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The local food environment and diet: A systematic review

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Abstract

Despite growing attention to the problem of obesogenic environments, there has not been a comprehensive review evaluating the food environment-diet relationship. This study aims to evaluate this relationship in the current literature, focusing specifically on the method of exposure assessment (GIS, survey, or store audit). This study also explores 5 dimensions of “food access” (availability, accessibility, affordability, accommodation, acceptability) using a conceptual definition proposed by Penchansky and Thomas (1981). Articles were retrieved through a systematic keyword search in Web of Science and supplemented by the reference lists of included studies. Thirty-eight studies were reviewed and categorized by the exposure assessment method and the conceptual dimensions of access it captured. GIS-based measures were the most common measures, but were less consistently associated with diet than other measures. Few studies examined dimensions of affordability, accommodation, and acceptability. Because GIS-based measures on their own may not capture important non-geographic dimensions of access, a set of recommendations for future researchers is outlined.

Keywords

Food environment; diet; measurement; GIS; survey; store audit

Introduction

The body of literature on the local food environment and its effects on health has been growing, particularly in response to evidence of “food deserts” pocketing the U.S. urban landscape (Michimi and Wimberly, 2010; Zenk et al., 2005). Yet, to date, there has not been a comprehensive review of the relationship between the local food environment and dietary outcomes. Previous food environment review articles have generally fallen into two categories. First, review articles have focused their discussion on disparities in access to healthy foods, including the existence of food deserts and neighborhood characteristics associated with food deserts (Larson et al., 2009; Walker et al., 2010). Other articles exploring the effects of food deserts have touched upon diet while focusing primarily on obesity as an outcome (Black and Macinko, 2008; Casagrande et al., 2009; Ford and

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Dzewaltowski, 2008; Holsten, 2009; Lovasi et al., 2009). For the most part, these reviews present comprehensive and theoretically sound discussions of the environmental determinants of obesity. Yet there has been relatively little discussion specifically devoted to what is conceivably the primary mechanism through which “obesogenic” settings operate – namely, the food environment-diet relationship.

Studies exploring the food environment-diet relationship have used a wide variety of methodologies to measure the degree of food access for study participants. In the past two decades, the increased use of Geographic Information Systems (GIS) technology has resulted in an outpouring of exposure assessment techniques (McKinnon et al., 2009). These measures commonly use store density (using buffer distances), or proximity to the nearest food store to operationalize food access (Charreire et al., 2010), although finding appropriate and consistent criteria for defining geographic boundaries has proved challenging (Charreire et al., 2010). Another common objective method for assessing food access is store audits, in which researchers visit stores and estimate the shelf-space occupied by certain foods in each store, or assess product variety or food prices within stores. Validated store audit measures, such as the Nutrition Environment Measure Survey (NEMS), have often been used to evaluate such store features (Glanz et al., 2007), although such measures have been used infrequently in studies linking food environments to health outcomes.

Still others studies have relied on respondent-based perceived measures to capture the food environment, including perceived availability and accessibility of food or food stores. Though uncommon, a few studies have used both a perceived and an objective measure in their study – for example, the availability of healthy food in the neighborhood and store density. In general, the proportion of studies using perceived measures of the food environment is small compared with those that use GIS-based methods; by 2007, GIS-based measures of the food environment outnumbered interview/questionnaire measures 57 to 10 (McKinnon et al., 2009), and the use of GIS measures is only likely to increase if current trends continue (Charreire et al., 2010). Undoubtedly, because of extensive variation in the operationalization of the local food environment, many measurement challenges remain unaddressed (Lytle, 2009) (Figure 1).

Despite major measurement inconsistencies, previous review articles have yet to examine comprehensively how the food environment-diet study results have differed according to the method of exposure assessment. One previous review article sorted results by exposure assessment type, but examined only the fast food environment (Fraser et al., 2010). A recent set of two reviews sought to overview different indicators of the food environment, but one included only GIS-based measures (Charreire et al., 2010); the other examined only non-geographic measures and stopped short of linking the different exposure measures to actual dietary outcomes (Kelly et al., 2011).

A theoretical framework for conceptualizing the local food environment

Beyond the strictly methodological task of selecting the best exposure assessment technique lies a more theoretical question concerning the very definition of food access. Frequently, food environment conceptualizations have been divided into the *community food environment* and the *consumer food environment* (Glanz et al., 2005), drawing a useful distinction between the distribution of food sources within a community and what consumers encounter while inside their local retailers. Several previous articles have also begun to explore even more subtle conceptualizations of the food environment (Charreire et al., 2010; McKinnon et al., 2009), including the different *dimensions* of access that food environment measures have actually tapped into. Although a complete list of such dimensions has never been compiled, it has been suggested (Charreire et al., 2010) that one way of conceptualizing food access dimensions is by adapting a model of access proposed

by Penchansky and Thomas, who outlined 5 dimensions relevant in the healthcare setting (Penchansky and Thomas, 1981). These dimensions include availability, accessibility, affordability, acceptability, and accommodation.

The first three are the most obviously familiar in the existing body of literature. *Availability* refers to the adequacy of the supply of healthy food; examples in the food environment might include the presence of certain types of restaurants near people's homes, or the number of places to buy produce. The dimension of *accessibility* may be more inherently geographic, as it refers to the location of the food supply and ease of getting to that location. Travel time and distance are key measures of accessibility. *Affordability* refers to food prices and people's perceptions of worth relative to the cost, and is often measured by store audits of specific foods, or regional price indices. *Acceptability* refers to people's attitudes about attributes of their local food environment, and whether or not the given supply of products meets their personal standards. As an attitudinal variable, it may be ideally measured by surveying participants; however, there have been a few creative attempts to estimate food acceptability by more objective means – for instance, by having store auditors assign food quality scores to produce. *Accommodation*, or how well local food sources accept and adapt to local residents' needs, is the final dimension of access. It is largely open to exploration in the current literature but could, for example, refer to store hours and types of payment accepted.

The primary aim of this paper is to evaluate the existing body of literature on the relationship between the local food environment and diet, with particular attention placed on the method of characterizing of the food environment. The secondary aim of this study is to explore the variety of conceptual definitions of “food access” within this body of literature. The relationship between food environments and diet will be dived according to different quantitative assessments of the food environment, as well as the different dimensions of access that could underlie each measure. Finally, this paper will identify understudied dimensions of “food access,” and make recommendations for future directions for the optimal study and improvement of food environments.

Methods

This paper is a review of 38 papers on the food environment and diet. Articles were retrieved through a systematic keyword search in Web of Science and supplemented via a “snowball method” in which references from relevant articles were reviewed and selected if they met inclusion criteria. Keyword searches included words pertaining to diet (diet*, fruit* and vegetable*, nutrition*, consumption, intake) and at least one other term pertaining to access (access*, availability, affordability, acceptability, accommodation), environment (neighborhood, neighbourhood, environment, community, urban, local, disadvantage*), or food source (food desert*, food outlet*, food store*, grocery store*, supermarket*, convenience store*, fast food, restaurant*, takeaway, corner store*). Because this review focuses on food environments surrounding residences, exclusion search terms included school* and worksite*. The search included articles published through March 2011.

Articles were excluded for formal review if they were non-empirical, if they did not use a dietary outcome, if they did not report directly on the relationship between the food environment and diet, or if there were fewer than 100 participants.

