## Review

# The association between the built environment and dietary intake - a systematic review

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We reviewed the literature that examines the association between the built environment and diet. The MEDLINE electronic database was searched. Eligible articles must have been published between 2000 and 2013, in the English language, and must have been conducted among a population-based sample of adults older than 18 years of age. Twenty-four articles met the inclusion criteria. The majority of studies (over 70%) focused on fruit and vege-table consumption. Most studies (88%) found a statistically significant relationship between diet and some aspect of the built environment. However, the results across studies were not consistent. These inconsistencies may be attributable to methodological challenges, including differing definitions of neighbourhood, and inconsistent approaches to measuring built environment features and diet. In order to explore the complex relationship between built environment and people's dietary behaviour, research design needs to be improved, and the items people actually buy need to be examined. In addition, more research is needed to investigate the causal pathways linking environmental factors and dietary intake.

Key Words: built environment, neighbourhood, diet, nutrition, review

#### INTRODUCTION

There has been a strong interest in understanding people's dietary behaviour, as diet plays an important role in people's health. Poor eating habits are a major contributor to obesity and other chronic diseases.<sup>1</sup> Nutrition-related chronic health conditions, such as obesity, diabetes, and cardiovascular disease, cause a remarkable economic and social burden to individuals, families, communities, and societies. These conditions can potentially be managed and prevented by maintaining a healthy diet.<sup>2,3</sup>

Eating behaviours are very complex, resulting from the interaction of multiple influences including the environment in which people live. In fact, it has been suggested that individual dietary changes might occur more easily if the environment supports people to make healthful food choices.<sup>4</sup> Previous studies regarding influences on people's eating behaviours have mainly focused on individual-level determinants such as attitude, preferences, selfefficacy, and behavioural intentions.<sup>5</sup> More recently, studies have indicated that factors related to the built environment (BE) may influence food choice and consequently nutrient intake.<sup>6,7</sup> The BE, encompassing urban design, land use, and transportation systems, refers to humanmade or modified characteristics of the physical environment in which human activity takes place.8 Studies that have examined the food environment have mainly investigated proximity and access to supermarkets as an influence on people's food consumption.<sup>7,9-11</sup> It has been noted

that people who live closest to a supermarket can take advantage of this resource and may have a healthier diet than people who live further away.<sup>12</sup>

The body of evidence examining the influence of BE on dietary intake is growing; however, it has been noted that the majority of studies to date have focused on the availability of, or access to, food provisioning facilities without exploring other BE features that may influence people's dietary behaviours.<sup>13</sup> Furthermore, the study reviews published to date have only focused on specific aspects of the built environmental features, such as "food deserts",<sup>14,15</sup> food availability in the home,<sup>16</sup> access to fast food,<sup>17</sup> or on a narrow dietary component such as fruit and vegetable consumption.<sup>18</sup> Consequently, the objective of our review was to explore in a more general sense the relationship between BE features (access and availability) and people's dietary behaviours. The results of our study will help inform future intervention strategies and research that addresses methodological gaps.

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#### METHODS

An electronic search of the MEDLINE database was conducted to identify papers related to the association between the BE and dietary behaviours. The search only included those published within the past 13 years (January 2000 up to September 2013). The goal was to explore the most recent evidence on the relationship between the BE and diet. The keywords used were "built environment" or "neigh\*"; and "food", "nutrition" or "diet"; and "availability" or "accessibility". We also searched the bibliographies of eligible studies for relevant articles.

To be included, studies must have been published in English and have been conducted among a populationbased sample of adults older than 18 years of age. Any studies that examined the association between the BE and diet were included. Also included were any studies that evaluated the association between diet and the availability and accessibility of food stores. Given that the aim was to review papers that focused on the association between diet and BE, articles that focused exclusively on the relationship between food environments and obesity were excluded from the study. Articles outlining other systematic reviews were also excluded. The titles and abstracts of all relevant articles were initially screened and full text articles were retrieved only for those articles that appeared to meet the inclusion criteria. The following data were extracted from these studies: characteristics; methodological details, such as sample size, dietary outcomes, BE features, data analyses; and study findings.

#### RESULTS

The article search was carried out in 2 phases: an initial search of articles published between January 2000 and May 2011, and an additional search for those published between May 2011 and September 2013. In the initial search, a total of 35 citations were identified, and this was reduced to 27 after the removal of duplicates (Figure 1). After the further removal of citations that did not meet the inclusion criteria, the abstracts of 15 papers were reviewed and 10 articles were selected for full article review. In addition to the database search, references were screened for articles that met the inclusion criteria. Following the references screening, 8 additional articles were included in the review. Two of these articles were published before 2000, but we decided to include them in the review since they met inclusion criteria. The additional search of 2011 to 2013 articles resulted in 7 papers, of which 3 met inclusion criteria; an additional 3 were subsequently added from their references. In total, the database search resulted in 24 unique titles that underwent full review and evaluation (Table 1).

