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Scale effects in food environment research: Implications from assessing socioeconomic dimensions of supermarket accessibility in an eight-county region of South Carolina

Timothy L. Barnes^{a,b}, Natalie Colabianchi^c, James D. Hibbert^a, Dwayne E. Porter^d, Andrew B. Lawson^e, and Angela D. Liese^{a,*}

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Abstract

Choice of neighborhood scale affects associations between environmental attributes and health-related outcomes. This phenomenon, a part of the modifiable areal unit problem, has been described fully in geography but not as it relates to food environment research. Using two administrative-based geographic boundaries (census tracts and block groups), supermarket geographic measures (density, cumulative opportunity and distance to nearest) were created to examine differences by scale and associations between three common U.S. Census-based socioeconomic status (SES) characteristics (median household income, percentage of population living below poverty and percentage of population with at least a high school education) and a summary neighborhood SES z-score in an eight-county region of South Carolina. General linear mixed-models were used. Overall, both supermarket density and cumulative opportunity were higher when using census tract boundaries compared to block groups. In analytic models, higher median household income was significantly associated with lower neighborhood supermarket density and lower cumulative opportunity using either the census tract or block group boundaries, and neighborhood poverty was positively associated with supermarket density and cumulative opportunity. Both median household income and percent high school education were positively associated with distance to nearest supermarket using either boundary definition, whereas neighborhood poverty had an inverse association. Findings from this study support the premise that supermarket measures can differ by choice of geographic scale and can influence associations

*Corresponding Author: Angela D. Liese, PhD, MPH, Department of Epidemiology and Biostatistics, and Center for Research in Nutrition and Health Disparities, Arnold School of Public Health, University of South Carolina, Discovery I, 461, 915 Greene Street, Columbia, SC, 29208, USA, liese@sc.edu Phone: (803) 777-9414 Fax: (803) 777-2524.

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between measures. Researchers should consider the most appropriate geographic scale carefully when conducting food environment studies.

Keywords

Food environment; Geographic scale; Neighborhood boundaries; Socioeconomic characteristics; Supermarket

1. Introduction

Over the past decade, in efforts to combat food insecurity and the obesity epidemic, researchers and policymakers have been concerned with the influence of local food environments and disparities in food access (Larson et al., 2009). In investigating this issue, many studies have shown significant associations between the neighborhood food environment, diet and obesity (Caspi et al., 2012; Morland and Everson, 2009; Wang et al., 2007); however, many other have suggested that no significant relationship exists (Hattori et al., 2013). Inconsistencies between findings could perhaps be due to how neighborhood and local food environments have been defined (Liu et al., 2015).

Food environments have been characterized in many ways, with geographic information systems (GIS) being the most frequently used analytical tool (Caspi et al., 2012; Thornton et al., 2011; Charreire et al., 2010; Larson and Story, 2009; Larson et al., 2009). Using GIS, geographic-based measures of availability and accessibility of specific food retailers (e.g., supermarkets) and healthier or less-healthy foods have been created (Thornton et al., 2011; Kelly et al., 2011; Charreire et al., 2010; Larsen et al., 2008; Apparicio et al., 2007). Availability is typically defined as the presence or count of an attribute, e.g., supermarkets, in a defined area (Thornton et al., 2011; Charreire et al., 2010). Availability can also be represented as a density, e.g., the number of supermarkets per population or per geographic area (Thornton et al., 2011). Accessibility has been defined as ease of access to available supermarkets, taking factors such as travel distance, travel time and financial resources into consideration (Thornton et al., 2011). Accessibility has been extensively measured within the field of geography (Handy and Niemeier, 1997; Geurs and van Wee, 2004). The simplest measure of access—distance or proximity to the nearest supermarket—has been most commonly used in food environment research. However, accessibility has also been characterized by several other measures, including the cumulative opportunity index (Thornton et al., 2011; Van Meter et al., 2010, 2011).

Studies have pointed out several challenges when deriving geographic measures of the food environment (Fleischhacker et al., 2013; Liese et al., 2010, 2013). Problems with GIS include count, type and spatial inaccuracies when using secondary, commercial databases (Liese et al., 2013). These issues have generally led to under- or over-counting of food venues and misclassification of venue type and have risked mixed, diminished or overstated findings and effects of associations. To improve data quality and minimize measurement error, researchers are increasingly conducting primary data collection and field validation (Fleischhacker et al., 2013).

