity, income, and education, urban sprawl was statistically significantly associated with overweight (RR* = 1.02, 95% CI*: 1.01, 1.02) and obesity (RR = 1.02, 95% CI: 1.01, 1.02).

Kelly-Schwartz et al., 2004 (51)	Cross-sectional US study of 9,252 adult participants in the Third National Health and Nutrition Examination Survey (1988–1994)	The metropolitan area sprawl index created by Ewing et al. (49) was used. This index incorporated dimensions of residential density, land-use mix, degree of centering (extent to which development is focused on region's core or regional subcenters), and street accessibility (length and size of blocks).	Measured height and weight data were used to compute BMI. BMI was used as a continuous variable in all models.	After adjustment for individual-level characteristics within a multilevel analysis, there was no association between the metropolitan area-level sprawl index and BMI (β = 0.001, *p* value not significant).
Ellaway et al., 2005 (39)	Cross-sectional survey of 6,919 adults conducted in eight European countries in 2002–2003	Trained surveyors assessed the immediate residential environment of all study participants along two dimensions measured from 1 (low) to 5 (high): 1) amount of greenery and vegetation and 2) amount of graffiti, litter, and dog waste visible around dwelling and surrounding streets	Self-reported height and weight were used to compute BMI, and overweight/obesity was defined as BMI $\geq$ 25.	There was a dose-response relation between increasing levels of greenery and lower levels of graffiti and reduced risk of overweight/obesity.
Rutt and Coleman, 2005 (40)	Cross-sectional community-wide health survey of 996 adults from a primarily Hispanic community in Texas	Neighborhood was defined as a 1/4-mile (0.4-km) radius around each person's residence. Sidewalk availability, number and distance to physical activity facilities, mixed land use, intersection density, and slope (average change in elevation) were used as measures of the built environment.	Self-reported height and weight were used to compute continuous measures of BMI.	Living in areas with greater mixed land use was associated with higher BMI values.
Lopez-Zetina et al., 2005 (42)	Ecologic study at the county level (n = 33 counties) using data from adults aged 18 years or more who participated in the California Health Interview Survey	Aggregate county-level indictors of the daily travel time to work measured using US Census data and the average number of daily vehicle miles traveled using data from the California Department of Transportation, as well as population density.	Self-reported height and weight were used to compute BMI, and obesity was defined as BMI $\geq$ 30.	Positive correlations between obesity and vehicle miles traveled (r = 0.79) and commute time (r = 0.55) and a negative correlation between obesity and population density (r = −0.342) (all p's < 0.05).
Nelson et al., 2006 (44)	Cross-sectional US study of 20,745 adolescent participants in the National Longitudinal Study of Adolescent Health	Neighborhood was defined as a 3-km radius around the residence. Six neighborhood types were identified using cluster analyses: rural working class, exurban, new suburban, older/upper middle class, mixed race/ethnicity urban, and low socioeconomic status/inner-city. The number of physical activity facilities, density and length of roadways, and street connectivity were used to describe each cluster.	Self-reported heights and weights were used to calculate BMI. BMI percentile and z scores for age and sex were computed based on CDC* growth references. Overweight was defined as a BMI $\geq$ 95th percentile.	After adjustment for socioeconomic status, age, and race/ethnicity, persons living in rural working class, exurban, and mixed race/ethnicity urban neighborhoods were more likely to be overweight (RRs = 1.4, 1.3, and 1.3, respectively) than were persons living in new suburban neighborhoods.
Gordon-Larsen et al., 2006 (47)	Cross-sectional US study of 20,745 adolescent participants in the National Longitudinal Study of Adolescent Health	Neighborhood was defined as an 8-km radius around the residence. The number of physical activity facilities and resources (e.g., YMCAs, athletic clubs, public pools/tennis courts, martial arts/dance studios, parks, and recreation services) per census block group was used.	Self-reported heights and weights were used to calculate BMI. BMI percentile and z scores for age and sex were computed based on CDC growth references. Overweight was defined as a BMI $\geq$ 95th percentile.	Odds of overweight declined with increasing number of physical activity facilities per census block group (for having one physical activity facility compared with no facility, odds ratio = 0.95, 95% CI: 0.9, 0.99).