#### Study characteristics

The majority of studies were conducted in the USA;<sup>7,9,11,19-31</sup> two studies were from each the UK<sup>10,32</sup> and New Zealand<sup>33,34</sup>, and the rest from Japan,<sup>6</sup> Australia,<sup>35</sup> Netherlands,<sup>36</sup> and Scotland.<sup>37</sup> The study population in a majority of these comprised of both men and women.<sup>7,10,11,19-22,24-<sup>34,36,37</sup> Four studies included only females.<sup>6,9,23,35</sup> Nine studies included people of various ethnical origins, most being Caucasian, African-American and Hispanic.<sup>19,23-26,28-31</sup></sup>



Figure 1. Results of search/strategy

There were two retail-provision intervention studies.<sup>32,37</sup> One looked at fruit and vegetable consumption of residents prior to and after the establishment of a supermarket in a poor-retail-access community. Another featured a community-based health promotion program; it assessed the association between perceived access to and consumption of fruits and vegetables at the start of the program, at its end and one year after program completion (Table 1).<sup>28</sup>

The rest of the studies were cross-sectional. All studies were quantitative in design with the exception of one by Dubowitz et al,<sup>23</sup> which was a qualitative study. Logistic or linear regression statistical analyses with adjustment for potential confounding variables were most commonly used in the quantitative studies. Three used different statistical methods, such as simple frequencies<sup>20</sup> and correlations (Table 1),<sup>21,22</sup> to address their research objectives. All studies clearly identified their objectives, defined their main outcome, and stated the main findings.

#### *Dietary and built environment measures* Dietary outcome

The majority of studies examined only fruit and vegetable intake as the indicator of dietary quality.<sup>10,11,19,20,26-29,32-34,36,37</sup>

First author (Year); country	Study sample	Dietary outcome (method of assessment)	Built environment feature or measure	Data analyses methods; Analyses adjusted for	Findings
Blitstein et al. (2012) ; USA <sup>27</sup>	495 adult men and women; majority were African Amer- ican (44.5%) or Hispanic (43%)	Fruit and vegetable index (Survey)	Perceived fresh fruit and veg- etable environment (estab- lishment where people shop for fruits and vegetables: su- permarket or farmers' mar- ket/co-op; satisfaction with the establishment; cost of fruits and vegetables).	Logistic regression; Age, sex, race / ethnicity; store type, cost of fruits and vegetables	Individuals who reported greater satisfaction with fruit and vegetable shopping options were more likely to eat three or more servings of fruits and vegetables per day. Individuals shopping for fruits and vegetables at farmers' market or at a local co-op were 2.8 more times more likely to report eating three or more serv- ings of fruits and vegetables per day. No association was found between per- ceived cost and intake of fruits and vegetables.
Bodor et al. (2008); USA <sup>19</sup>	102 adult men and women; majority of them were African Amer- ican (53.5%) followed by White (37.4%) individuals.	Fruit and vegetable intake (24 hour recall question- naire)	In-store fruit and vegetable availability (objectively measured linear shelf space) Access to supermarkets and small food stores (straight-line distances from household to each store; Geographic Infor- mation Systems (GIS). Neighbourhood fruit and veg- etable availability (sum of all the fruit and vegetable shelf space in all small food stores within 100 m of household residence).	Linear regression; Age, gender, ethnic- ity, income, food assistance participa- tion, car ownership. Neighbourhood food availability regression models were additionally adjusted for dis- tance to nearest supermarket.	Greater fresh vegetable availability within 100 m of a residence was positively associated with vegetable intake. No such association was observed for fruit intake. There was no significant association between access to supermarkets and fruit and vegetable intake. There was no significant difference in fruit and vege- table consumption between White and African American participants.
Bodor et al. (2010); USA Features two previously un- published New Orleans pilot projects <sup>20</sup>	Project 1: 219 low-income persons Project 2: 60 small-store customers and 12 small-store operators	Project 1: Food shopping practices and food prefer- ences (Food access and preferences survey). Project 2: Food shopping practices (customer intercept surveys); Feasibility of working with small food stores to increase the acces- sibility and promotion of fruits and vegetables and to reduce the accessibility and promotion of energy-dense foods and beverages (semi- structured interviews with small-store operators).	Projects 1 and 2: Access to supermarkets and small food stores. In-store fruit and vegetables (objectively measured linear shelf space).	Frequencies; N/A	Project 1: Out of surveyed low-income individuals, 67% reported living within walking distance of a small "corner" store and about 60% reported living more than 3 miles from a supermarket. Shopping at small stores (12 times per month) was far more frequent than shopping at supermarkets. The majority of participants reported higher preference for fruits and vegetables than for energy-dense foods. The majority would also be willing to buy fruits and vegetables from their local small store if these foods were available.Project 2: One of the main reasons participants shopped at small stores was proximity to their home. People were more likely to purchase foods that were highly stocked in small food stores (e.g., beverages, snack foods, candy, and prepared take-out food). Only 3% of customers at small stores reported buying fruits, while no customers reported purchasing vegetables. Owners and managers of small stores reported that low customer demand for fruits and vegetables was the main reason for not stocking them. Although receptive to the idea of increasing the stock of healthy foods, store owners expressed concerns about low demand and spoilage of those foods and the need for more cooler space. They also feared a major profit loss from not selling snack foods.

