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Comparing Perception-Based and Geographic Information System (GIS)-Based Characterizations of the Local Food Environment

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ABSTRACT *Measuring features of the local food environment has been a major challenge in studying the effect of the environment on diet. This study examined associations between alternate ways of characterizing the local food environment by comparing Geographic Information System (GIS)-derived densities of various types of stores to perception-based measures of the availability of healthy foods. Survey questions rating the availability of produce and low-fat products in neighborhoods were aggregated into a healthy food availability score for 5,774 residents of North Carolina, Maryland, and New York. Densities of supermarkets and smaller stores per square mile were computed for 1 mile around each respondent's residence using kernel estimation. The number of different store types in the area was used to measure variety in the food environment. Linear regression was used to examine associations of store densities and variety with reported availability. Respondents living in areas with lower densities of supermarkets rated the selection and availability of produce and low-fat foods 17% lower than those in areas with the highest densities of supermarkets (95% CL, −18.8, −15.1). In areas without supermarkets, low densities of smaller stores and less store variety were associated with worse perceived availability of healthy foods only in North Carolina (8.8% lower availability, 95% CL, −13.8, −3.4 for lowest vs. highest small-store density; 10.5% lower 95% CL, −16.0, −4.7 for least vs. most store variety). In contrast, higher smaller store densities and more variety were associated with worse perceived healthy food availability in Maryland. Perception- and GIS-based characterizations of the environment are associated but are not identical. Combinations of different types of measures may yield more valid measures of the environment.*

KEYWORDS *Environment, Neighborhoods, Food, GIS, Survey assessment.*

Several studies have linked local food environments to diet quality,[1–11] although the extent to which these associations reflect causal processes remains a topic of research. A major challenge in this work has been developing valid and reliable measures of the local food environment. Many studies have characterized food environments by counting the number of certain types of stores (usually supermarkets) in the census tracts or zip codes in which study participants live.[12–16] This approach relies on the assumptions that only supermarkets offer an array of healthy foods and that the range and quality of healthy foods offered by supermarkets are invariant over space.

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Surveys have increasingly been used to characterize neighborhoods[17,18] but, to date, have been infrequently used in studies of the local food environment. Surveys can be used to obtain information on residents' perceptions of the availability of healthy food items in their neighborhood. Perception-based measures may also be helpful in detecting variation in healthy food availability and quality that is not captured by measures based on the types of stores present. For example, stores with the same classification such as supermarkets may offer different goods depending on neighborhood characteristics.[19] It is also plausible that the presence of a variety of smaller stores may increase healthy food availability in the absence of supermarkets.

Perception-based measures, however, are necessarily affected by a host of individual factors and, therefore, have their own sources of measurement error. Although the relationship between perception-based and locational (geographic information systems or GIS) measures has increasingly been examined with respect to the physical activity environment,[20–24] few studies[7] have explored associations between GIS-based and perception-based measures of the local food environment. Understanding the relationship between these different measures of the local food environment is important to the interpretation of studies that use them and to the development of more valid and reliable measurement instruments.

This study examined the association between GIS-derived densities of different types of stores in areas and the availability of healthy foods as reported by those residing in the area. The primary purpose of these analyses is to describe how these two measures of the local food environment are associated. Based on prior work,[25–28] we hypothesized that greater densities of supermarkets within a mile of a person's home would be related to greater perceived availability of healthy foods within the same 1-mile radius. We also examined whether having greater numbers or several different types of smaller stores in a neighborhood would be associated with greater perceived healthy food availability in the absence of supermarkets.