Less discussed is the choice of appropriate “neighborhood” boundaries or scale and the geographic context in which to operationalize food environment data (Liu et al., 2015; Fan et al., 2014; Larson et al., 2009). Many geographical boundaries have been used to define neighborhood food environments, ranging from egocentric buffer distances of 100 meters to 2.5 kilometers (~1.6 miles) around individual residential, worksite or school addresses or using administrative-based units, e.g., census tracts or block groups (Liu et al., 2015; Fan et al., 2014; Caspi et al., 2012; Charreire et al., 2010). However, there is no consistent methodology with which food environment researchers have agreed to construct geographic measures. Therefore, when comparing findings across studies, the measurements of neighborhood food exposure can vary depending on the geographical units selected. In geography, this effect is attributed to the modifiable areal unit problem (MAUP) (Flowerdew et al., 2008; Schuurman et al., 2007; Haynes et al., 2007; Openshaw, 1983; Fotheringham and Wong, 1991).

The MAUP is composed of two aspects, a scale effect and zonation effect, which through their tandem relationship can have significant influence on characterizing and modeling associations between the environment and health-related outcomes (Flowerdew et al., 2008; Haynes et al., 2007; Jackson, Davies & Leyland, 2010; Reijneveld, Verheij & de Bakker, 2000; Oliver & Hayes, 2007; Martikainen, Kauppinen & Valkonen, 2003; Ross, Tremblay & Graham, 2004; Oliver & Hayes, 2007). The scale effect causes analytical differences based on the size and number of geographic units used. Thus, associations will vary based on how refined and robust the measures are for these different geographic units (Oliver & Hayes, 2007; Parenteau & Sawada, 2011). Understanding the scale effect and the associated MAUP is particularly important for many geographic-related analyses (Kwan and Weber, 2008).

To the best of our knowledge, scale effects have not been well explored in food environment research, although one of the most probable contributors to the many mixed findings relating neighborhood food environments to diet and/or weight is the choice of geographic scale (Liu et al., 2015; Fan et al., 2014). To date, only one study has explicitly examined the effect of geographic scale on detecting relationships using a neighborhood food environment measure (Fan et al., 2014). In cross-sectional analyses comparing four different scales, Fan and colleagues found that the choice of neighborhood geographic scale did affect the estimated significance of the association between neighborhood food environments and individual obesity risk. Specifically, if the relevant neighborhood is defined as too large, (i.e., larger than a census tract for a convenience store or full-service restaurant) or too small (smaller than a census tract for limited-service restaurants), then the statistical relationship became insignificant (Fan et al., 2014). However, this study had several limitations, including the use of a secondary database to define the food environment and using only store count as the measurement criteria.

The objective of this study, therefore, was to evaluate the influence of two commonly used administrative-based geographic definitions (i.e., census tract and block group) on the relationships between GIS-derived supermarket measures and common U.S. Census-based socioeconomic characteristics using data from a 2010 South Carolina food environment study (Liese et al., 2010, 2013; Van Meter et al. 2010, 2011). Supermarkets were selected

for this analysis because compared with other food retailers, they provide access to a greater quantity, variety and quality of food items (Franco et al., 2008; Block and Kouba, 2006) and have been used as a major criterion of the quality of the food environment in many studies (KriYan et al., 2014; Larson et al., 2009; Bader et al., 2010; U.S. Department of Agriculture, 2009). The association of supermarket measures and neighborhood socioeconomic characteristics was used because previous studies have shown significant associations between these attributes (Larson et al., 2009; Walker, Keane and Burke, 2010; Beaulac, Kristjansson and Cummins, 2009; Sharkey and Horel, 2008; Powell et al., 2007a, 2007b; Moore and Diez-Roux, 2006; Zenk et al., 2005; Morland et al., 2002; Morland and Filomena, 2007).

2. Methods

2.1 Study Design

This analysis was part of a large methodological study of the food environment in South Carolina (Liese et al., 2010, 2013; Van Meter et al., 2010, 2011). The study area consisted of a contiguous geographical area and encompassed eight counties in the Midlands region of the state. The project's efforts established a spatially and temporally verified database comprising 2,208 food outlets in South Carolina, including the global positioning system coordinates of all retail food outlets (Liese et al., 2010, 2013). This study was reviewed and deemed exempt by the Institutional Review Board of the University of South Carolina.