First author	Study sample	Dietary outcome	Built environment feature	Data analyses methods;	Findings
(Year); country Caldwell et al. (2008); USA <sup>28</sup>	266 men and women (7.5% younger than 18 years of age; White 92.6%);	(method of assessment) Change in consumption of fruits and vegetables in the past 7 days from program start to program end (self-administered question- naire); assessed at the start of the community based health promo- tion program, at program end and at 1-year follow-up.	Perceived access to fresh fruits and vegetables Objectively measured the amount of display space devoted to fruits and vegetables (produce), total varieties of produce available and the price of produce ("produce basket" and the minimum price for fresh produce); number of stores in community; freshness of produce; availability of organic produce.	Analyses adjusted for t-test; linear mixed modelling; nesting of participants within pro- grams, target popula- tion, sex, fruit and vege- table consumption at program start.	Greater perceived access to fruits and vegetables was associated with increased consumption of produce from program start to program end (but not at follow- up). Greater availability and variety of fresh fruits and vegetables, greater number of grocery stores in the community and availability of organic produce were all associated with increased consumption of fruits and vegetables from program start to program end (but not ats follow-up). Higher prices of fruits and vegetables was associated with their greater intake from program start to end and from program start to follow-up.
Cheadle et al. (1991); USA <sup>21</sup>	12 communities subdivided into 34 grocery store "market areas," defined by zip code boundaries	Diet (Telephone survey): percent- age of calories from fat and intake of saturated fat and dietary fibre; derived from the average number of days per week respondents ate red meat during their main meal; the proportion of people drinking reduced-fat milk, and the propor- tion of people eating whole-grain, pumpernickel, or rye bread the previous day.	Objective assessment of grocery store variables (grocery store survey): 1) Presence/absence of health educa- tion items (provide nutritional infor- mation or increased awareness of healthful food choices independent of those present on product packaging). 2) Shelf-space: the proportion of red meat, reduced-fat milk, and non-white bread in meat, milk, and bread dis- plays, respectively.	Correlation analyses at the community and zip code levels; N/A	There was a positive and statistically significant corre- lation between the availability of healthful (low-fat and high-fibre) products in stores and the reported consumption of healthful products by individuals liv- ing near those stores. No correlation was found be- tween measures of the amount of health-education materials provided by stores and the healthfulness of individual diets. Results were similar at both community and zip code levels.
Cheadle et al. (1993); USA <sup>22</sup> Follow-up data for Cheadle (1991) <sup>21</sup>	12 communities with about 500 adults per each community	Diet (Telephone survey): percent- age of calories from fat and intake of saturated fat and dietary fibre; derived from the average number of days per week respondents ate red meat during their main meal; the proportion of people drinking reduced-fat milk, and the propor- tion of people eating whole-grain, pumpernickel, or rye bread the previous day.	Objective assessment of grocery store variables (grocery store survey): 1) Presence/absence of health educa- tion items (provide nutritional infor- mation or increased awareness of healthful food choices independent of those present on product packaging). 2) shelf-space: the proportion of red meat, reduced-fat milk, and non-white bread in meat, milk, and bread dis- plays, respectively.	Correlation analyses at the community level; N/A	Compared to baseline assessment (Cheadle (1991) <sup>21</sup> ), consumption of red meat and dark or whole grain bread declined, whereas low fat milk consumption increased. There was a significant positive correlation between self-reported diet in a community and shelf-space measures of low-fat and high-fiber product availabil- ity, but correlations between changes at the individual and store level over the 2-year interval were not signif- icant.

First author (Year); country	Study sample	Dietary outcome (meth- od of assessment)	Built environment feature or measure	Data analyses methods; Analyses adjusted for	Findings
Cummins et al. (2005); Scotland	412 men and women aged 16 or over	Fruit and vegetable con- sumption (reported number of portions per day).	Improvement in local food shopping opportunities in most deprived communities (intervention: opening a superstore)	Logistic regression; Pre- intervention mean differ- ence between intervention and comparison areas, age, sex, education, em- ployment status	Establishing the large-scale food retailing in de- prived communities did not have an effect on fruit and vegetable consumption.
Dubowitz et al. (2007); USA <sup>23</sup>	44 US- and for- eign-born (Span- ish-speaking im- migrant) low- income women	Food purchasing and preparation (Focus group discussions).	Access to food stores, proximity to food purchasing places, proximity to fast-food and take-away restaurants in neighbour- hoods, obstacles to shopping such as transporta- tion and climate	Qualitative data analyses of key response themes; N/A - qualitative study	Challenges in transportation to food stores, restricted time for shopping, cooking and family activities were more likely to influence food purchasing and preparation compared to limited access to food pur- chasing points. Immigrant and United States-born women who live in the United States showed differing attitudes to- ward food purchasing and preparation.
Franco et al. (2009); USA <sup>24</sup>	759 adult men and women aged 45-84 years (Caucasian and African Amer- ican)	Two dietary patterns (Food frequency ques- tionnaire): low quality, and high quality.	Objectively assessed availability of healthy foods: 1) In the neighbourhood (census tract); 2) in the food store closest to home; and 3) in all of the food stores within 1 mile (1.6 km) of one's resi- dence.	Linear regression; Age, sex, income, education, race-ethnicity	Compared to Black study participants, White indi- viduals were more likely to live in a census tract with high healthy food availability, and to have healthy food available in the food store closest to home and in all the food stores within a one-mile radius of their home. However, the distance from home to the clos- est food store was significantly lower for Black par- ticipants. Lower availability of healthy foods in a participant's census tract or in the store closest to the residence was associated with the consumption of a poorer- quality diet. This association was no longer signifi- cant after adjustment for race-ethnicity.
Fuller et al. (2013); USA <sup>29</sup>	1266 adult men and women; pre- dominantly Afri- can American (86%)	Fruits and vegetable consumption (number of portions per day) (block food frequency ques- tionnaire).	Objectively measured road network distance (in km) to respondents' primary food stores.	Linear regression (bivari- ate)	Distance to a primary food store was not associated with residents' fruit and vegetable consumption.
Giskes et al. (2009); The Netherlands <sup>36</sup>	4333 adult men and women aged 23-85 years	Fruit and vegetable in- take (food frequency).	Perceived household environment (e.g. presence of fruit and vegetables in a household) and food shopping environment factors (neighbourhood availability of shops that carry fruits and vegeta- bles, ease of getting to shops that sell fruits and vegetables, quality and price of fruits and vegeta- bles sold in food stores).	Logistic regression; Age and gender	Odds of not eating fruits and vegetables were higher among individuals who reported no shops or difficul- ty to get to the shops in the neighbourhood that sell fruits and vegetables.