METHODS

Perceived availability of healthy foods was measured through a survey administered between January and August 2004 to a random digit dialing sample of 5,988 adults in 685 census tracts in Forsyth County, NC, parts of Baltimore City and Baltimore County, MD, and Northern Manhattan and the Bronx, NY. These areas were surveyed because they are the geographic areas represented in the MESA Neighborhood Study, a study of the neighborhood-level determinants of cardiovascular risk.[17,29] Survey details are provided elsewhere.[17]

Participants were asked to think of their neighborhood as the area within a 20-minute walk (or a mile) from their home and indicate the extent to which they agreed with the following statements: (1) A large selection of fruits and vegetables is available in my neighborhood, (2) the fresh fruits and vegetables in my neighborhood are of high quality, and (3) a large selection of low-fat products is available in my neighborhood. Each question was graded on a five-point Likert scale (0 = strongly agree–4 = strongly disagree), reverse coded, and aggregated into a summary score with 0 indicating worst availability of healthy foods and 12 indicating best availability. Cronbach's alpha and test–retest reliability for the three items was high (α=0.78; p=0.69 95% CI 0.57, 0.77).[17] The New York site consisted of only urban census tracts. Less than 1% of the Maryland study site and 4% of the North Carolina site were rural tracts (less than 50% of the population in the census

tract living in an urban area as defined by the US Census). The final survey response rate was 46.5%.

Information on the types and locations of food stores in the 685 census tracts was obtained from InfoUSA in November of 2003. Food stores were classified based on supplemented Standard Industrial Classification codes into grocers and supermarkets (541101, 541104–541106), convenience stores (541102, 541103), meat and fish markets (5421, 549907, 549911), fruit and vegetable markets (543101, 543102, 543103, 549933), bakeries (5461), natural food stores (549901, 549909, 549935), and specialty food stores that include ethnic grocery stores and various miscellaneous specialty stores (SIC 549910, 549912, 549914, 549916–549921, 559923, 549926–549928, 549930, 549937). Supermarkets were differentiated from smaller stores based on chain name recognition and/or having an annual payroll of greater than 50 employees.[12,15,19,30]

Densities of supermarkets and all other smaller stores per square mile (including grocers, convenience stores, fruit and vegetable markets, specialty stores, natural food stores, meat and fish markets, and bakeries) were estimated separately by the kernel density method[31,32] using the spatial analyst extension of ArcGIS v.9.1 (ESRI, Inc., Redlands, CA, USA). Densities were generated by first plotting each store on a map as a smoothed cone (kernel) centered on the point location of the store. The radius of the cone represents the proposed service area of the store in the community, known as the window size or buffer. A 1-mile buffer was used in this study to correspond with perceived availability measures. Service areas overlap when stores are less than 2 miles apart. Cones are then smoothed over space to form layers of densities for stores such that the service area of stores is highest at the point location and declines from the center according to a quartic function, a bivariate, Gaussian distribution.[32]

The three study areas were partitioned into 10-m-grid cells, and the density value of each cell was assigned by summing the densities corresponding to the overlapping cones. A density value was assigned to each survey respondent based on the averaged cell densities that were within a 1-mile radius of respondents' home addresses. This density value can be interpreted as the density of supermarkets (or smaller stores) per square mile within a mile of the home, with more weight being given to stores closer than further from the residence. As there is no clear theory about the most appropriate radius for assessing the spatial availability of stores in exploratory analyses, we also investigated 2- and 5-mile densities. Sensitivity of results to adjustment for population density was also examined. Population density adjustment was accomplished by dividing the store densities (stores per area) by the corresponding population densities (population per area), yielding a measure of stores per population. In addition to densities of supermarkets and densities of smaller stores, we also created a measure of variety of smaller stores by summing the number of different types of smaller food stores (range, 0 to 7) within a 1-mile radius of the survey respondent's home.

Associations between perceived healthy food availability and the density of stores were investigated by modeling the perceived healthy food availability for each survey participant as a function of the densities of supermarkets, the densities of smaller stores, and the variety of smaller stores in three separate models using linear regression in SAS version 9.1 (SAS Institute Inc., Cary, NC, 2002). Analyses using the density of smaller stores and variety of smaller stores were restricted to the 2,044 persons who had no supermarket within a mile of their home. The perceived healthy food availability was logged for ease of interpretation so that coefficients can be interpreted as relative differences (or percent differences) in the perceived availability measure.