In total, 380 abstracts were reviewed, of which 22 met the full inclusion criteria for this study. In addition, 16 articles cited in reference lists of relevant articles or brought to the attention of the authors in the process of writing the review were included. In cases where there were multiple studies reporting on the same results, only one paper was included (e.g.,

Murakami et al. 2009 was selected and another similar article from the subsequent year was excluded (Murakami et al., 2010)), although multiple studies of the same cohort were included if the exposure or outcome reported was different in the two papers. Results report only on the relationships between the food environment and dietary outcomes.

Results

In total, 38 studies met inclusion criteria and were included in this review (Table 1). Most studies examined an adult population, but seven (Beydoun et al., 2008; Beydoun et al., 2011; Caldwell et al., 2009; Jago et al., 2007; Leung et al., 2010; Powell and Han, 2011; Timperio et al., 2008) included children or adolescents. Studies overwhelmingly used a cross-sectional design, but three were natural experiments or interventions that compared pre- and post-test dietary measures (Caldwell et al., 2009; Cummins et al., 2005; Wrigley et al., 2003).

Overview of exposure assessment methods

The greatest variability in the set of included studies was the method of exposure assessment. Table 2 sorts these studies by assessment technique. More than two-thirds of the studies reviewed relied on at least some kind of geographic data to measure of exposure ($n = 26$). These GIS-based measures captured the geographic relationship between residents' homes and an array of food store types, including supermarkets, convenience stores, fast food outlets, and other types of stores. Twelve studies used participant-reported measures to assess a variety of dimension of food access, including perceived availability, perceived accessibility of food, perceived food store affordability, and perceived quality and selection of local foods. These measures of food access were commonly single- item indicators, but some studies used short scales which demonstrated moderate to high levels of reliability (Cronbach's α range 0.51 to 0.90) (Moore et al., 2008; Osypuk et al., 2009; Rose and Richards, 2004, 2004). Nine studies used a store audit measure – including the presence, price, and quality of fresh produce – to assess the relationship between store content and diet. Store audit measures were sometimes combined with GIS-based methodologies – for example, to assess the number of stores selling certain foods near participants' homes (Gustafson et al., 2011). Store audit measures were different in every study and only occasionally (Cheadle et al., 1991; Franco et al., 2009) use a measure with reported reliability.

Dimensions of access

Table 2 presents the *dimensions of access* captured by each exposure assessment methodology. Most survey questions related to food access looked at residents' perceptions of healthy food availability and store accessibility, although a handful of studies crossed into the domains of affordability, and acceptability (including quality and selection of produce). Store audits captured much of the spectrum of access dimensions – particularly affordability – but only one store audit study contained any kind of measure of accommodation. GIS-based measures assessed only constructs related to the availability and accessibility dimensions. Table 2 also depicts the degree to which these different dimensions of access were found to be associated with dietary outcomes.

Availability—Overall, measures which tapped in to the availability dimension showed fairly consistent positive associations with a healthy diet. Studies that used measures of *perceived* food availability were particularly consistent in showing a relationship with dietary outcomes (6/7 studies). No standardized measure of healthy food availability exists; rather, each study measured this construct according to a unique set of items – for example, agreement that “a large selection of low-fat foods is available in my neighborhood” (Moore, Diez Roux, Nettleton, et al. 2008; Osypuk et al. 2009).

Studies that used GIS-based methods to look at store presence or store density were mixed. These availability measures were by far the most common way to measure the food environment; they were used in 20 studies, 13 of which showed a significant association between geographic availability and dietary outcomes. Notably, there was a wide range of buffer distances used, ranging from 100 meters (Bodor et al., 2008) to 2 miles (Jeffery et al., 2006). Three studies did not use a buffer distance from residents' houses, but instead looked at the presence of stores within a census tract (Gustafson et al., 2011; Morland et al., 2002) or block group (Laraia et al., 2004), and several recent national studies used store density within a defined geographic area per 100,000 people as the geographic measure of interest (Michimi and Wimberly, 2010; Powell and Han, 2011; Powell et al., 2009).

The handful of studies that used store audit metrics of product availability and variety generally showed a relationship with healthier diets, while the construct of shelf-space devoted to foods showed an association in only one of two studies which it was measured.

Accessibility—Measures representing food accessibility demonstrated a remarkably inconsistent relationship with dietary outcomes. Of the 13 studies that examined distance to a food store in relation to diet, seven revealed null associations. Two of the remaining six studies showed associations in mixed directions. For instance, Timperio et al. (2008) found higher vegetable consumption among those who lived a farther from a fast food outlet, but also among those who lived farther from a supermarket. One of the four studies which showed an association between store distance and fruit and vegetable intake used a particularly sophisticated method of assessing distance which included actual produce content at the stores (Sharkey et al., 2010).

Survey questions pertaining to store accessibility also showed no significant relationship with dietary outcomes in 4 of 6 studies; in one of the remaining studies, store access was operationalized as a multi-faceted combination of variables, including car access, where participants shopped, and travel time (Rose and Richards, 2004).

Affordability—Affordability cannot be assessed by GIS-based measures, but was measured by three other methodologies: 1) an index of food prices in the area in which participants lived, 2) participants' perceptions of produce affordability, and 3) store auditors' accounts of food prices. Lower regional food prices were associated with at least one measure of dietary health in every study in which it was measured ($n = 4$), while the *perceived* produce affordability measure was inconsistently associated with diet. In one study, participants who reported that fruit cost too much unexpectedly consumed more fruit than those who reported that it did not cost too much (Inglis et al., 2008). Likewise, food audit affordability measures were resoundingly not predictive of healthier diets – in fact, two store audit studies showed that more *expensive* produce prices were associated with healthier diets.

Acceptability and accommodation—Only a handful of studies examined acceptability and accommodation; these studies generally showed a significant relationship between constructs such as food quality and hours open for local stores and fruit and vegetable consumption.

Overview of dietary outcome assessment methods

Studies used a range of assessment techniques (Table 3) to calculate an array of dietary outcomes, including fruit and vegetable intake, fast food consumption, diet quality indices, as well as specific foods, food groups, and nutrients. The use of validated semi-quantitative Food Frequency Questionnaires (FFQs) was common ($n = 11$ studies). By and large, FFQs

were the method of assessment of choice for those studies using a diet quality index as the outcome. These indices were generally well-established measures derived either from USDA guidelines (Laraia et al., 2004; Moore et al., 2008; Moore et al., 2009; Morland et al., 2002) or principal components analysis (Franco et al., 2009; Moore et al., 2008; Moore et al., 2009; Osypuk et al., 2009) and validated by association with health outcomes (Nettleton et al. 2006).

The most common dietary assessment technique was the use of custom brief instruments assessing consumption patterns of specific foods- either fruit and vegetable intake or fast food (n = 16 studies). While questions were often worded similarly to the FFQ, they asked about food groups rather than specific foods. Examples of this type of assessments included, “How many times in the last 7 days have you eaten meals at fast food restaurants?” (Inglis et al., 2008) or “How many servings of fruit do you usually eat each day?” (Thornton et al. 2010).

The Behavioral Risk Factor Surveillance System (BRFSS) Questionnaire for fruit and vegetable intake was a validated assessment tool used in three studies. This measure was related to other brief instruments, but asks a set of 6 questions related to the consumption of certain foods and food groups (fruit juice, other fruit, green salad, potatoes, carrots, and other vegetables). Other less common methods of dietary assessment were the 24 hour recall (n = 4 studies) and food diaries (n = 2 studies).