First author (Year); coun- try	Study sam- ple	Dietary outcome (method of assessment)	Built environment feature or measure	Data analyses methods; Analyses adjusted for	Findings
Inglis et al. (2008); Aus- tralia <sup>35</sup>	1580 women of working age (18-65 years) from high, mid, and low socioeco- nomic positions	Fruit, vegetable, and fast food con- sumption (Survey)	Perceived physical environment factors: 1) food availability (e.g. doing most of the shopping at stores in a local neighbourhood), 2) accessibil- ity (difficulty to get to or from a food store, having a food store within walking distance, the time needed to get from home to a food store) and 3) affordability.	Logistic regression; medi- ating analyses (variables that mediate association between socioeconomic position and diet); Food availability, accessibility and affordability, and marital status	Women who reported having fresh produce and healthy dine out options available locally were more likely to have high levels of fruit and vegetable con- sumption. On the other hand, the inability to afford healthy foods was negatively associated with fruit and vegetable consumption. Furthermore, having plenty of healthy eating-out options in the local neighbourhood was negatively associated with fre- quent fast food consumption. Food availability, accessibility and affordability were found to mediate the association between individuals' socioeconomic position and their diet.
Laraia et al. (2004); USA <sup>9</sup>	918 low- to middle- income pregnant women	Diet quality (Tertiles of diet quality index for pregnancy (DQI-P) (Food Frequency Questionnaire)	Objectively measured (GIS) access to food stores (supermarkets, grocery stores, and con- venience stores): 1) density of food stores within a census block group and within 0.5 miles of each woman; 2) distance from the closest food store.	Logistic regression; Age, race, income, education, marital status; analyses with supermarkets were additionally adjusted for distance to grocery and convenience stores	Greater distance to supermarkets and convenience stores was associated with a lower diet quality of pregnant women. The odds of falling into the lowest compared to the highest tertile of DQI-P were more than two times higher for women living more than 4 miles compared to the ones living within 2 miles of a supermarket. There was no association found be- tween density of food stores and diet quality.
Lucan et al. (2012); USA <sup>30</sup>	10450 adult men and women ; Asian (6.9%), Black (21.4%), Hispanic (4.8%), Oth- er (5.5%), White (61.4%)	Fruit and vegetable consumption (number of servings per day); Fast-food consumption (number of times people ate food from a fast- food restaurant in the past seven days) (Survey)	Perceived food environment (availability of fruits and vegetables in the neighbourhood; accessibility to a supermarket in the neighbour- hood; quality of groceries in neighbourhood stores).	Multi-level modelling; Individual-level socio- demograhics (age, race, ethnicity, gender, educa- tion, income, household cohabitants) and neigh- bourhood sociodemo- graphics (medina age, % male, % White, % His- panic, % not graduating high school, % in poverty, % households with more than one adult, any chil- dren, ad any older adults)	Perceiving difficulty finding fruits and vegetables, the need to travel outside of the neighbourhood to get to a supermarket, and poor perceived grocery quality were associated with greater fast-food consumption. There was no association between perceived food environment and fruit and vegetable consumption.
Moore et al. (2008); USA <sup>7</sup>	2384 adult men and women aged 45-84 years	The Alternate Healthy Eating Index (AHEI) and the "fats and processed meats" (FPM) dietary pattern score (via a self-administered, modified- Block style questionnaire) A healthy diet was defined as scor- ing within the top quintile of the AHEI and within the bottom quin- tile of the FPM dietary pattern.	<ol> <li>Objectively measured density of supermarkets within 1 mile of participants' homes (GIS);</li> <li>Perceived (participant-reported) availability of healthy foods in their neighbourhoods;</li> <li>Perceived availability of healthy foods - aggregated perceptions of non-study participants (independent informants) residing in the same neighbourhood as study participants.</li> </ol>	Binomial regression; Age, sex, race/ethnicity, and continuous annual per capita household income. Additional adjustment for education did not impact the results.	Compared to participants who had the highest num- ber of stores within 1 mile of their home, participants with no supermarkets near their home were 25% and 46% less likely to have a healthy diet as measured by AHEI and FPM respectively. Participants living in neighbourhoods with the worst-ranked availability of healthy foods (as reported by participants or by inde- pendent informants) were less likely to have healthy diet than those living in the neighbourhoods with best-ranked availability.