All models were adjusted for race/ethnicity and income of respondents because these personal characteristics are associated with the location of stores[12] and may affect reported food availability. Site was examined as a potential effect modifier to examine regional variation in the relationship between the densities of stores and perceived availability. Heterogeneity was tested by including appropriate interaction terms in regression models. In the absence of a priori theory of relevant thresholds for the effects of the local food environment, density measures were categorized based on tertiles of the full distribution for supermarkets (tertile cutoffs of 0.4 and 2.1 supermarkets per square mile). Cutoffs for densities of smaller stores and variety in smaller stores were based on distribution-based tertiles of those living in areas without supermarkets (tertile cut points 0.3 and 1.7 stores per square mile for smaller stores and 1.0 and 3.0 store types for variety in smaller stores). The use of these distribution-based categories allows investigation of thresholds while ensuring sufficient numbers in each category to allow meaningful estimation.

RESULTS

Ninety six percent of respondents ($n=5774$) answered all three survey questions and were included in the analyses. Descriptive statistics are shown in Table 1. Perceived healthy food availability differed by site, with New York residents reporting higher availability of healthy foods. New York participants lived in areas with significantly higher densities of supermarkets and smaller stores per area, as well as a greater variety of smaller stores, because of the higher population density of this area (65,230 people per square mile for New York vs. 747 and 4,127 people per square mile for North Carolina and Maryland, respectively). In general, minorities (except for Asians) and lower income respondents reported lower perceived availability of healthy foods than whites and higher income respondents, respectively. Supermarket densities were lower for blacks than for other race/ethnic groups and were higher for participants with incomes over $50,000 compared to those under $50,000. In general, non-white and lower income participants lived in areas with higher densities of smaller stores and greater variety of smaller stores than white and higher income participants, respectively.

Table 2 shows percent differences in the perceived healthy food availability score across categories of store densities after adjustment for race/ethnicity and income. Respondents who lived in areas within the lowest tertile of supermarket densities rated the perceived availability of healthy foods 17% lower than those who lived in areas with the highest densities of supermarkets (95% CL, –18.8%, –15.1%). This effect decreased as the window for which the density was calculated increased: 15.2% lower (95% CI, –17.1, –13.2) for the bottom vs. the top category of 2-mile densities and 13.0% lower (95% CI, –15.0, –11.0) for the 5-mile densities (not shown). Respondents who had moderate densities of supermarkets around their home (the intermediate category of densities) also rated their environment significantly lower than those with the best access. Results for supermarkets did not change substantially when population density was taken into account.

Among participants without a supermarket within a mile of their home, those living in areas with low densities of smaller stores or little variety in smaller stores reported a 5–6% lower perceived availability of healthy foods than those living in areas with high smaller store densities or more variety (6.3% lower 95% CL, –10.4 and –2.1, for smaller stores, and 5% lower 95% CL, –8.9 and –0.9, for smaller store variety for the lowest vs. highest tertile). No consistent trend in perceived

TABLE 1 Mean (standard deviation) perceived availability of healthy foods and densities of stores within 1 mile of residence by site and selected personal characteristics