Table 3 presents the frequency of each dietary assessment method by the type of neighborhood exposure technique. By far the most common studies were those that used GIS-based neighborhood assessments to examine diet with a brief instrument or FFQ. There was substantial variability in the outcome assessment for survey-based studies, as well as those that used store audits and food prices. The oldest studies were most likely to use unusual dietary assessment methods – for instance, asking participants about whether they had a specific food at home (Fisher and Strogatz, 1999).

Results by dietary outcome

Fruit and vegetable intake (n = 26) was by far the most common outcome measure. In general, results from these studies (Tables 4a and 4b) are consistent with the trends in the findings described above. Twelve of the 18 studies using GIS measures and five of the eight studies using cross-sectional survey measures showed at least one significant positive association. While it is difficult to compare the magnitude of effects across studies given the variety of measurement strategies, those studies that used survey measures of the food environment consistently reported small but meaningful differences in fruit and vegetable consumption. For example, one study showed that those who reported shopping at a supermarket consumed, on average, 1.22 more servings per day of fruits and vegetables than those who did not, and in another study (Zenk et al., 2005), those who reported easy supermarket access consumed, on average, 86 more grams per day of fruit (approximately half a serving) than those who reported poorer access (Rose and Richards, 2004). Results for GIS-based measures were occasionally statistically significant but not clinically meaningful; for instance, in one study, a difference of one mile in distance to a supermarket was statistically significant, but only associated with a 0.02 difference in fruit and vegetable servings per day (Sharkey et al., 2010), and in another study, the effect size for distance to the nearest food store on fruit and vegetable consumption was not measurable ($\beta = 0.00$), but still statistically significant (Jago et al., 2007). Most store audit measures – including food prices, variety, shelf-space and price – were *not* found to be associated with fruit and vegetable intake, but availability of specific produce items and hours open at greengrocers were two notable exceptions (Thornton et al. 2010).

Beyond fruit and vegetable intake, eight studies examined fast food consumption, seven studies used a diet quality index as an outcome, and five looked at either food group consumption patterns (e.g., nonmeat protein) or consumption of specific foods (e.g., low-fat milk). Four studies used specific nutrients (e.g., saturated fat) or total energy as an outcome. The vast majority of studies within each category of outcomes showed some evidence of an association with food environment features. Notably, the evidence was the weakest for studies of fast food consumption, where 4 out of 8 were positive (Table 5).

Overview of results by country

Twenty-four studies were U.S.-based, of which 6 were national studies of the U.S.; the others examined selected U.S. regions. Eight studies were based in Australia or New Zealand, four in the United Kingdom, and 1 each from Canada and Japan. Studies outside the U.S., Australia and New Zealand demonstrated inconsistent evidence of an association between the food environment and dietary behavior. The Canadian and Japanese study showed null results, whereas in the U.K. results were mixed. Both of the natural experiments which explored the effects of opening a new supermarket were conducted in the U.K. (Table 4b). One natural experiment study showed no change in fruit and vegetable consumption between the intervention and control group (Cummins et al., 2005), and in the other, fruit and vegetable consumption was increased among residents who switched stores, lived closest to the new store, and had the lowest consumption at baseline, although there was no overall increase in fruit and vegetable consumption (Wrigley et al., 2003).

Discussion

Overview

This review of 38 studies of the food environment found moderate evidence in support of the causal hypothesis that neighborhood food environments influence dietary health. Yet, even though the number of studies on the subject is substantial, overall reproducibility was lacking because of the absence of an “industry standard” for measuring local food access.

Perceived measures of availability were consistently related to multiple healthy dietary outcomes. On the other hand, GIS-based measures of accessibility (primarily operationalized as distance to various food stores) were overwhelmingly unrelated to dietary outcomes. GIS-based availability measures – such as store presence and density – were somewhat more promising, although results were mixed; in general, the vast array of store types studied made it difficult to discern which, if any, true associations exist. Survey-based perceived measures of store accessibility were comparably weak and inconsistently operationalized.

Unexpectedly, more than one store audit study showed an association between higher fruit and vegetable costs and higher consumption (Caldwell et al. 2009; Thornton et al. 2010). However, neither of these studies controlled for area-level deprivation, which could conceivably be related to both store prices and individual fruit and vegetable intake. It is also possible that in these studies, the quality of the produce in the more expensive stores was substantially higher and, consequently, consumption of these more appealing foods was higher. Perceived affordability measures have turned up mixed results, perhaps because someone who buys very little produce might under-report prices because they do not have a good sense of what they cost. Measures of affordability based on regional price indices offer some promise of assistance in future studies.

Dietary outcomes and assessment measures varied substantially across studies. Yet it appears that studies with and without demonstrable validity of the outcome measure were equally dispersed between those that used GIS, survey methods, store audits, and other

techniques. The very oldest studies use instruments that could be deemed outlier instruments, (Cheadle et al., 1991; Fisher and Strogatz, 1999; Rose and Richards, 2004) but by and large, outcome assessment has been standardized in more recent studies. Overall, there was no comprehensible correlation between the quality of assessment method for the exposure and for the outcome.

Although fruit and vegetable intake was the most commonly studied outcome, a variety of dietary outcomes showed evidence of a meaningful association with food environment features, consistent with the notion that poor food environments may have cross-cutting effects on dietary behaviors. The evidence for fast food outlets and fast food consumption was the weakest, perhaps due to a relative ubiquity of fast food outlets compared to other food sources. Another possibility is that factors such as individual preference govern fast food-seeking behavior even more than either perceived or objective availability of fast food outlets. Perceived access to “healthy places to eat out” was associated with less likelihood of consuming fast food in one study (Inglis et al., 2008), supporting the idea that improving non-fast food options for eating out may be a promising approach.

It has been suggested in previous literature that countries outside the U.S., Australia, and New Zealand do not show the same kind of patterns in the existence of food deserts, (Cummins and Macintyre, 2002) perhaps because “food deserts” may take a different form in places without the economic segregation that commonly occurred in U.S.-based downtown areas in the second half of the 20th century (Walker et al., 2010). But beyond the question of the existence of food deserts in the international setting, the body of literature assessing the relationship between the food environment and diet is currently too small to make an adequate comparison between studies in the U.S. and outside the U.S. Only a total of six studies from outside the U.S. and Australia/ Zealand met criteria for inclusion in this review.

In reviewing the overall results of this study, it is also worthwhile to acknowledge that, in general, studies that show a positive relationship may be more likely to be published than those with null results. Because of this publication bias, almost all of the studies included in this review contained at least one significant positive relationship; it is, therefore, impossible to assess the true proportion of studies in which a positive association is found between a food environment feature and a dietary outcome. Nevertheless, nearly all of the studies tested multiple food access constructs and multiple outcomes; dicing the findings by exposure and outcome, as was done in this review, helps to discern which categories of associations may be the most robust.

Comparisons between GIS-based and perceived measures

Studies which relied on GIS-based measures were substantially more common than those using other measures, yet these studies – particularly distance-based studies – less consistently revealed a significant relationship between food environment features and dietary outcomes than other measures. One chief explanation for this pattern is that GIS-based measures on their own simply cannot capture non-geographic dimensions of access that are key factors in the food environment-diet relationship. These factors include produce affordability, food choice and acceptability, and store accommodation to local residents, all of which can be assessed by participant-report. The empirical assessment of these components of food access is still in its infancy, and currently, no gold standard exists for their measurement.