2.2 Neighborhood Geographic Boundaries

Two geographic units were selected for analysis. Data were based on both the census tract and block group administratively defined geographical boundaries obtained from the 2000 U.S. Census and the range of populations therein (U.S. Census Bureau, 2000). In our analyses, the selection of these units enabled us to examine changes in the relationship between supermarket accessibility measures and socioeconomic characteristics because of the differently sized and shaped spatial units. Illustrations of the geographic boundaries for the study region are shown in Figure 1.

2.3 Neighborhood Socioeconomic Characteristics

Analyses utilized demographic, geographic and socioeconomic status (SES) data at the level of census tracts and block groups from the 2000 U.S. Census. Census tracts cover, on average, a population of 4,000 individuals. The block group is a smaller geographical unit for which the U.S. Census Bureau publishes data (U.S. Census Bureau, 2000). In total, 150 census tracts and 484 eligible block groups lie within the eight-county study region. Data utilized in the analyses included population size, area size (e.g., square miles), urban classification (i.e., urbanicity), percent minority population (percentage of non-white residents), median household income, percentage of the population living below the federally defined poverty level and percentage of the population (≥ 25 years of age) with at least a high school education. Individual variables were selected for the analyses because they represented the socioeconomic variables that typically serve as a proxy for neighborhood SES. However, in addition to individual measures, a summary score of area socioeconomic characteristics previously developed by Diez Roux and colleagues (2001)

was also constructed by summing the z-scores of six variables (Diez-Roux et al., 2001a, 2001b; Unger et al., 2015). The variables were log median household income; percentage households with interest, dividend or rental income; log median value of housing units; percentage of persons 25 years or over with complete high school education; percentage of persons 25 years or over with complete college education; and percentage of persons in executive, managerial or professional specialty occupations. A higher score indicated better SES conditions compared to a lower (or negative) score.

2.4 Supermarket Availability and Accessibility Measures

We focused on supermarkets as a defining attribute of the food environment because compared to other types of food venues, supermarkets, supercenters and grocery stores typically provide access to healthy food in greater variety and of higher quality (Bilková and Križan, 2015; Krizan et al., 2014; Franco et al., 2008; Block & Kouba, 2006), and this classification was used previously by the U.S. Centers for Disease Control and Prevention in their *2013 State Indicator Report on Fruits and Vegetables* (Centers for Disease Control and Prevention (CDC), 2013). Supermarkets were defined as any food outlet classified as a supermarket, supercenter, grocery store or warehouse club in our validated eight-county food environment database (Liese et al., 2010, 2013).

Availability and accessibility measures were determined by considering the count and distribution of supermarkets within the eight-county study region for both neighborhood geographic boundary measures. The availability and accessibility measures utilized in this analysis were supermarket density, cumulative opportunity and distance to nearest supermarket. Supermarket density is an availability measure and is defined as the number of food outlets adjusted for the geographic area of the specific geographic unit, i.e., census tract or block group (Van Meter et al., 2010, 2011; Thornton et al., 2011). Density is useful when explaining the distribution of features across areas (Thornton et al., 2011). The supermarket cumulative opportunity (also known as the cumulative opportunity index) was used as a measure of local accessibility (Guy, 1983; Van Meter et al., 2011). Similar to supermarket count or density, opportunity represents the number of food outlets within a certain area but gives less weight to food venues that are farther away. Thus, cumulative opportunity can be defined as $C_p(s)$ where A is a predefined area within which the distances are measured and s represents the location points considered (Van Meter et al., 2010, 2011). The distance is measured to all outlets within the area A . For example, for an indexed location (i), the

cumulative opportunity can be calculated using: $C_{pi} = \sum_{j \in A} \frac{1}{d_{ij}}$. This measure provides cumulative evidence for accessibility at a spatial location and can be calculated for special cases such as C_p to the nearest outlet, C_p for a specified distance buffer and C_p total (calculated over the entire study region) (Van Meter et al., 2010, 2011). In our study, cumulative opportunity was determined for each census tract or block group's population-weighted centroid (Thornton et al., 2011; Van Meter et al., 2011), giving less weight to food outlets that were farther away over the entire eight-county study region. Higher values of cumulative opportunity indicated higher supermarket access in that neighborhood boundary. The distance to nearest measure represented the closest food outlet determined by the

shortest road and street network distance (i.e., drive time) to each census tract or block group's population-weighted centroid (Thornton et al., 2011; Van Meter et al., 2011).