			Stores per square mile		
	Number of participants	Perceived availability	Supermarkets	Smaller stores	Variety of smaller stores
Overall mean	5,774	7.4 (3.1)	2.1 (2.7)	30.0 (33.0)	4.8 (2.4)
Site					
MD	1,677	7.0 (3.1)	0.6 (0.6)	8.7 (10.9)	4.0 (1.9)
NC	1,545	6.8 (3.1)	0.3 (0.5)	1.4 (1.7)	2.2 (1.7)
NY	2,552	7.9 (2.9)	4.1 (3.0)	61.4 (24.5)	6.8 (0.5)
p Value[a]		<0.0001	<0.0001	<0.0001	<0.0001
Race/ethnicity					
Asian	129	8.1 (2.5)	3.1 (3.1)	39.0 (32.1)	5.6 (2.1)
Non Hispanic black	1,647	6.5 (3.0)	1.3 (1.4)	26.4 (31.0)	4.8 (2.0)
Hispanic	765	7.1 (2.7)	2.5 (1.7)	60.8 (30.8)	6.3 (1.3)
Other	203	7.1 (3.2)	2.2 (2.3)	35.7 (31.8)	5.4 (2.1)
Non-Hispanic white	3,030	7.9 (3.0)	2.3 (3.3)	23.4 (30.0)	4.3 (2.6)
p Value[a]		<0.0001	<0.0001	<0.0001	<0.0001
Household income					
Missing	667	7.6 (3.0)	2.1 (2.7)	30.5 (33.9)	4.6 (2.6)
$0–11,999	750	6.7 (2.9)	1.9 (1.7)	44.5 (34.1)	5.7 (1.7)
2–34,999	1,385	7.0 (2.9)	1.6 (2.1)	29.2 (33.5)	4.8 (2.2)
$35–49,999	743	6.9 (3.1)	1.7 (2.4)	25.0 (31.5)	4.4 (2.4)
Over $50,000	2,229	7.9 (3.1)	2.5 (3.3)	27.2 (31.0)	4.6 (2.6)
p Value for trend[b]		<0.0001	<0.0001	<0.0001	<0.0001

[a] *p* Value for differences between means using ANOVA.
[b] *p* Value for trend excludes missing household income category.

TABLE 2 Population unadjusted and adjusted percent differences and 95% confidence limits in perceived availability of healthy foods by categories of store densities and store variety (all models adjusted for race and categorical household income)

	Number of participants	Population unadjusted[a]	Population adjusted[b]
Supermarket	5,774		
Low density		−17.0 (−18.8, −15.1)	−16.8 (−18.6, −15.0)
Medium density		−6.7 (−8.8, −4.6)	−5.7 (−7.8, −3.6)
High density		Referent	Referent
Smaller stores[c]	2,044		
Low density		−6.3 (−10.4, −2.1)	−2.8 (−6.9, 1.4)
Medium density		4.4 (0.1, 8.9)	7.7 (3.3, 12.2)
High density		Referent	Referent
Variety of smaller store[c,d]	2,044		
Low variety		−5.0 (−8.9, −0.9)	–
Medium variety		2.6 (−1.7, 7.1)	–
High variety		Referent	Referent

[a]Based on tertiles of densities of stores per square mile pooled across sites. Categories of densities of supermarkets were based on cutoffs of 0.4 and 2.1 stores per square mile; categories of densities for smaller stores were 0.3 and 1.7 stores per square mile; categories for smaller store variety were based on cutoffs of 1.0 and 3.0.

[b]Based on tertiles of densities of stores per 1,000 population pooled across sites.

[c]Densities for smaller stores and store variety are restricted to persons in areas without supermarkets ($n=2,044$).

[d]Variety measures were not investigated after population density adjustment because these measures are not densities.

availability was observed for smaller store densities or variety (Table 2) or across window sizes (not shown).

Perceived availability of healthy foods was positively associated with the densities of supermarkets in the neighborhood across the three sites (Table 3). However, effect sizes were greater in North Carolina than in New York and Maryland. North Carolina respondents in the lowest density tertile rated their environment 19% lower than those in the highest tertile, compared to 12% lower and 9% lower for New York and Maryland, respectively (p value for heterogeneity between sites <0.0001). Among persons living in areas without supermarkets, greater density of smaller stores was associated with better perceived availability of healthy foods only in NC: NC respondents in the lowest density tertile rated their environment significantly lower than those in the highest density tertile (8.8% lower 95% CL, –13.8 and –3.4; p value for heterogeneity between sites=0.0009). In contrast, in Maryland, lower densities of smaller stores and less variety of smaller stores were associated with better perceived availability, although confidence intervals were wide. Relative differences in perceived availability for density of smaller stores and smaller store variety are not shown for New York because of the very small number of New York residents living in areas without supermarkets.