Even within the dimensions of availability and accessibility, GIS-based measures were surprisingly inconsistent in their relationship with dietary outcomes. There are several possible explanations for this. First, it is possible that the geographic boundaries that GIS

imposes are not always relevant to residents. Buffer distances, street network distances or other geographic domains such as zipcodes and census tracts serve only as a rough estimate of a resident's neighborhood. Calculating store densities within those areas may be more of an exercise in pushing the limits of GIS technology than a reflection of what a resident considers part of his neighborhood. Second, GIS-based measures are usually derived from secondary source data that is not ground-truthed, and such data may misrepresent true geographic access, either by including stores that are no longer open or by missing stores entirely (Liese et al., 2010). Third, it may be that other, primarily non-geographic, axes of food access are embedded in respondents' reports of food availability and accessibility in their neighborhoods. Although accessibility is primarily a geographic notion, in perceived measures it may legitimately include the safety of walking routes or the reliability of public transportation. Finally, it may be that same-source bias on survey measures accounts for much of the excess portion of the positive results found in perception-based studies. An array of individual tastes and cognitive processes may serve as unmeasured confounders in the findings of survey measures. Those who have an innate preference for unhealthy foods and those who feel a need to self-justify unhealthy food consumption may also under-report access to healthy foods.

Comparability between studies is made all the more challenging by the fact that different assessment techniques may inherently represent different underlying constructs. For example, accessibility measured by a survey might more accurately reflect public transit options, which is a truly different construct from distance to a store. The comparisons drawn between methods are, therefore, inevitably limited by these conceptual differences.

Recommendations—Refining the measures used to capture multiple dimensions of food access should be a top priority for researchers conducting studies on the food-environment diet relationship. Based on this review of 38 studies of the food environment, we make the following recommendations for future research:

1) Standardize and validate measures: The field is in need of more standardized measures for assessing the food environment. Studies using buffer distance-based measures only occasionally provided a rationale for the buffer distances they selected (Thornton et al., 2010; Timperio et al., 2008) and some researchers have noted the lack of criteria for determining suitable buffer distances (Jennings et al., 2011; Turrell and Giskes, 2008). As a first step in discussing appropriate buffer distance, it may be useful to examine the existing built environment literature to help determine how far people typically walk or drive to services in their neighborhood, in both urban and non-urban areas. Validated store audit measures, while promising, have only rarely reported psychometric properties, even though methods for applying psychometric terms to these environmental measures have been suggested (Lytle, 2009). Defining the proper methods for assessing *perceived* availability and accessibility dimensions should also be a top priority for those who wish to accurately depict the food environment, as these measures have been inconsistently measured across surveys.

Steps for establishing the validity of different environmental measures might include: a) specifying in advance the dimension of food environment one wishes to capture; b) specifying the dietary outcome of interest; c) specifying the theoretical relationship between exposure and outcome; d) establishing the convergent validity of the proposed measure against alternative measures of the environmental dimension, recognizing that there is currently no accepted “gold standard”.

It is also not enough to develop and validate exposure measures, but these measures must be considered in terms of their relevance to public health (Lytle, 2009). Many studies on the

food environment have discussed the characterization of the food environment, but more work should be done in linking these constructs to relevant public health outcomes. The proper measurement of dietary outcomes is particularly critical in the characterization of the food environment-health link. The brief instruments so commonly used to measure fruit and vegetable intake and fast food consumption have often not been validated, and the intelligent use of multiple dietary outcomes – for instance fruit and vegetable intake and a healthy eating index (Beydoun et al. 2008; Beydoun et al. 2011) – may begin to establish convergent validity of such measures.

2) Develop and refine understudied measures: Very few studies have so far examined acceptability measures, such as food quality, but in general, the studies that have show some promise. The availability of specialty foods that that might be in demand by residents may be a relevant concept, but it has so far only been explored in the literature in terms of organic food selection (Dibsdall et al. 2003, not reviewed). Yet accurately defining food acceptability might require moving well beyond quality and organics, and also examining constructs such as cultural relevance and food familiarity. Cultural relevance might be particularly salient in areas with larger immigrant populations, where survey questions might begin to explore whether the range of neighborhood food products appeals to residents or makes it easy to cook meals.

To date, there is almost no study looking at accommodation; notably, the one study that looked at the store hour for greengrocers found that the total number of hours open was associated with fruit consumption, and the number of hours a supermarket was open after 5:30pm was associated with vegetable consumption (Thornton et al. 2010). Time of day, day of the week, or accommodation to residents' schedules might be a particularly relevant concept for farmer's markets, which are increasingly providing a large supply of seasonal produce to neighborhoods, but tend to have extremely limited hours. Other relevant ways to assess accommodation might include whether the stores or markets accept EBT cards, or how well stores adapt to cultural food preferences or local residents' demands.

A final area for developing measures, directly related to food access but tremendously understudied, is the *utilization* of food stores by area residents. Almost all of the articles included in this study studied operate under the grand assumption that people use what is geographically proximate, or what in their neighborhood. Yet a study examining shopping behavior showed that low-income WIC recipients in urban areas only rarely shopped at the closest supermarket, and did much of their grocery shopping outside of their own neighborhood (Hillier et al., 2011). Where people ultimately decide to do their shopping likely depends on both individual factors such as car ownership and employment, as well as the “social distance” to stores, reflected by the larger socio-demographics of residents neighborhoods and the surrounding areas (Hillier et al., 2011). Careful analyses of the gap between potential access and realized access (Sharkey, 2009) is essential in accurately depicting the food environment.

3) Revamp the notion of accessibility: The current body of literature suggests that it may be time to abandon purely distance-based measures of accessibility. Store distance has remarkably consistently showed no association with diet across a variety of dietary outcomes. In their current form, the use of GIS-based measures of accessibility may not accurately reflect a the boundaries of participants' neighborhoods, nor do these measures take into account how easy or difficult it is for participants to get to stores that may be defined as accessible solely based on distance.

Current uses of GIS, however, may not represent the full potential of spatial measures of food access. Although distance and store presence are among the simplest and most

common GIS-based measures, more sophisticated spatial techniques exist, including kernel density estimation (a more precise density measures that gives more weight to closer features), estimates of walkability, and estimates of travel time by car that incorporate traffic density (Thornton et al., 2011). Such methods allow for a more multidimensional approach to mapping “accessibility”. Hence, the challenge in future research becomes pushing the current standards in GIS methodology past the one-dimensional, so that they reflect the most relevant features of geographic access.

Perceived physical access to stores has also turned up disappointing results with relation to diet (Gustafson et al., 2011; Inglis et al., 2008; Pearson et al., 2005; Williams et al., 2010). So far, the strongest association between perceived physical accessibility of stores and diet occurred in a measure of accessibility that included how long it took participants to travel to the store (Rose and Richards, 2004). To further refine measure perceived availability, surveys might include questions asking how people get to the store (not just if they own a car), how long it takes them, or other specific barriers to shopping. Furthermore, store audit tools might include less obvious components of accessibility – for instance, whether the surrounding area is pedestrian-friendly, the placement of food within stores, or – in the case of fast food outlets – whether there is a drive through (Glanz et al., 2005).