Table 1.	. Study	characteristics	and findings	(cont.)
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First author (Year); country	Study sample	Dietary outcome (method of assessment)	Built Environment feature or measure	Data analyses methods; Analyses adjusted for	Findings
Moore et al. (2009); USA <sup>31</sup>	5633 adult men and women (non- Hispanic White 40.4%, non- Hispanic Black 25.6%, Hispanic 21.4%, Chinese 12.6%)	The Alternate Healthy Eating Index (AHEI) and the "fats and processed meats" (FPM) dietary pattern score (via a self- administered, modified- Block style question- naire). Fast-food consumption (frequency of eating	Perceived opportunities to purchase fast food in the neighbourhood (1 mile radius around home); informant-based measures of neighbourhood exposure to fast food (aggregated survey responses from neigh- bouring study participants); objectively- measured density of fast-food restaurants within a 1-mile buffer of the residence (GIS).	Logistic regression; Study site, age, sex, race/ethnicity, educa- tion, income.	Compared to individuals who lived in areas with lower perceived opportunities to purchase fast food in the neighbourhood, those who lived in areas with higher perceived exposure to fast food had 27 % (self-reported exposure) and 61% (informant-reported exposure) higher odds of consuming fast food. Only in one site out of the 6 was the density of fast food outlets positively associated with fast food con- sumption.
		meals from fast-food restaurants located within one mile of home). A healthy diet was de- fined as scoring within the top quintile of the AHEI and within the bottom quintile of the FPM dietary pattern.			Higher exposure to fast food as reported by informants was associated with a decrease in healthy diet as meas- ured by AHEI. No association was found between per- ceived opportunities to purchase fast food in the neigh- bourhood or the density of fast food outlets and AHEI scores. Higher perceived individual and informant-reported opportunities to purchase fast food in the neighbour- hood and higher density of fast food outlets were asso- ciated with decrease in healthy diet as measured by FPM.
Morland et al. (2002); USA <sup>25</sup>	10623 adult men and women of Black and White American origin	Consumption of fruits, vegetables, total fat, satu- rated fat and cholesterol (A semi-quantitative Food Frequency Ques- tionnaire). A healthy diet defined as (a) at least 2 servings of fruit and at least 3 serv- ings of vegetables per day, (b) 30% or less of calories from total fat, (c) less than 10% of calories from saturated fat, and (d) 300 or fewer milli- grams of dietary choles- terol per day.	The number and types of food stores (supermarkets, grocery stores) and food service places (full-service restaurants, fastfood restaurants) located in the census tract where participants lived.	Random-effects log- linear modelling (mod- els stratified by race); Food stores and food service places other than ones that modelled, education, and income	Black Americans' fruit and vegetable intake increased by 32% for each additional supermarket in the census tract where they lived. Black Americans living in cen- sus tracts with supermarkets were more likely to meet dietary recommendations for total fat and saturated fat compared to counterparts living in census tracts with no supermarkets. Similarly, compared to Black Americans from census tracts without full-service restaurants, the ones living in census tracts with at least one full-service restaurant had healthier diets in terms of saturated fat. White Americans' fruit and vegetable intake increased by 11% with the presence of one or more supermarket. The presence of at least one supermarket was associat- ed with meeting the dietary recommendation for satu- rated fat; while the presence of fast-food restaurants was associated with a 12% increase in meeting fruit and vegetable recommendations.

First author (Year); country	Study sample	Dietary outcome (method of assessment)	Built environment feature or measure	Data analyses methods; Analyses adjusted for	Findings
Murakami et al. (2009); Japan <sup>6</sup>	990 Female dietet- ics students aged 18-22 years	Dietary habits during the preceding month (intake of meat, fish, fruit and vegetables, confectionar- ies, bread, and rice) (Self-administered Diet- History Questionnaire).	Neighbourhood food-store availability- the number of food stores within approximately $1 \text{ km} \times 1 \text{ km}$ square i.e. 1-km mesh-block of residence.	Linear regression; Survey year, household socioeconomic vari- ables (institution type and living status), frequency of eating out, geographical variables (region and municipality level)	Neighbourhood store availability for confec- tioneries and bread was independently and positively associated with the intake of these products. The association between neighbour- hood store availability for the other foods (meat, fish, fruit, vegetables, rice) and intake of each food was not significant.
Pearce et al. (2008); New Zealand <sup>33</sup>	12529 adult men and women	Consumption of fruit and vegetables as recom- mended (two servings of fruit per day, and three servings of vegetables). Data were collected as part of New Zealand Health Survey.	Objectively measured access to supermar- kets and convenience stores along the road network (GIS) in the neighbourhood (popu- lation weighted centroid).	Logistic regression; Age, sex, socioeconomic variables (edu- cation, social class, benefits receipt, employment status, and household income), area depri- vation, urban area classification	Individuals with the best access to convenience stores had 25% lower odds of consuming the recommended daily intake of vegetables com- pared to individuals with the worst access. No association was found between neighbourhood access to supermarkets and eating vegetables as recommended. Similarly, there was no associa- tion between neighbourhood access to super- markets or convenience stores and the con- sumption of fruit.
Pearce et al. (2009); New Zealand <sup>34</sup>	12529 adult men and women	Consumption of fruit and vegetables as recom- mended (two servings of fruit per day, and three servings of vegetables). Data were collected as part of New Zealand Health Survey.	Objectively measured fast-food retail ac- cess (travel distance to the closest fast-food outlet: multinational and locally operated) (GIS).	Logistic regression; Design variables (ethnic composition of a meshblock, deciles of number of respondents in the mesh- block, number of adults in the household and ethnicity), age, sex, socioeconomic variables (education, social class, benefits receipt, employment status, and household income), area depri- vation, urban area classification	Compared to neighbourhoods with best access to multinational fast-food outlets, neighbour- hoods with poorer access to multinational fast- food outlets than the national median had 17% higher odds of eating vegetables as recom- mended. However, no association was found between access to locally-operated fast food outlets and vegetable intake. There was no association between access to fast-food outlets and the consumption of the recommended daily intake of fruits.
Pearson et al. (2005); UK <sup>10</sup>	426 adult men and women	Fruit and vegetable con- sumption (number of portions per say) (24- hour recall question- naire).	Access to supermarket (road travel distance from participant's home to the nearest su- permarket).	Generalised linear regression modelling; Distance to nearest supermarket, age, sex, potential difficulties with grocery shop- ping, fruit and vegetable price and deprivation.	Distance to the nearest supermarket was not significantly associated with either fruit or vegetable consumption.