DISCUSSION

On average, respondents who lived in areas with the lowest densities of supermarkets around their home (less than 0.5 supermarkets per square mile) rated the availability of healthy foods 17% lower than those in areas with the highest

TABLE 3 Site stratified population unadjusted percent differences in perceived availability of healthy foods and 95% confidence limits by categories of store densities and store variety (adjusted for race and categorical household income)

	Maryland	North Carolina	New York
Supermarkets[a]	$N=1,677$	$n=1,545$	$n=2,552$
Low density	−9.1 (−12.8, −5.1)	−19.2 (−22.4, −15.9)	−11.5 (−14.2, −8.7)
Medium density	−6.9 (−10.8, −2.9)	−12.4 (−17.3, −7.2)	−10.4 (−13.1, −7.6)
High density	Referent	Referent	Referent
Smaller stores[a,b]	$n=803$	$n=1,208$	$n=33$
Low density	7.2 (0.1, 14.7)	−8.8 (−13.8, −3.4)	–
Medium density	10.7 (3.7, 18.2)	1.3 (−4.2, 7.2)	–
High density	Referent	Referent	Referent
Smaller store variety[a,b]	$N=803$	$n=1,208$	$n=33$
Low variety	9.6 (2.1, 17.6)	−10.5 (−16.0, −4.7)	–
Medium variety	7.0 (0.2, 14.2)	−1.1 (−6.2, 4.2)	–
High variety	Referent	Referent	Referent

[a]Based on site-specific tertiles of densities of stores per square mile.

[b]Percent differences in perceived availability for density of smaller stores and smaller store variety are not shown for New York because of the very small number of New York residents living in areas without supermarkets.

densities of supermarkets. The relationship between supermarket density and perceived availability of healthy foods was stronger in North Carolina and weaker in Maryland and New York. Among persons living in areas with no supermarkets, having higher densities and a larger variety of smaller stores within close proximity of the home was associated with improved perceived availability of healthy foods only in North Carolina.

Our results are consistent with previous studies that have shown that areas served by supermarkets have better availability of healthier food items.[4,16,25,26,28] Sloane et al. inventoried selected markets in the Los Angeles metropolitan area and found that low-fat dairy, whole grain products, and lean meats were significantly less available and of lower quality and less variety in areas of high African-American concentration[27] possibly because of the lack of supermarkets in these areas.[12,13,15,16,19,33,34] A survey of stores in New York also reported that only one in three smaller neighborhood stores sell reduced fat milk compared to nine in ten supermarkets, and less than a third carry fresh produce compared to 91% of the supermarkets.[19] Similarly, mean quality of fresh produce was significantly lower in the predominately African-American, low-SEP community where supermarkets are less likely to be located than in the racially heterogeneous, middle-income community.[16,28] In a recent study by Jetter et al. in neighborhoods served by smaller grocery stores, access to whole-grain products, low-fat cheeses, and lean ground meat was limited with 64% of all items unavailable in small grocery stores.[26] Adjustment for population density did not substantially alter our results, suggesting that the number of people a store services may not be as relevant as simply having a store in spatial proximity. The association between supermarket density and perceived healthy food availability became weaker as the size of the area for which supermarket densities were calculated increased. This is consistent with the fact that survey respondents were asked to report on healthy food availability within a mile of their home, and hence, stronger associations are expected for the 1-mile window than for the larger windows.