Table continues

TABLE 1. Continued

Study author(s) and year (ref. no.)	Study population, design, and size	Exposure assessment	Outcome assessment	Study findings
Doyle et al., 2006 (48)	Cross-sectional study of US adults living in county populations of 500,000 or more who participated in the Third National Health and Nutrition Examination Survey (1988–1994)	A composite measure of walkability based on three county-level indicators: 1) the negative of average block size; 2) percentage of all blocks having areas less than 0.01 square miles (0.02 km^2); 3) the number of three-, four-, and five-way intersections divided by the total number of road miles	Measured height and weight data were used to compute BMI with BMI used continuously in all models.	Results from multilevel analyses indicated a statistically significant inverse association between walkability and BMI ($\beta = -0.054$ (standard error, 0.028); $p < 0.05$) after adjustment for potential confounders.
Ewing et al., 2006 (49)	Cross-sectional ($n = 8{,}984$) and longitudinal ($n = 7{,}756$) study of US adolescent participants (ages 12–17 years) in the 1997 National Longitudinal Survey of Youth	A previously developed county-level sprawl index was created that incorporated dimensions of residential density, land-use mix, degree of centering (extent to which development is focused on region's core or regional subcenters), and street accessibility (length and size of blocks).	Self-reported heights and weights were used to calculate BMI. BMI percentile and *z* scores for age and sex were computed based on CDC growth references. For cross-sectional analyses, overweight/being at risk for overweight was defined as a BMI $\geq$ 85th percentile. For longitudinal analyses, a continuous BMI outcome was used.	Cross-sectional analyses demonstrated statistically significant associations between urban sprawl and being at risk for or being overweight. Longitudinal analyses revealed no statistically significant associations between urban sprawl and changes in BMI over time.
		Access to/availability of food sources		
Morland et al., 2006 (45)	Cross-sectional study of 10,763 adults participating in the Atherosclerosis Risk in Communities Study (Mississippi, North Carolina, Maryland, and Minnesota)	Census tracts were used to define neighborhoods. The presence of several types of food stores within census tracts where people resided, including supermarkets, grocery stores, convenience stores, full-service restaurants, fast-food franchises, and limited-service restaurants, were used to characterize the built environment.	Self-reported height and weight data were used to compute BMI; adults were classified as overweight (BMI > 25 and $\leq$ 30) or obese (BMI > 30).	Prevalence ratios computed using random-effects generalized linear models indicated lower prevalences of overweight (PR* = 0.94) and obesity (PR = 0.83) with the presence of supermarkets and an increased association of the presence of grocery stores and convenience stores with prevalences of overweight (PR = 1.03 and PR = 1.06, respectively) and obesity (PR = 1.07 and PR = 1.16, respectively).
Inagami et al., 2006 (52)	Cross-sectional study of 2,144 adult participants in the Los Angeles Family and Neighborhood Study	Individuals provided locations of grocery stores where they shopped. Information was available at the census tract level, and the distance from the residence to the grocery store was estimated from the centroid of the residential census tract to the centroid of the grocery store census tract.	Self-reported height and weight were used to compute a continuous BMI variable.	Compared with persons shopping in their census tracts, those shopping more than 1.8 miles (2.9 km) away had greater BMI values ($\beta = 0.78$, $p < 0.05$). Greater BMI was also associated with greater area-level disadvantage scores of the census tract where participants shopped.
Maddock, 2004 (38)	Cross-sectional ecologic study at the US state level using data from the 2002 BRFSS, the 2000 Census, and the 2002 Verizon SuperPages (Idearc Media, Inc., Dallas, Texas)	Two measures of the built environment included square miles per fast-food restaurant and population per fast-food restaurant. Data were also available on physical inactivity and fruit and vegetable intake.	Self-reported height and weight were used to compute BMI, and state obesity rates were defined as the percentage of the population with a BMI $\geq$ 30.	Associations were found between decreasing numbers of square miles per fast-food restaurant and increasing population per fast-food restaurant and an increasing statewide prevalence of obesity.