First author (Year); country	Study sample	Dietary outcome (method of assessment)	Built environment feature or measure	Data analyses methods; Analyses adjusted for	Findings
Rose et al. (2004); USA <sup>11</sup>	963 men and women from low-income households who are participants of Food Stamp Program	Reported household fruit vegetable use (used from the home food supply; grams per adult male equivalent per day).	Self-reported access to a food store: -distance to store (1-5 miles vs. >5 miles); -difficulty of supermarket access (little, mod- erate, and easy).	Linear regression; Urbanization, household income, household size, single parent status, em- ployment status, race/ethnicity, schooling	People living more than 5 miles away from their principal food store consumed 62 grams per adult male equivalent per day less fruit compared to those living within a mile of the food store. Easy access to supermarket shopping was associated with increased household use of fruit but not of vegetables.
Wrigley et al. (2003); UK <sup>32</sup>	615 men and women living in a poor-retail- access commu- nity ('food de- sert')	Fruit and vegetable con- sumption (portions per person per day) (Survey)	Retail-provision intervention: building a su- permarket, i.e., improving physical access to high-quality "healthy foods" in a poor-retail- access community.	Linear regression; Pre- intervention fruit and vegetable consumption, switching to a new store in the post-intervention period, proximity to the new store, switching from limited- range or budget store in pre- intervention period, effect of household living in postcode sector, respondent quit smoking	Univariate models: Fruit and vegetable consump- tion increased among people who had the poorest diets in the pre-intervention period, people who switched to the new store from limited-range or budget stores, and those who lived within 750 m of the new store. Multivariate model: the above mentioned associa- tions remained significant, keeping the other fac- tors in the model constant.
Zenk et al. (2009); USA <sup>26</sup>	919 African- American, Lati- no, and non- Hispanic White adults	Daily servings of fruit and vegetables (Modified Block 98 semi- quantitative Food Fre- quency Questionnaire)	Food store availability (count of food stores located in the residential neighbourhood by type); Objectively measured supermarket proximity (street-network distance in miles from the centroid of the residential census block to the nearest supermarket) (GIS). Neighbourhood-0.5-mile Euclidean distance buffer from the centroid of the residential census block.	Linear regression; Socio- demographic characteristics (age, gender, household size, years of neighbourhood resi- dence, marital status, race/ethnicity, education, annual income, employment status, car ownership), and neighbourhood store availability and proximity	Presence of a large grocery store in the neighbour- hood was associated with 0.69 more daily fruit and vegetable servings. There was no association be- tween supermarket proximity and fruit and vegeta- ble consumption. Similar relationships between the food environ- ment and fruit and vegetable intake were noted for both African-Americans and whites. Compared to African-Americans, Latinos who had a large gro- cery store in their neighbourhood consumed 2.2 more servings of fruit and vegetables per day. In Latinos, compared to African-Americans, presence of convenience store was associated with 1.84

fewer servings of fruit and vegetables per day.

Several articles explored fruit and vegetable consumption along with the consumption of other foods and food components such as fast food,<sup>30,35</sup> meat, confectionaries, bread, rice,<sup>6</sup> total fat, saturated fat and cholesterol.<sup>25</sup> One study focused on food purchasing and preparation,<sup>23</sup> while others examined diet quality.<sup>7,21,22,24,31</sup> All the dietary data were self-reported and collected using various instruments (Table 1).

#### **Built environment measures**

Built environment measures varied across studies (Table 1). Of the 24 studies reviewed, seven studies made use of perceived environmental measures,<sup>11,23,27,28,30,35,36</sup> some used both perceived and objective environmental measures,<sup>7,31</sup> and the rest measured BE features of interest objectively (Table 1). Two BE intervention studies explored residents' diets prior to and after the opening of a supermarket in a poor-retail-access community.<sup>32,37</sup> The majority of studies focused on access to food stores (distance and/or density/availability).<sup>6,7,9-11,19,20,23,25,26,29,31,33-36</sup> Some studies additionally looked at neighbourhood availability of healthy foods<sup>7,24</sup> or shelf-space dedicated to fruits, vegetables<sup>19,20,28</sup> and other healthful products such as ones low in fat and high in fibre.<sup>21,22</sup>

Studies that measured access to food stores focused either on distance to stores (perceived<sup>11,23</sup> and objectivelymeasured<sup>10,19,26,29</sup>) or on the objectively-measured density/availability of food stores within a predefined geo-graphical area.<sup>6,7,25,28,31</sup> Some studies included both distance to and density of food stores, measured objectively<sup>9,26</sup> or as reported by study participants.<sup>35,36</sup> Distances to food stores were measured using straight lines<sup>9,19</sup> or road networks.<sup>10,26,29,33,34</sup> Studies that explored the density/availability of food stores used various types of area measurements. For example, one study explored the density of food stores within a census block and a 0.5-mile (0.8 km) radius of each study participant,<sup>9</sup> while others focused on food store density within 1 mile (1.6 km) of a participant's home.<sup>7,31</sup> Other studies used census tracts,<sup>25</sup> one-square-kilometre areas surrounding participant residences,<sup>6</sup> 0.5-mile Euclidean-distance buffers from the centroid of residential census blocks<sup>26</sup> and suburbs in which participants resided<sup>35</sup> as ways to define areas in which to explore the availability of food stores and/or food service places. Among studies that explored neighbourhood availability of foods (including healthy foods<sup>7,24</sup> or fast food<sup>31</sup>), some defined area both by census tracts and 1-mile (1.6 km) radii surrounding individual residences<sup>24</sup>, and others by radii alone<sup>7,31</sup>.