4) Pay attention to stores and food: Researchers might do well to acknowledge the distinction that has previously been made between the community food environment versus the consumer food environment (Glanz et al., 2005; Kelly et al., 2011). Essentially, this entails distinguishing the measurement of *stores* versus the measurement of *foods*. Neighborhood food environments likely cannot be accurately depicted without attention to both. Assessment of the actual food that stores are carrying seems an essential component, given the evidence from store audit studies (Thornton et al. 2010; Cheadle et al. 1991; Franco et al. 2009; Fisher & Strogatz 1999). Yet neighborhood store characteristics like size and price trends may play an important role in determining residents' food shopping patterns even beyond the food items they carry. Produce at supermarkets may not be comparable to produce at corner stores, as it may be fresher (Webber et al. 2010; Zenk et al. 2011) and cheaper (Chung and Myers, 1999).

It is, however, likely short-sighted to use store type alone as an indicator of food healthfulness. While researchers have generally labeled supermarkets a desirable feature of neighborhoods (Chung and Myers, 1999; Sallis et al., 1986), just as convenience stores are labeled detrimental (Pearce et al. 2008; Morland et al. 2006), on a practical level, it is easy to see why the expected associations with dietary health do not always hold. It is often challenging to draw a categorical distinction between convenience stores and small grocery stores. Supermarkets, of course, are comprised not only of the produce and fresh foods on the perimeter, but primarily of the packaged goods and sugar-sweetened beverages that line the isles. Hence, it may be overly simplistic to categorize certain stores as protective or detrimental to health. Ultimately, the characterization of food availability both at the store level and the neighborhood level will add much to the discussion of the food environment (Gustafson et al., 2011).

5) Combine methods: Given the complexities in defining the important features of food environments and the lack of association with many purely distance-based measures, perhaps the single most important strategy for future research is combining multiple environmental assessment techniques. Using an intelligent mix of store audit measures along with GIS-based methods would aid in providing an accurate characterization of neighborhood food environments. For example, two 2011 studies -Izumi et al. and Sharkey et al. – used GIS-based measures to define the geographic regions relevant to participants. They next examined all types of food stores within those geographic boundaries for their

merchandise and developed a metric – density or distance – of healthy foods in the neighborhood. Although the exposure assessment technique for these studies fall under the category of GIS-based measures, ultimately, both of these studies examined the relationship between food items and diet, not store types. Reliable store audit measures have been underused; for example, only two studies in the current review relied on the validated NEMS (Franco et al., 2009; Gustafson et al., 2011). This measure could easily be combined with GIS, or even street audits, which may be able to objectively capture features of the built environment relevant to access, like walkability in the areas surrounding stores.

It is easy to see the appeal of using GIS-based measures only, given the relative ease and cost of using them, the ability to quickly measure multiple exposures, and their avoidance of same-source bias issues. Though GIS measures are an indispensable tool for assessing geographic components of food environments, these measures should be used rigorously and only employed where the constructs they represented are theoretically relevant – that is, if they truly represent those things that can enable or hinder healthy consumption patterns. In many cases, this may mean supplementing broad geographic information with specific information that can be derived only from asking actual people what is in their neighborhood. Researchers have already begun to creatively integrate multiple methods for assessing food environments. The use of informant-report measures (Franco et al. 2009; Moore et al. 2009) for example, cleverly sidesteps the same-source bias challenge by aggregating the reports of others in the neighborhood besides the participant, although it still requires the time and effort of survey measures.

These studies, along with a handful of others that have used both GIS and perceived measures have produced nuanced analyses which are able to compare the relative merits of each type of measure (Moore, Diez Roux, Nettleton, et al. 2008; Williams et al. 2010; Moore et al. 2009; Gustafson et al. 2011; Sharkey et al. 2010). Indeed, perception-based measures have the unique advantage of being able to tap into residents' *intentions* to utilize nearby food outlets. And yet, these studies must consider the simultaneous measurement of (and statistical control for) people's food preferences in order to begin to make causal statements about food environment-diet relationships. These discussions of causality have begun to be explored in the built environment literature. In one study, Frank et al. (2007) measured the relationship between objective walkability and walking behavior, as well as people's preferences for living in a walkable neighborhood (Frank et al., 2007). This study elegantly showed not only that people with low preference for living in a walkable neighborhood walk less, but also that, after stratifying by personal preferences, those living in objectively less walkable neighborhoods end up walking less. Researchers have yet to demonstrate these principles for the local food environment.

6) Keep defining “food access”: Finally, researchers should to continue to expound upon the conceptual definitions of food access as they develop and refine new combinations of measure for the food environment. The five dimensions of access which frame the discussion in this review are not the only way to dice the weighty concept of “food access.” Models of community nutrition environments have previously put forth suggestions for constructs related to the food environment and outlined exogenous influences on food retail, such as advertising and government policies (Glanz et al., 2005); other categories of access dimensions have also been proposed (for example, proximity, diversity, availability, affordability, perception (Charreire et al., 2010)). Continuing to cultivate a discussion around the underlying constructs contained in measures seems a worthwhile endeavor given the continued need for research on disparities in food access.

Conclusion

The assessment of the local food environment is likely to be the topic of a great number of studies in the coming years, if current trends continue (McKinnon et al. 2009). While many measurement challenges remain, only through accurate and comprehensive assessments of the food environment-diet relationship can researchers provide insight into how the local environment may be altered to elicit actual improvements in dietary health. Ultimately, the combination of rigorous spatial and store audit measures, coupled with the intelligent use of neighborhood informant data may yield the best prospects for the careful characterization of food environments.

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1. What should we measure? (e.g., access, quality, utilization)
2. What are the different dimensions of “food access”? (e.g., geographic accessibility of stores, selection of produce, affordability)
3. What kind of assessment techniques are appropriate for capturing each dimension of access? (e.g., store audits, GIS, surveys)
4. What, if anything, do residents’ perceptions of their food environment add to the measurement of food access?
5. What is the “gold standard” for each access dimension, and how should we establish the validity of proposed measures? (e.g., convergent validity of GIS-based measures against store audits)
6. How do we integrate both “good” and “bad” features of food retail so that it accurately reflects the environment of residents? (e.g., neighborhoods that have an abundance of supermarkets as well as fast food outlets)
7. How might the best measure food environments require adaptation by geographic region? (e.g., urban versus rural, U.S. environments versus non-U.S. environments)
8. Which measures of access have been adequately studied and which are most ripe for attention?
9. Which features of the food environment are most important for health? (i.e., how do various measures of the food environment affect dietary patterns?)
10. What features of the food environment might be most amenable to interventions to improve food access?