Sturm and Datar, 2005 (41)	3-year longitudinal study of a nationally representative sample of 6,918 US kindergarteners aged 4 or 5 years at recruitment	Four variables indicating the average prices of meats, dairy products, fast food, and fruits/vegetables in metropolitan areas where children resided were used to measure food pricing. Food availability was measured as the number of grocery stores, fast-food restaurants, convenience stores, and full-service restaurants per 1,000 persons in each child's ZIP code.	Trained staff measured heights and weights of all children at baseline and year 3. The dependent variable was measured by the change in BMI over the 3-year period.	Lower prices for fruits and vegetables predicted lower gains in BMI over the 3-year period. No other environmental variables had an effect on BMI change over time.
Access to/availability of both physical activity and food sources				
Mobley et al., 2006 (46)	Cross-sectional study of 2,692 adult female participants in the WISEWOMEN* Study	Seven measures of the built environment were developed at the ZIP code level from US Census and US Geological Survey data. These included land-use mix and the number of fitness facilities, grocery stores, fast-food establishments, restaurants, and minimarts per 1,000 residents. At the county level, the percentage of the workforce commuting outside the county was examined.	Measured height and weight were used to compute a continuous BMI variable.	Ordinary least-squares models, corrected for heteroskedasticity and cluster-induced correlation, revealed a statistically significant association between increasing land-use mix and increasing numbers of fitness facilities with lower BMI levels ($\beta = -2.6$ and $\beta = -1.4$, respectively).
Burdette and Whitaker, 2004 (36)	Cross-sectional survey of 7,020 low-income children aged 3 and 4 years who were enrolled in WIC* programs in Cincinnati, Ohio	Playground proximity, fast-food restaurant proximity (distance in miles from child's home to nearest playground or fast-food restaurant), and neighborhood safety (measured by the numbers of serious crimes and 911 emergency calls)	Heights and weights were measured by trained personnel, and BMI percentile and *z* scores for age and sex were computed based on CDC growth references. Overweight was defined as a BMI $\geq$ 95th percentile and being at risk for overweight as a BMI $\geq$ 85th percentile.	No association was found between proximity to playgrounds, proximity to fast-food restaurants, or neighborhood crime and risk of overweight or being at risk for overweight.

* YMCA, Young Men's Christian Association; BMI, body mass index; BRFSS, Behavioral Risk Factor Surveillance System; RR, relative risk; CI, confidence interval; CDC, Centers for Disease Control and Prevention; PR, prevalence ratio; WISEWOMEN, Well-Integrated Screening and Evaluation for Women Across the Nation; WIC, Women, Infants, and Children.

† Weight (kg)/height (m)^2.

TABLE 2. Summary measures of the built environment used in 20 published articles on the built environment and risk of obesity

Measure of the built environment	No. of studies
Access to physical activity	
Proximity (m) to play space/recreational facilities	4
Type of street of residence (cul-de-sac, highway)	1
Sidewalk availability	2
Connectivity	2
Net residential density	1
Land use mix	4
Neighborhood walkability scale*	2
No. of recreational facilities	5
Intersection density	1
Slope (change in elevation)	1
Density and no. of roadways	1
Access to food outlets	
Square miles per fast-food restaurant	1
Population per fast-food restaurant	1
Fast-food restaurant proximity	1
Average food pricing	1
No. of food stores/area measure	4
Distance to usual grocery store	1
Additional measures	
Metropolitan sprawl index†	4
Daily no. of miles driven in a car	1
Daily amount of time spent in a car	2
Neighborhood safety (no. of serious crimes and 911 calls)	2
Amount of greenery	1
Amount of graffiti	1

* Scale included measures of residential density, land-use mix, and street connectivity.