With the exception of North Carolina, we found no clear evidence that residential proximity to smaller grocery stores or variety in smaller stores were correlated with better perceived availability of healthy foods in the absence of supermarkets. In fact, in Maryland, lower densities of smaller stores and less variety in smaller stores were actually associated with better perceived availability. This may have to do with the nature and quality of these small stores in the specific areas we studied, many of which may offer few, if any, affordable and high-quality healthy food items.[25–28] However, the fact that healthy food availability was positively associated with the presence of smaller stores in one site suggests that efforts to improve the healthy foods available in small stores may be one avenue toward improving the local food environment in poor and minority neighborhoods, often characterized by the presence of many small stores but no large supermarkets. The presence of many small stores may also have important advantages in terms of walkability, social interactions, safety, and community development generally, which have other potential health benefits.

There was some evidence of regional variation in the relationship between store densities and perceived food availability across the three sites studied. For example, supermarket density was most strongly associated with perceived availability of healthy food in North Carolina. In addition the density and variety of smaller stores were significantly associated with perceived availability of healthy foods only in North Carolina. The spatial proximity of food stores may be more relevant in less densely populated areas like North Carolina than in areas with higher population densities that will also have generally higher densities of stores overall. In addition, different store types may contribute differently to healthy food availability in different regions and cultural contexts. For example, smaller grocery stores and ethnic grocers could be a primary source of healthy foods in some areas, whereas large supermarkets may be the primary source in other areas. Our results point to some of these differences, but additional work contrasting a broader range of areas is needed.

Although perceived availability and density of supermarkets were positively associated, associations were generally not very strong. The observed increase of 17% in the perceived availability score when comparing the bottom to the top tertile of supermarket densities is equivalent to a difference of 1.25 points on the absolute scale (compared to a standard deviation of 3.1 points and an interquartile range of 3.0). Measurement error in both GIS and perceived measures may have resulted in weak observed associations (bias toward the null), even if supermarkets are an important source of healthy foods. Important measurement error in GIS-derived densities may be introduced by error in the identification and classification of stores.[35–38] Although we defined supermarkets using methods analogous to those used in prior work,[12,15,30] measurement error is clearly a possibility. Our measure of the density of smaller stores pools together a heterogeneous group of stores that may differ substantially in the healthy foods they offer. Perception-based measures may also be subject to measurement error. Respondents were asked about resources within 1 mile around their home, which may introduce misclassification if respondents misestimate the geographic bounds of 1 mile. Also, reports of availability are necessarily based on perceptions that are influenced by various subjective experiences and personal behaviors, including personal preferences, awareness of food shopping in the neighborhood, and knowledge/ability to recognize low-fat and "high-quality" fresh produce. Perceptions of availability may also be influenced by different cultural, economic, and regional contexts.

Another potential limitation of these analyses was the survey response rate of 46.5%. Although information is not available on non-respondents, the sample was approximately representative of the areas from which it was drawn.[39]

Another potential reason for the weak associations is that both measures may be imperfect proxies for the construct of healthy food availability. Supermarket densities (even when measured with little error) may simply not capture important variability across areas in the availability of healthy foods. These stores may not be the only source of healthy foods, and supermarkets in different areas (e.g., in low-income vs. high-income areas) may be very different in terms of the healthy foods offered.[17,19] In addition, even in the absence of measurement error related to resident's knowledge of the area, the small number of items and the types of items included in the survey scale used to characterize perceptions have important limitations when characterizing healthy food availability. Additional work to develop more appropriate scales is needed.

Despite the many challenges in measuring both the presence of stores and the perceived availability of healthy foods, our results indicate that characterizations of the local food environment based on perceived measures are associated with GIS-based characterizations of the local food environment. These results also suggest that both measures may provide complementary information. Additional work is needed to determine to what extent the actual healthy food availability observed in stores (for example, by systematic raters or observers[40]) correlates with the availability reported by residents and how availability varies by the sociodemographic characteristics of residents. Exploring ways to combine survey measures with locational data may help to create more reliable and valid characterizations of the food environments.[41] Future research on how the local food environment is related to diet may benefit from complementary approaches to measurement of the environment.

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