# Associations between the built environment and dietary intake

Both dietary and BE measures varied across studies. The most commonly researched dietary outcome was consumption of fruits and vegetables alone<sup>10,11,19,20,26-29,32-34</sup> or in combination with other food items.<sup>6,25,30,35</sup> Across studies, the association between consumption of fruits and vegetables and BE measures was not consistent. While some reported no significant association between the neighbourhood food-store availability of fruits and vegetables and their intake,<sup>6,30</sup> others found that a greater local availability of fresh produce and healthy food options was associated with greater odds of fruit and/or vegetables

consumption.<sup>19,35</sup> Similarly, individuals who reported shopping for fruits and vegetables at a local co-op or farmers' market rather than a supermarket were about 3 times more likely to eat three or more servings of fruits and vegetables per day.<sup>27</sup> One study found that living closer to a food store was associated with a greater consumption of fruit,<sup>11</sup> while another observed that objective-ly measured distance to a primary food store was not associated with residents' fruit and vegetable consumption.<sup>29</sup> Yet other findings show that people were less like-ly to consume fruit and vegetables if they reported a lack of neighbourhood shops or difficulty getting to shops that sell fruit and vegetables.<sup>36</sup> Finally, no association was found between the perceived cost of fruits and vegetables and their intake.<sup>27</sup>

People living in neighbourhoods with high access to convenience stores had 25% lower odds of meeting vegetable recommendations compared to their counterparts living in neighbourhoods with the lowest conveniencestore access.<sup>33</sup> Low-income individuals were more likely to shop at corner stores that were within walking distance. Even though these individuals reported a higher preference for fruits and vegetables than for energy-dense foods, they were more likely to purchase energy-dense foods (snack foods, candy, prepared take-out food and beverages) as these were highly stocked in the corner stores.<sup>19,20</sup>

Several studies used presence and/or access to a supermarket as a measure of the BE. Four studies found no significant association between access to supermarkets and fruit and vegetable intake,<sup>10,19,26,33</sup> one found a positive association with household use of fruit but not vegetables,<sup>11</sup> and another study found that the presence of supermarkets was associated with greater fruit and vegetable intake among both Black and White Americans.<sup>25</sup> Two studies explored consumption of fruit and vegetables before and after the establishment of a supermarket.<sup>32,37</sup> In one study, the opening a large-scale store in deprived communities did not increase fruit and vegetable consumption.<sup>37</sup> In contrast, the opening of a superstore in a poor-retail-access community resulted in increased consumption of fruit and vegetables among people with poor diets who had previously shopped at local convenience stores and now lived within walking distance of the new store.32

In addition to the above-mentioned study that explored the association between diet and the BE among Black and White Americans,<sup>25</sup> one other study researched differences between individuals of different ethnic backgrounds.<sup>26</sup> They found that among Latinos, the presence of a large grocery store in the neighbourhood was associated with 2.2 more servings of fruit and vegetables per day compared to individuals of African-American origin.<sup>26</sup> Furthermore, the presence of a convenience store in the neighbourhood was associated with 1.84 fewer servings of fruit and vegetables per day in Latinos compared to African-Americans, while no significant differences were noted for African-Americans and Whites.<sup>26</sup>

In addition to fruits and vegetables, some studies explored other products such as confectioneries, bread, meat, rice, fish<sup>6</sup> or healthful products that are low in fat and high in fibre.<sup>21,22</sup> It was noted that higher availability of confectioneries and bread in neighbourhood food stores was associated with a greater intake of these products.<sup>6</sup>

However, the same authors did not find a significant association between the intake of meat, fish and rice and their availability in neighbourhood food stores.<sup>6</sup> Furthermore, greater grocery store availability of healthful (low-fat and high-fibre) products was found to be associated with greater consumption of these products among people living near the grocery store.<sup>21,22</sup>

Three studies tackled fast food consumption. The first study found that having plenty of healthy dine-out options in the neighbourhood was associated with lower odds of being a frequent fast-food consumer.<sup>35</sup> In the second study, individuals with perceived difficulty in finding fruits and vegetables, those who had to travel outside the neighbourhood to get to a supermarket, and those who perceived that local grocery quality was poor consumed more fast food than counterparts with more positive perceptions of the food environment.<sup>30</sup> A third study showed that higher perceived opportunities for fast-food purchases in a neighbourhood were associated with higher fast-food consumption.<sup>31</sup>

In a few studies, diet was presented as a contrast between low and high quality<sup>24</sup> or was depicted by indices and scores.<sup>7,9,31</sup> These studies found that, among pregnant women<sup>9</sup> and adults aged 45 to 84 years,<sup>7</sup> greater proximity to supermarkets was associated with better diet quality. No association was found between density of food stores and diet quality among a sample of pregnant women.<sup>5</sup> People living in neighbourhoods with highest-ranked food availability more often had a healthy diet compared to counterparts living in neighbourhoods with the worstranked availability of healthy foods.<sup>7</sup> Furthermore, lower availability of healthy foods in stores closest to home was associated with poorer quality of diet;<sup>24</sup> the association was, however, no longer significant after adjustment for race/ethnicity. In addition, higher perceived opportunities to purchase fast food in the neighbourhood were associated with decrease in healthy diet.<sup>31</sup>

#### DISCUSSION

The main objective of this paper was to examine the relationship between BE features and people's dietary intake. Our study reviewed available literature by searching the MEDLINE electronic database of studies published in the past 13 years. Of the 24 studies that met the eligibility criteria, 21 studies (88%) showed a significant association between diet and some aspect of the BE. The majority of studies (over 70%) explored fruit and vegetable consumption either alone or in combination with other foods.<sup>6,10,11,19,20,25-30,32-37</sup> Furthermore, most of the studies (15 out of 24) researched access to food, <sup>6,7,9-11,19,20,23,25</sup>, <sup>26,30,33-36</sup> and more than 65% of studies researched supermarkets as BE features, alone<sup>10,32,37</sup> or in combination with other features.<sup>6,7,9,11,19,20,25-27,30,33</sup> Although some studies included ethnically diverse populations, 19,23-31 only two studies explored the association between the BE and diet across ethnic groups.25,26