† Indices included dimensions of residential density, land-use mix, and street accessibility.

et al. (48) used them to classify neighborhoods as to their degree of ''walkability''; and Nelson et al. (44) used them to identify neighborhood patterns or clusters, making comparability across these studies difficult. In addition to these standard community design measures, Ellaway et al. (39) developed a measure of community design through direct observation, classifying residences as to the amount of greenery or graffiti visible near the dwelling.

Finally, two studies examined measures relating to transportation (37, 42). Frank et al. (37) collected 2-day travel diaries and counted the total number of minutes per day spent in a car. Lopez-Zetina et al. (42) had county-level data on the total number of miles traveled in a vehicle each day, as well as the total number of minutes spent commuting to work. Both of these studies found significant positive associations between the measures of use of motorized transportation and risk of obesity.

Outcome measurement: body weight

The measure of body weight used in all of the studies was BMI, determined either from self-reported weights and heights ($n = 14$) or measured weights and heights ($n = 6$). Fifteen of the 20 studies used categories of BMI to define overweight (BMI $\geq$25 and <30) and obesity (BMI $\geq$30), and seven of the 20 used BMI as a continuous variable. Of the 15 studies with BMI measured categorically, three also examined BMI as a continuous variable (35, 43, 49). Five studies did not include categories of BMI, examining it only as a continuous variable (40, 41, 46, 51, 52).

One of the two cross-sectional investigations in children (36) and all of the cross-sectional investigations in adolescents (44, 47, 49) used age- and sex-specific percentile values for BMI and classified children/adolescents as being at risk for overweight (BMI $\geq$85th percentile and <95th percentile) and/or overweight (BMI $\geq$95th percentile). In an article examining proximity to play space and obesity in children, Liu et al. (33) classified children aged 4–18 years as normal weight, overweight, or obese, applying adult BMI categories. Within the United States, national guidelines recommend defining childhood overweight status by applying age- and sex-adjusted norms and using percentile cutpoints to classify overweight. The use of adult definitions within this investigation may have introduced misclassification, which could have contributed to the null results. Burdette and Whitaker (36) used measured weights and heights of a sample of 7,000 urban, low-income children aged 3 and 4 years and applied age- and sex-specific BMI percentiles to classify overweight. The three investigations in adolescents (44, 47, 49) used data from either the National Longitudinal Study of Adolescent Health (44, 47) or the National Longitudinal Survey of Youth (49), where self-reported data on weight and height were collected and age- and sex-specific BMI percentiles were used to classify overweight.

The two longitudinal studies within this area of research investigated change in BMI during a 3-year period for children aged 4 and 5 years (41) and during a 7-year period for adolescents aged 12–17 years (49). Although BMI z scores or percentiles are the optimal method for assessing childhood adiposity at one point in time, for longitudinal studies, evidence points to BMI itself as being the best method for assessing change in body weight over time in children (56).

DISCUSSION

Recently, there has been a growing body of evidence linking aspects of the built environment to obesity (33–52). The 20 articles that met the eligibility criteria for this review have all been published within the past 5 years. Of these 20 studies, 17 found a statistically significant relation between some aspect of the built environment and risk of obesity.

Balancing the research emphasis between activity and food behaviors

Primarily because of limited data availability, there has been a lack of work on the food environment relative to the

physical activity environment. The majority of the studies reviewed here (16/20) examined aspects of the built environment that have been linked to opportunities for physical activity. To date, investigations of food availability within communities have primarily focused on either the spatial distribution of food stores in relation to socioeconomic characteristics of communities (57–61) or the association between neighborhood food availability and individual-level dietary consumption (62, 63). Understanding the influence of both access to healthy foods and opportunities for physical activity is critical to obtaining a comprehensive picture of the relation between the built environment and obesity.