Figure 1. Unanswered challenges in the measurement of food environments

Table 1
Studies examining the relationship between the food environment and diet

First Author	Year	Outcomes	Location	Cohort/Population
Beydoun	2011	Specific nutrients, incl. fruit and vegetable consumption; Healthy Eating Index (HEI) and Alternate Mediterranean Diet index (aMED)	U.S. (nation)	CSFII, children
Beydoun	2008	Specific nutrients, fruit and vegetable consumption, Healthy Eating Index (HEI), and fast food consumption	U.S. (nation)	CSFII, adults
Bodor	2008	Fruit and vegetable consumption	New Orleans, LA	Adults
Caldwell	2009	Change in fruit and vegetable consumption from baseline to follow up	Colorado	Youth and adults
Cheadle	1991	Red meat, low fat milk, and non-white bread consumption; calories from fat	U.S. (CA and HI)	CHPGP, adults
Cummins	2005	Fruit and vegetable consumption	Greater Glasgow	Springburn Intervention, adults
Fisher	1999	Percent of households in zip code that consumed low-fat milk	NY state	Adults reporting on households
Franco	2009	Diet pattern 1: Fats and Processed Meats (FPM); Diet pattern 2: Whole Grains and Fruits (WGF)	Baltimore, MD	MESA (Baltimore only), adults
Gustafson	2011	Fruit and vegetable consumption	North Carolina (6 counties)	Women, 40-64
Inglis	2008	Fruit and vegetable consumption; fast food consumption	Australia	SESAW, low- SEP women
Izumi	2011	Dark green or orange vegetables consumption	Detroit, MI	HEP, adults
Jago	2007	Fruit and 100% fruit juice consumption; high-fat and low-fat vegetable consumption	Greater Houston, TX	Boy Scouts
Jeffrey	2006	Fast food consumption	Minnesota	Adults
Jennings	2011	Food group consumption patterns	UK	SPEEDY, children 9-10
Laraia	2004	Diet Quality Index	NC state	PIN, adult women
Leung	2010	Total energy	San Francisco, CA	CYGNET, young girls
Michimi	2010	Fruit and vegetable consumption	U.S. (nation)	BRFSS, adults
Moore	2008	Alternate Healthy Eating Index (AHEI) and Fats and Processed Meats (FPM)	U.S. (3 sites)	MESA Neighborhood study, adults
Moore	2009	Fast food consumption; Alternate Healthy Eating Index (AHEI) and Fats and Processed Meats (FPM)	U.S. (3 sites)	MESA Neighborhood study, adults
Morland	2002	Fruit and vegetable consumption; specific nutrients	U.S. (4 sites)	ARIC, adults
Murakami	2009	Food intake in one of 5 food groups	Japan	Japan Dietetic Students Study for Nutrition and Biomarkers, female students
Osypuk	2009	Fats and Processed Meat (FPM) consumption	U.S. (6 sites)	MESA, adults
Paquet	2010	Fast food consumption	Montreal, Canada	Montreal Neighborhood Survey of Lifestyle and Health, adults
Pearce	2009	Fruit and vegetable consumption	New Zealand (nation)	NZHS, adults

First Author	Year	Outcomes	Location	Cohort/Population
Pearce	2008	Fruit and vegetable consumption	New Zealand (nation)	NZHS, adults
Pearson	2005	Fruit and vegetable consumption	UK	Adults
Powell	2011	Consumption of specific food groups, including fruits and vegetables	U.S. (nation)	Child Development Supplement of the Panel Study of Income Dynamics

Table 2
Studies assessing the food environment and diet by exposure assessment technique, access dimension, construct, and results

Exposure assessment	Access dimension	Construct	At least one positive association with dietary outcome $\geq e$	Only null associations with dietary outcome	Results opposite from expected
Survey	Availability	Perceived healthy food availability	Inglis (2008) Moore (2008) Moore (2009)	Osypuk (2009) Sharkey (2010) Williams (2010)	Gustafson (2011)
		Accessibility	Perceived access to healthy food	Caldwell (2009) ^a Rose (2004)	Inglis (2008) Gustafson (2011)
		Affordability	Cost, affordability	Williams (2010) Zenk (2005)	Sharkey (2010)
		Acceptability	Quality, selection	Inglis (2008) Sharkey (2010)	Zenk (2009)
Store audit	Availability	Shelf-space	Bodor (2008)	Caldwell (2009) ^a	
		Product-availability	Cheadle (1991) Fisher (1999)	Franco (2009) Thornton (2010)	
		Variety	Caldwell (2009) ^a	Bodor (2008)	
	Affordability	Price		Pearson (2005) Zenk (2009)	Caldwell (2009) [§] Thornton (2010) [§]
GIS	Acceptability	Quality	Caldwell (2009) ^a	Zenk (2009)	
	Accommodation	Hours open	Thornton (2010)		
	Availability	Store presence	Gustafson (2011) Jennings (2011)	Bodor (2008) Williams (2010)	Leung (2010) [§]
		Store density	Izumi (2011) Moore (2008) Moore (2009) Murakami (2009) Powell (2011)	Jeffrey (2006) Laraia (2004) Paquet (2010) Thornton (2009) Turrell (2008)	Williams (2010)
Accessibility		Variety	Thornton (2009)		
		Distance	Laraia (2004) Michimi (2010) Sharkey (2010) Thornton (2010)	Bodor (2008) Gustafson (2011) Pearce (2009) Pearson (2005)	Thornton (2009) Turrell (2008) Williams (2010)
		Travel time	Pearce (2008)		Jago (2007) [*] Timperio (2008) [*]
		Informant report	Moore (2008)	Moore (2009)	
Other	Availability	Opening of a new store	Wrigley (2003) ^a	Cummins (2005) ^a	

Exposure assessment	Access dimension	Construct	At least one positive association (p<0.05) with dietary outcome >e	Only null associations with dietary outcome	Results opposite from expected
	Affordability	<i>Regional food price index</i>	Beydoun (2008) Powell (2011)	Powell (2009) Beydoun (2011) *	

^aNatural experiment or intervention study

[§]Significant results only in opposite direction from expected

^{*}Mixed results (significant results in both directions)

Table 3
Dietary assessment technique by environmental exposure technique

	Survey	Store audit	GIS	Other
<i>Food Frequency Questionnaire</i>	Moore (2009) Moore (2008) Osypuk (2009) Zenk (2009)	Franco (2009) Zenk (2009)	Izumi (2011) Jago (2007) Laraia (2004) Moore (2009) Moore (2008) Morland (2002) Murakami (2009) Timperio (2008) Zenk (2009)	Moore (2009) Moore (2008)
<i>24-hour recall</i>		Bodor (2008)	Bodor (2008) Leung (2010)	Beydoun (2011) Beydoun (2008)
<i>Brief, customized screener</i> (E.g., "In a typical day, how many servings of fruit do you consume?" or "How many times per week do you eat meals from fast food restaurants?")	Gustafson (2011) Inglis (2008) Williams (2010) Moore (2009) Pearson (2005) Sharkey (2010)	Gustafson (2011) Thornton (2010) Pearson (2005)	Gustafson (2011) Jeffrey (2006) Moore (2009) Paquet (2010) Pearce (2009) Pearce (2008) Pearson (2005) Powell (2011) Powell (2009) Sharkey (2010) Thornton (2010) Thornton (2009) Turrell (2008) Williams (2010)	Cummins (2005) Powell (2011) Powell (2009) Moore (2009)
<i>Food diary</i>			Jennings (2011)	Wrigley (2003)
<i>BRFSS</i>	Caldwell (2009) Zenk 2005	Caldwell (2009)	Michimi (2010)	
<i>Other</i>	Rose (2004)	Cheadle (1991) Fisher (1999)		