Although a majority of studies found a significant association between diet and some aspect of the BE, the results were not consistent across studies. A number of factors in study methodology may have contributed to the inconsistency of study results. Firstly, access to food stores was explored in relation to people's places of residence. However, shops close to people's work places should also be considered, as they may be accessible. In fact, this gap in connecting residents' shopping patterns to a neighbourhood's local food environment may, in part, be responsible for the limited associations reported in these studies. Indeed, we have recently shown that residents did not necessarily shop in their immediate neighbourhoods but rather in supermarkets that were more than 1km away from their residence.<sup>38</sup>

Secondly, a number of studies examined food environments by counting the number of supermarkets in the areas in which study participants lived.<sup>6,9,25,26</sup> This approach relies on the assumption that only supermarkets offer healthy food and that the availability and quality of food offered by supermarkets does not vary across neighbourhoods. In reality, supermarkets carry a variety of food outside of what is considered healthy: they also have large stocks of creamy, salty and sugary snacks, processed food and sugar-sweetened beverages. On the other hand, shopping from convenience stores may also not always result in the purchase of unhealthy items. Future studies should therefore also focus on what customers are actually purchasing from food stores. Thirdly, all dietary behaviour data were self-reported and based on participants' abilities to accurately recall, describe and quantify their food consumption, which has the potential to introduce recall bias. The way that diet was assessed also varied between studies; the development and consistent use of standardized dietary tools and measures would improve researchers' abilities to compare studies across locations.

Comparing results across studies was also challenging since BE features of interest varied among studies, as did the geographical area of measurement (the neighbourhood) in which the data were obtained. For instance, some researchers defined a neighbourhood as a census tract,<sup>24</sup> a 0.5-mile radius around each study participant<sup>9</sup> or a 1-square-kilometre area surrounding a participant's home.<sup>6</sup> To further limit comparability, BE features were assessed using perceived as well as objective measures, each of which captures different environmental constructs.<sup>39</sup> Although some studies included both measures, 9,26,31 they weren't compared to show which had a stronger association with diet. Lastly, almost all studies were cross-sectional, making conclusions about direction and the possible causality of associations between food-store access and dietary intake impossible.

Future studies that address the above methodological issues are needed to help unravel the complex relationship between the BE and dietary behaviours. Studies should also examine options that may help encourage the stocking of healthy foods in neighbourhood stores. For example, although participants in one study reported a preference for buying fruits and vegetables over energy-dense foods, the high availability of unhealthy food in the closest food stores encouraged them to buy less-healthy food.<sup>20</sup> In-store food stock is the responsibility of food store owners, yet only one study surveyed owners and managers.<sup>20</sup> In this study, food store owners were receptive to the idea of increasing stocks of healthy foods if they were profitable. However, they were concerned that their profits would decrease due to low demand for and frequent spoilage of fruits and vegetables, due to the cost of increasing cooler space for perishable foods and because of reduced sales of highly profitable snacks and sodas.<sup>20</sup> Lower demand for healthier foods may potentially be associated with the costs of fruits and vegetables compared to those of snacks and sodas. Namely, individuals who reported not being able to afford healthy foods were less likely to consume them.<sup>35</sup> Consequently, improving the affordability of healthy foods may result in higher demand, which will in turn motivate owners and managers to stock more produce in their stores.

One limitation of our study is that our literature search was limited to a single database. Searches of additional databases might have identified a larger number of articles on the association between BE and diet. However, we also searched the references of each of the articles identified through MEDLINE, and those that met the inclusion criteria were included in the review. Despite the limitations, this study covers the breadth of knowledge in the area of BE and diet, and it identifies significant methodological challenges to research in this area.

#### Conclusion

In conclusion, the majority of studies in the above summary featured a statistically significant relationship between diet and some aspect of the BE, but the results across studies were not consistent. These inconsistencies may be attributable to methodological challenges, including differing definitions of neighbourhood, and inconsistent approaches to measuring BE features and diet. In order to explore the complex relationship between the BE and people's dietary behaviours, research design needs to be streamlined and people's actual purchases need to be examined. Furthermore, additional research is needed to explore BE and diet among low-income populations and diverse ethnic and immigrant groups. Finally, longitudinal studies are needed to investigate causal pathways linking environmental factors and peoples' dietary behaviours. A deeper understanding of the impact of the BE on people's dietary choices may provide information necessary to develop successful community-based prevention efforts.

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#### AUTHOR DISCLOSURES

We have no relevant interests to disclose.

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# Review

# The association between the built environment and dietary intake - a systematic review

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# 居住环境与膳食摄入之间的联系:一篇系统性综述

我们对居住环境和饮食的相关文献进行了整理和研究。文献主要从 MEDLINE 电子数据库获得。我们收录文献的条件是 2000-2013 年发表的英 文文章,调查人群年龄为 18 岁以上。结果有 24 篇文章符合要求。多数文献 (70%)是研究蔬菜和水果的消费情况,大部分文献(88%)的研究都认为饮食和 居住环境的某一方面有关联。然而各个研究的结果却并不一致。或许是由于 采用了不同的研究方法,包括对邻里的定义不同,以及对居住环境饮食特征 的测定不同。为了更加深入了解居住环境和人们饮食习惯的复杂关系,研究 设计应当有所改进,并将人们实际购买的物品归入研究范围。此外,也应该 对环境因素和食物摄入的因果关系加以研究。

关键词:居住环境、邻里、饮食、营养、综述