2.5 Statistical Methods

Descriptive statistics calculated included the mean, standard deviation (SD), median and minimum and maximum values for all demographic, geographic, socioeconomic and supermarket availability and accessibility measures (Table 1).

General linear models were utilized to examine the association between the four neighborhood socioeconomic variables (median household income, percentage of the population below the poverty level, percentage of the population with at least a high school education and neighborhood SES z-score) and the three supermarket measures (density, cumulative opportunity and distance to nearest) in separate models. Median household income and distance to nearest supermarket were both log transformed to account for skewed distributions. Additionally, the distributions of supermarket density and cumulative opportunity were also slightly skewed because of outliers and were Winsorized at the 95th percentile. After adjustments, no violations of the assumptions of independent observations, linearity, homoscedasticity or normality were further noted. All linear models were adjusted by percent minority population and urbanicity, assuming a normal distribution. Linear models for supermarket cumulative opportunity and distance to nearest were also adjusted for population. No violations of multicollinearity between the demographic and socioeconomic measures were found (all variance inflation factors < 10).

3. Results

Descriptive characteristics by census tract (N=150) and block group (N=484) are displayed in Table 1. The median sizes of the census tract and block group geographic areas were 8.2 and 1.4 square miles, respectively. Additionally, as expected based on U.S. Census Bureau definitions, the median population size for census tracts was much larger (median=3,872 people) than for block groups (median=1,104 people). The corresponding median population densities and percent minorities are also reported, along with the means and standard deviations of all variables. Not shown are the percentages of census tracts and block groups classified as urban. In the study region, 48% of census tracts and 43.8% of block groups were classified as urban based on the 2000 U.S. Census definitions.

When examining the availability and accessibility measures by neighborhood geographic boundaries, the mean density of supermarkets was quite low. These values reflect the fact that many geographic units did not have a single supermarket present. However, 86.6% of census tracts and 41.3% of block groups contained a supermarket. More importantly, the mean and median density of supermarkets were higher when using census tracts compared to block groups. This pattern continued when examining supermarket cumulative opportunity measures. However, there was little difference in the mean and median distances to the nearest supermarket between the two units. The median distances to the closest supermarkets were 1.7 and 1.5 miles in census tracts and block groups, respectively. The neighborhood SES z-score ranged from -1.3 to 4 and -2.1 to 4.5 in census tracts and block groups, respectively.

In examining the association between socioeconomic characteristics and density of supermarkets, there were some significant associations observed in linear models (Table 2). First, as median household income increased, supermarket density decreased using both census tract and block group boundaries. This effect was stronger when using larger geographic boundaries, i.e., census tracts (CTs) compared to block groups (BGs) ($B_{CT} = -0.25$, $p\text{-value} = 0.04$ vs. $B_{BG} = -0.04$, $p\text{-value} = 0.04$). In addition, the model fit—indicated by R^2 —was much larger using census tract compared to block group boundaries (0.13 vs. 0.01, respectively). As the percent of the population below the poverty line increased, supermarket density increased significantly using census tract boundaries ($B_{CT} = 0.72$, $p\text{-value} = 0.05$).

Both median household income and percent high school education were significantly associated with supermarket cumulative opportunity (Table 2). Specifically, cumulative opportunity significantly decreased as median household income increased using the census tract boundaries ($B_{CT} = -2.21$, $p\text{-value} < 0.01$) and block group boundaries ($B_{BG} = -1.41$, $p\text{-value} < 0.01$) and decreased with increased high school education using the block group boundaries alone ($B_{BG} = -3.99$, $p\text{-value} < 0.01$). In addition, using block group boundaries, supermarket cumulative opportunity significantly increased with increasing percent below poverty ($B_{BG} = 4.80$, $p\text{-value} < 0.01$). There was no significant association between supermarket cumulative opportunity and percent below the poverty line using the census tract boundary. When assessing the neighborhood SES z-score, there was a significant positive association using census tract boundaries ($B_{CT} = 0.97$, $p\text{-value} = 0.01$) and a negative association using block group boundaries ($B_{BG} = -0.10$, $p\text{-value} = 0.04$). In all models, the model fit (R^2) was better using census tract compared to block group boundaries. Additionally, the results suggest that based on the neighborhood characteristics included, a large percentage of the variation (30–80%) in models can be contributed to the cumulative opportunity measure, population density, percent minority, and urbanicity.