Table 4a
Cross-sectional studies using fruit and vegetable intake as an outcome

Author	Year	n	Specific exposure reported	Outcome	Key findings		
					GIS measure	Perceived measure	Store Audit or Other Measure
Beydoun	2008	7331	<i>Price index</i> : Fast food price index (FFPI); fruit and vegetable price index (FVPI)	Fruit grams per day (g/d), vegetable (g/d)			No statistically significant price index measures
Beydoun	2011	6759 children; 1679 adolescents	<i>Price index</i> : Fast food price index (FFPI); fruit and vegetable price index (FVPI)	Fruit and vegetables (g/d)			FFPI for children: $\beta > 0$, $p < 0.05$ Other price index measures not statistically significant
Bodor	2007	102	GIS: Distance (km) to nearest small food store and supermarket; presence of small food store (within 100m) or supermarket (within 1000m) of residence; <i>Store audit</i> : shelf space and variety of fruit and vegetables	Fruit servings per day (s/d), vegetable (s/d)	No statistically significant GIS measure		Fresh vegetable shelf space: $\beta > 0$, $p = 0.025$ Other store audit measures not statistically significant
Gustafson	2011	186	GIS: Presence of food stores within census tract, access (distance < 5 miles) from home; <i>Participant report</i> : Foods store access < 5 miles or > 10 min, neighborhood and store availability of healthy foods; <i>Store audit</i> : Food store availability of healthy foods	fruit and vegetable (s/d)	Presence of a supercentre and convenience store (combo): $\beta < 0$, $p = 0.04$ Other GIS measures not statistically significant	No statistically significant perceived access measures	No statistically significant store audit measures
Ingilis	2008	1328 for fruits; 1376 for vegetables	<i>Participant report</i> : Perceived availability, perceived accessibility, and perceived affordability (tested as mediators)	High fruit consumption (at least 2 s/d) versus low; high vegetable consumption (at least 3 s/d) versus low		High quality fresh produce available: Fruit: OR = 1.40 (1.08 to 1.83) Veg: OR = 1.65 (1.24 to 2.19) Plenty of healthy options to eat Fruit: OR = 1.37 (1.06 to 1.76) Veg: OR = 1.34 (1.05 to 1.71) Fruit does not cost too much: Fruit: OR = 0.39 (0.24 to 0.64) Other perceived measures not statistically significant	

Author	Year	n	Specific exposure reported	Outcome	Key findings		
					GIS measure	Perceived measure	Store Audit or Other Measure
Izumi	2011	919	GIS: Number of stores within 800m of census block centroid with 5 or more dark green or orange vegetables	Consumption of dark green or orange vegetables (s/d)	No. of stores carrying at least 5 varieties of vegetables, compared to 2 stores: No store: $\beta < 0$, $p = 0.047$ One store (compared to 2) not statistically significant		
Jennings	2011	1669	GIS: Presence of BMI-healthy and BMI-unhealthy stores with 800 m of participants' residences	% difference in intake of fruit and vegetables (g/d)	No statistically significant GIS measure		
Jago	2007	210	GIS: Distance to nearest food store	Fruit and juice, high-fat vegetable, low-fat vegetable	Distance to small food store: Fruit and juice: $\beta > 0$, $p = 0.008$ High-fat veg: $\beta > 0$, $p < 0.001$ Distance to fast food outlet: High-fat veg: $p < 0$, $p < 0.001$ Other GIS measures not statistically significant		
Michimi	2010	568,584; 267,697	GIS: Distance to supermarket	Fruit and vegetables, $>=5$ and <5 servings	Distance to supermarket: Metro: OR = 0.95 (0.92 to 0.99) Non-metro distance not statistically significant		
Morland	2002	2392 blacks; 8231 whites	GIS: Presence of a supermarket, grocery store, full service or fast food restaurant within the census tract of a participant	Fruit and vegetables, consuming at least 2 s/d fruit and 3 s/d veg	Presence of supermarket: Blacks: RR = 1.54 (1.11 to 2.12); Other GIS measures not statistically significant		
Murakami	2009	990	GIS: Quartile categories for neighborhood availability of fruit and vegetables within 0.5 mil radius of residences	Fruit and vegetables (g/d)	No statistically significant GIS measure		
Pearce	2009	12,529	GIS: Street network distance to fast food outlets (multi-national and locally operated) from population-weighted centroid of mesh block group	Fruit, at least 2 s/d, and vegetables, at least 3 s/d	No statistically significant GIS measure		

Author	Year	n	Specific exposure reported	Outcome	Key findings		
					GIS measure	Perceived measure	Store Audit or Other Measure
Pearce	2008	12,529	GIS: Travel time to the nearest supermarket and convenience store along the road network	Fruit, at least 2 s/d, and vegetables, at least 3 s/d	Best access to convenience stores: Veg: 0.75 (0.60 to 0.93) Better access to convenience stores: Veg: 0.80 (0.64 to 0.99) Other GIS measures not statistically significant		
Pearson	2005	426 for fruit; 420 for vegetable	GIS: Distance to a supermarket (km); Participant report: Difficulties shopping; Store audit: Price of fruits and vegetables at supermarkets where participants shopped	Fruit and vegetable (s/d)	No statistically significant GIS measure	No statistically significant perceived measure	No statistically significant store audit measure
Powell	2011	1134	Price index: Price of food items in nearest city to participants home; GIS: number of food stores per 100,000 residents per 10 square miles	Number of days per week respondents consumed fruit and vegetables	Supermarket/grocery store density: Veg: $\beta > 0$, $p = 0.05$ Other GIS measures not statistically significant		No statistically significant index measure
Powell	2009	3739	Price index: Price of fruit and vegetables in county of resident; GIS: number of food stores in the county of residents per 100,000 residents	Fruit (s/d), vegetable (s/d), count model	No. of non-fast food restaurants: RR = 1.013, $p < 0.05$ No. of fast food restaurants: RR = 0.951, $p < 0.05$ Other GIS measures not statistically significant		Price of fruit and vegetables RR= 0.678, $p < 0.01$
Rose	2004	963	Participant-report: Distance to a supermarket, round trip travel time and supermarket access	Household fruit and vegetable consumption (g/ adult male/ day)		Difference for supermarket Fruit: $\beta > 0$ (7 to 157) Distance to store > 5 miles: Fruit: $\beta < 0$ (-117 to -7) Easy supermarket access: (reference = worse access) Fruit: $\beta > 0$ (7 to 164) Other perceived measures not statistically significant	
Sharkey	2010	582	GIS: Network distance to nearest store from home; Survey: availability, variety, and affordability of food	fruit and vegetables (s/d)	Supermarket: $\beta < 0$, $p = 0.002$	Few grocery stores: $\beta < 0$, $p = 0.000$	