Methodological challenges in measurement

Research into the association between the built environment and obesity faces several methodological challenges. The wide range of conceptualization and operationalization of measures of the built environment makes it challenging to compare results across studies. Often metrics and measures are not developed solely for the question at hand but are derived from existing data sources, which may result in methodological compromises. For example, data from the US Census provide inexpensive and easily available measures of some aspects of the built environment. However, the areal units of Census data—block, block group, and tract—represent aggregations of populations created for data collection and are thus without consistent geographic size. Therefore, analyses of the built environment's effect on obesity, if measured by necessity at a Census-unit level, may fail to correctly capture the appropriate geographic effects. Similarly, analyses of business locations often rely on postal ZIP codes, defining a business's area of influence by the geography of local mail delivery. Incorporating more uniform measures of the built environment into future research will aid in the decision of which interventions to pursue (e.g., zoning density increases or removal of mixed-use restrictions) and facilitate the development of policy interventions at the community level.

A second challenge relates to the concept of accessibility. The accessibility of activities is thought to be the primary determinant of travel choices, affecting both physical activity and dietary behaviors. Accessibility is defined in terms of ease of access to desired activities. The more activities available within a given travel time, the better the accessibility of a location. Two types of accessibility may affect physical activity and dietary behaviors. ''Residential accessibility'' refers to the ease of access to activities from people's places of residence. Residential accessibility determines the destination, mode, and arguably even the frequency of home-based trips (64). It is the focus of the majority of research on proximity of recreational and dietary facilities. Destination accessibility, the distribution of activities around each other, is also an important determinant of household travel patterns (65). For example, ''. . .a shop which is close to a decision-maker's place of employment may be quite accessible (as indicated by the frequency of use) even though it may be quite distant from the decision-maker's place of residence'' (66, p. 76). Given the large number of linked trips people make in today's society, destination accessibility is potentially significant in that it affects people's ability to efficiently link trips for different purposes or complete more than one activity at a single stop.

Two investigations examining metropolitan indices of sprawl (43, 51) found no statistically significant association with obesity. County-level sprawl indices, on the other hand, were statistically significantly associated with obesity. Activity spaces within metropolitan areas and county-level areas may differ. The activity space of most metropolitan residents beyond childhood is certainly larger than the residential neighborhood. The average length of trips in the United States is 6.8 miles (10.9 km), taking residents well beyond the confines of their neighborhoods (67). The average walking trip is 0.7 miles (1.1 km), again beyond the confines of a neighborhood (67). Several studies have found that choice of transportation mode (driving, walking, biking) depends on the built environment at both the origin (home) and the destination (work or shopping). The appropriate geographic scale for active-living research is far from clear and can only be determined empirically. Ideally, different scales would be tested against outcomes in the same study, and more than one scale might have explanatory power.

Methodological challenges in analysis

More than half of the investigations reviewed (41, 43–49, 51, 52) incorporated measures of both group-level variables and individual-level variables within a multilevel framework (68); the majority of them were published within the last year (44–49, 52). Multilevel analytical tools will allow for simultaneous computation of the effects of group-level variables and individual-level variables on outcomes such as BMI. Since people can be conceptualized as nested within their groups or communities, multilevel modeling techniques take into consideration the nesting or hierarchical structure of these data (69). Multilevel models have been used in investigations of area-level effects on cardiovascular disease (26) and may be useful in future investigations examining the impact of the built environment on risk of overweight. When investigating measures of distance, it may still be necessary to use multilevel models to adjust for area-level confounders, such as neighborhood social cohesion or socioeconomic status, which may be associated with both the distance a person has to travel to the nearest facility or food store and the person's risk of obesity.

Although the use of multilevel modeling methods is an important advancement, there is additional information to be gained by adopting more spatially explicit analytical tools as well. Analyses of individual data using nested spatial units, such as census tracts, often fail to examine model fit from a spatial perspective. Examining models for spatial autocorrelation in the unexplained variance can reveal nonstationarity in the model and may shed light on important but overlooked small-area effects (70, 71).

The role of theory

Because the overarching goal of this field of research is to explain and potentially change two fundamental human

behaviors (physical activity and food consumption), the use of behavioral theory may provide guidelines as to how we should anticipate that the environment will influence these behaviors and ultimately rates of obesity. There is evidence that, in addition to measuring structural aspects of the built environment, measures of the social environment are also important influences on food consumption and activity (72). Social environmental influences may include community norms and values related to eating and activity, as well as contextual influences such as social networks and social support for behaviors such as leisure walking. For example, in addition to its structural characteristics, the use of a common space such as a park by a given subpopulation within a community is likely to be influenced by local norms and whether or not these persons feel ''out of place'' among the other users at a given time of day. Compositional demographic characteristics, such as the age structure of a neighborhood, may become social-contextual influences on community life (73).

Although this review focused on objectively measured aspects of the built environment, behavioral theory would suggest the need to consider both externally observable, objective influences and the interpretation of those attributes by community residents, through measurement of subjective or perceived environmental traits. Research comparing externally measured attributes of communities, such as physical appearance, walkability, and safety, with assessments made by residents has demonstrated the value of considering both perspectives (74–77). For example, Whitley and Prince (78) found that residents of a low-income area of London, United Kingdom, rated aspects of their neighborhood, such as housing quality, far more positively than third-party raters. In a study carried out in Perth, Australia, Giles-Corti and Donovan (79) found that residents of low-socioeconomic-status neighborhoods had better spatial access to recreational facilities than residents of high-socioeconomic-status neighborhoods but perceived their neighborhoods as less conducive to physical activity. Use of community-participatory research methods, which involve stakeholders in both the design and interpretation of research, is an important way to incorporate the perspectives of the community and add to our understanding of these seeming contradictions (80).

In addition, researchers examining the relation between a person and his or her environment need to consider how the person's social attributes, including sex, age, family structure, and social roles (parent, worker, retiree, etc.) shape the person-environment interaction. Studying adolescents in China, Li et al. (81) found differing neighborhood influences on activity for boys and girls, and Whitley and Prince (82) found that three subpopulations in low-income neighborhoods (the mentally ill, the elderly, and mothers) were more likely than other groups to restrict their travel because of fear of crime.

Research to date has focused on three life stages: childhood, adolescence, and adulthood. Research on the built environment and obesity among youths could benefit from a stronger consideration of life-course stage in the selection of measures. For example, access to play spaces for young children may incorporate several dimensions beyond convenient locations within walking distance, since it may be unlikely that very young children are allowed to walk to playgrounds without adult supervision. Therefore, access to safe areas to play and a playground density appropriate for the population, as well as parental perceptions of playground safety, may be important factors influencing physical activity among children. In a recent study of access and safety within neighborhoods in Boston, Massachusetts, Cradock et al. (83) found that youths in high-poverty neighborhoods lived closer to playgrounds, but on average these playgrounds tended to be less safe than those in neighborhoods of higher socioeconomic status. This has also been observed for neighborhoods in Chicago, Illinois (84). The investigation by Burdette and Whitaker (36) included low-income children enrolled in the Women, Infants, and Children program in Cincinnati, Ohio. If the observations in Boston and Chicago are applicable to Cincinnati, it may be possible that access to safe play space, versus any play space, may be more relevant in the lives of these young children.