Author	Year	n	Specific exposure reported	Outcome	Key findings		
					GIS measure	Perceived measure	Store Audit or Other Measure
Thomton	2010	1082	stores, variety, freshness, and price of fruits and vegetables in stores		Any store with fresh/processed fruit: $\beta < 0$, $p = 0.005$ Other GIS measures not statistically significant	Fruit/vegetable variety: $\beta < 0$, $p = 0.043$ Other perceived measures not statistically significant	
			GIS: Road network distance from the nearest food store; count of each of these stores within 3 km of home; Store audits: mean cost difference of fruits and vegetables between stores; opening hours	High fruit and vegetable consumption (at least 2 s/d) versus low	Supermarkets: Store density, veg: $\beta > 0$, $p < 0.001$ Proximity, veg trend $p < 0.001$ Greengrocers Store density: veg: $\beta > 0$, $p < 0.001$ Proximity: veg trend $p < 0.001$ Other GIS measures not statistically significant		For supermarkets: Veg availability: $\beta < 0$, $p = 0.032$ Fruit price: $\beta > 0$, $p = 0.009$ \$ Veg price: $\beta > 0$, $p = 0.002$ \$ For greengrocers: Fruit availability: $\beta > 0$, $p = 0.038$ Veg availability: $\beta > 0$, $p < 0.001$ Fruit price: $\beta > 0$, $p = 0.026$ \$ Veg price: $\beta > 0$, $p < 0.001$ \$ Opening hours: Fruit: $\beta > 0$, $p = 0.034$; Other store audit measures not statistically significant
Timperio	2008	775 for fruit; 784 for vegetable	GIS: Distance to closest food store, number of food stores within 800m, and presence of at least 1 food store within 800m	High fruit consumption (at least 2 s/d) versus low; high vegetable consumption (at least 3 s/d) versus low	Convenience stores At least 1 store within 800m Veg: OR = 0.75 (0.57 to 0.99) Number within 800m Fruit: OR = 0.84 (0.73 to 0.98) Veg: OR = 0.84 (0.74 to 0.95) Supermarket Veg: OR = 1.27 (1.07 to 1.51) \$ Other GIS measures not statistically significant		

Author	Year	n	Specific exposure reported	Outcome	GIS measure	Key findings	
						Perceived measure	Store Audit or Other Measure
Williams	2010	243 for fruit; 225 for vegetable	<i>Participant report:</i> Cost of fruit and vegetables, whether food stores were within walking distance of home, and perceived availability of healthy food; <i>GIS:</i> # of supermarkets and fruit and vegetables stores within 2km road network distance; distance to nearest supermarket or fruit and vegetable store	High fruit intake (at least 2 s/d) versus low; high vegetable intake (at least 3 s/d) versus low	<i>GIS results not statistically significant in bivariate models. Results not reported in fully adjusted models.</i>	Cost of fruit: Fruit: OR = 0.63 (0.45 to 0.86) Availability of healthy food Fruit: OR = 1.14 (1.04 to 1.25) Veg: OR = 1.10 (1.01 to 1.21) <i>Perceived access to healthy food options no statistically significant in bivariate models; results not reported in fully adjusted models.</i>	
Zenk	2005	266	<i>Participant-reported:</i> Type of store in which respondents purchased their food; selection and quality of fresh produce; affordability of fresh produce	Fruit and vegetable (combined) intake (s/d)		Shopping at supermarket: $\beta > 0$, $p < 0.001$ Shopping at a specialty store: $\beta > 0$, $p < 0.05$ Selection/quality: $\beta > 0$, $p < 0.05$ <i>Other perceived measures not statistically significant</i>	
Zenk	2009	919	<i>GIS:</i> No. of food stores in the 0.5 mile buffer around census block centroid; <i>Store Audit:</i> distance to nearest supermarket; availability of produce; variety, quality and affordability of produce; <i>Participant reported:</i> Satisfaction with variety, quality, cost and affordability of fresh produce	Fruit and vegetable intake (s/d)	Large grocery store: $\beta > 0$, $p = 0.002$ <i>Other relationships with GIS measures not statistically significant</i>	<i>No statistically significant relationships with store audit measure</i>	

\$ Association in the opposite direction from expected

Table 4b
Studies using a before-and-after design to assess change in fruit and vegetable intake

Author	Year	n	Study design	Exposure	FV outcome	Key findings	
						Exposure measured by survey	Exposure measured by store audit or other
Caldwell	2009	130	Broad intervention to achieve Healthy People 2010 objectives; Before-after design; no control group. Results estimate the association of each exposure with change in fruit and vegetable consumption from intervention baseline to intervention end.	<i>Participant reported:</i> Ease or difficulty in getting fresh produce; <i>Store audit:</i> shelf space, cost, variety, and quality	Change in fruit and vegetable consumption (servings per week), measured at the beginning and end of the intervention	Perceived access to fresh produce: $\beta > 0, \beta = 0.011$	Square meters of fresh fruits and veg: $\beta > 0, \beta = 0.0137$ Variety of fruit and fresh fruits and veg: $\beta > 0, \beta = 0.007$ No. of stores in community: $\beta > 0, \beta = 0.0013$ Produce freshness: $\beta > 0, \beta = 0.045$ Minimum price of produce basket: $\beta > 0, \beta = 0.0022$ § Minimum price of fresh produce: $\beta > 0, p = 0.0187$ §
Cummins	2005	412	Before-after natural experiment for residents who lived with 1 km of a newsupermarket; control site 5 km away. Results estimate difference in change in FV between groups.	Presence of a new supermarket within 1km of residence	Fruit and vegetable consumption (portions per day)		Participants with new stores not statistically significant
Wrigley	2003	598	Before-after natural experiment; no control group. Results estimate the before-after change in FV consumption.	Switching stores, distance to new store	Fruit and vegetable consumption, (s/d)	Switched from budget store to new store, FV change: $\beta > 0, p < 0.05$ <i>Switched to new store not statistical significant</i>	Distance to the new store $\leq 500m$: FV change: $\beta > 0, p < 0.05$

§ Association in the opposite direction from expected

Table 5

Studies using fast food consumption as an outcome

				Key findings		
Author	Year	n	Specific exposure reported	FF outcome	GIS result	Perceived result
Beydoun	2011	8438	<i>Price index:</i> Fast food price index (FFPI); fruit and vegetable price index (FVPI)	Number of fast food items consumed in the last 24 hours		Children: FFPI: $\beta < 0$, $p < 0.05$; No other statistically significant relationship with price index
Beydoun	2008	6759	<i>Price index:</i> Fast food price index (FFPI); fruit and vegetable price index (FVPI)	Number of fast food items consumed in the last 24 hours		No statistically significant relationships with price index
Inglis	2008	1580	<i>Participant report:</i> Perceived availability, perceived, accessibility, and perceived affordability (tested as mediators)	Consumption of fast food at least once per week		Healthy options to eat out: OR = 0.70 (0.52 to 0.94) No other statistically significant relationship with perceived measures
Jeffery	2006	911	<i>GIS:</i> Number of fast food outlets within 2 miles of resident's home	Frequency of eating at fast food restaurants, dichotomized (not specified further)	No statistically significant relationships with GIS measures	
Moore	2009	5633	<i>GIS:</i> Fast food store density in square mile around residents house <i>Participant report:</i> Access to fast food; neighborhood scores)	Consumption of fast food at least once in the last week	No statistically significant relationship with GIS measures	Participant report of fast food access: OR = 1.61 (1.51 to 1.72)
Paquet	2010	415	<i>GIS:</i> Number of fast food outlets within 500m of participants' home	Consumption of fast food at least once in the last week	No statistically significant relationship with GIS measures. Interaction effect with attitude variable was significant.	Informant report of fast food access: OR = 1.27 (0.17 to 1.39)
Thomton	2009	2547	<i>GIS:</i> Number of fast food restaurants within 3 km of resident's house; Variety of different fast food restaurants within 3 km; Road network distance to the nearest store	Purchase of fast food in the last month (never, weekly, or monthly)	Variety of stores: Monthly: OR = 1.13 (1.02 to 1.25) No other statistically significant relationship with GIS measures	
Turrell	2008	1001	<i>GIS:</i> Number of takeaway stores within 2.5 km of centroid of neighborhood unit; Average road distance to each type of store; closest road distance	Purchase of fast food for consumption (4 consumption categories)	No other statistically significant relationships with GIS measures	