Sturm and Datar (41) found that lower area prices for fruits and vegetables were associated with decreases in children's BMIs over a 3-year period, but measures of food availability were not associated with changes in BMI over the 3-year period. Although there was no information as to whether or not prices actually influenced the purchase or consumption of fruits and vegetables, within this population of children, the price of foods seemed to have a greater effect on BMI than the availability of foods. Glanz et al. (85) found that cost is one of the most important reasons why particular foods are purchased, second only to taste. Healthier diets that may reduce the risk of obesity cost more, and high-energy-density foods, which have been found to be associated with increased risk of obesity, cost less (86). The other two studies investigating the built environment and obesity among children reported null results (33, 36). Neither of these studies included measures of cost within their investigations. For young children who are unable to obtain their own food, influences on parental food choices for the home, such as the cost of foods, may be a key environmental factor influencing consumption and, in turn, weight gain. Understanding the role that the environment plays in influencing parental behaviors, both for themselves and for their children, may provide insight into the impact of the built environment on young children.

Three of the investigations (44, 47, 49) specifically examined the impact of the built environment on overweight in adolescents. Adolescence is a critical life period marked by rapid growth and development, and it is typically characterized by an increasing need for autonomy and a desire to make lifestyle choices that conform to peer norms (87, 88). As adolescents begin to explore the environment around them independently of parental influences, the impact of the built environment may be a strong determinant in influencing behaviors regarding physical activity and diet. Young children, as compared with adolescents or adults, may be more influenced by their immediate environment than by the larger built environment. Investigating associations between the built environment and obesity within different age groups is important to our understanding of how these relations play out across the life span. In the future,

investigators may want to compare the roles that the built environment plays in populations of adolescents and younger children, in order to take into account differential effects of the built environment on individuals at varying levels of psychosocial and physical development.

Research on the built environment in adults has not, for the most part, distinguished between the life stages of adulthood. However, there is evidence that the built environment has a unique impact on older adults. British research has identified two aspects of the perceived neighborhood environment (availability of services for seniors and ''neighborliness'') as having independent effects, net of individual characteristics, on the physical functioning of home-dwelling persons aged 65 years or older (89). Given the increasing numbers of older adults in developed countries, as well as the many barriers to healthful aging associated with obesity, a better understanding of the built environment's relation to diet and activity among the elderly is needed.

Comparisons across populations and societies

The majority of research on the built environment-obesity relation has been conducted within non-Hispanic White populations in the United States. An understanding of the built environment-obesity relation in different racial/ethnic groups may aid in the development of culturally specific community-level obesity prevention programs in communities with high rates of obesity (55). Conflicting results were evident for the association between land-use mix and risk of obesity. Reasons for this conflicting evidence are unclear but may include differential effects of mixed land use on obesity risk within different racial/ethnic groups. More research is needed to further investigate the association between measures of the built environment, such as land-use mix, and obesity rates within different racial/ethnic groups.

Only two (34, 39) of the 20 studies reviewed were conducted in populations outside of the United States, limiting the generalizability of these findings to non-US populations. Evidence tends to support the notion that one aspect of the built environment, namely access to affordable, healthy foods, is constrained within low-income communities in the United States, thus partially explaining the higher rates of obesity seen in low-income communities. This social patterning of food availability may not be as evident in other developed nations, where healthy foods may be more readily available across socioeconomic groups. Therefore, the contextual mechanisms that influence obesity rates may not be universal across developed nations (90). Work emerging from Australia, for instance, has demonstrated an interesting counterexample to the findings from other developed countries: Strong associations between individual-level socioeconomic factors and dietary habits exist in the context of weak or null associations between neighborhood-level socioeconomic factors and food availability (91–93). At this stage, more work is needed to explore environmental influences on diet and physical activity, both within the United States and abroad, in order to facilitate our understanding of and elucidate the population-level determinants of obesity.

To date, there is a growing evidence base pointing to the importance of the physical and social contexts within which individual behaviors are enacted. This evidence, coupled with the limited success of individual-based interventions in long-term obesity prevention, points to an urgent need for additional research on the impact of the built environment on obesity (94). Understanding the mechanisms through which environmental factors may influence obesity will aid in developing future community-level intervention strategies to curb this epidemic.

Conflict of interest: none declared.

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