For distance to nearest supermarket, we found that as median household income or percent high school education increased, the distance to the nearest supermarket significantly increased using either census tract or block group boundaries ($B_{CT} = 0.59$, $p\text{-value} < 0.01$ and $B_{BG} = 0.40$, $p\text{-value} < 0.01$ for median household income; $B_{CT} = 1.46$, $p\text{-value} = 0.02$ and $B_{BG} = 0.88$, $p\text{-value} < 0.01$ for education) (Table 3). Distance to nearest supermarket decreased significantly with increased percent below the poverty level ($B_{CT} = -1.86$, $p\text{-value} < 0.01$ and $B_{BG} = -0.96$, $p\text{-value} < 0.01$). For all effects, the associations were stronger using the census tract compared to the block group boundaries.

4. Discussion

Through our analyses, we explored whether using either of two common geographic boundaries would influence measures of supermarket accessibility and their relationship with U.S. Census-based neighborhood socioeconomic characteristics. We observed that supermarket density and cumulative opportunity were all higher when using census tract compared to block group definitions. However, distance to the nearest supermarket and distributions of supermarkets were quite similar between the two units. We also observed significant relationships of supermarket density and cumulative opportunity with

socioeconomic characteristics, and larger effect sizes and improved model fit were observed when using census tract compared to block group boundaries. Additionally, significant associations between all three individual socioeconomic characteristics and distance to the nearest supermarket were observed. Specifically, median household income and percentage of the population with at least a high school education were both positively related (p -value<0.05) to supermarket distance, and poverty was inversely related (p -value<0.05) to distance to the nearest supermarket using either census tract- or block group-based centroids. Larger effect sizes were observed using census tract compared to block group boundaries. Interestingly, the neighborhood SES z-score, a summary index, was only significantly associated with the supermarket opportunity measure; however, the direction of this effect was different depending on whether census tracts or block group boundaries were utilized.

Findings from this study demonstrate that food environment measures and associations can differ based on choice of geographic scale used to define a neighborhood. These differences and changes in associations are most likely due to the impact of scale effects, which comprise part of the MAUP properties. To the best of our knowledge, only one study of the food environment has explicitly compared administratively defined neighborhood measures in the context of scale effects (Fan et al., 2014). However, determining the appropriate boundaries to operationalize geographic data should be an important concern, as many public health policies and initiatives are based on spatial measures of supermarkets and other food sources in local communities and neighborhoods (U.S. Department of Agriculture, 2009, 2011; Centers for Disease Control and Prevention, 2009, 2011a, 2011b).

In our study, higher availability and access to supermarkets were associated with low-income, less-educated, high-poverty neighborhoods. This is an uncommon finding in food environment research, as most studies have suggested that non-poor neighborhoods have a greater availability of supermarkets and healthy food options compared to poorer neighborhoods (Alwitt & Thomas, 1997; Morland et al., 2002; Giang et al., 2008; Glanz et al., 2007; Lewis et al., 2005; Powell, Chaloupka & Bao, 2007). However, the relationship between neighborhood demographics and socioeconomics has not been reported conclusively in the literature (Walker et al., 2010; Larson et al., 2009). Discrepancies between our results and those of some previous studies may be due to most published studies having been conducted in urban communities, with little or no variation in urbanicity. However, a study in a six-county rural region of Texas found that the most deprived neighborhoods with the greatest minority composition had better potential spatial access to food stores (Sharkey and Horel, 2008). In comparison, our study area consisted of neighborhood boundaries spanning both urban and rural geographic areas in South Carolina.

Strengths of our study include the use of multiple measures of the food environment—three different accessibility measures—to assess scale effects and examine associations with neighborhood socioeconomic characteristics. This study also utilized two of the most commonly used neighborhood boundaries: census tract and block group designations. In addition, all supermarket measures were based on a ground-truthed, field-validated database (Liese et al., 2010, 2013). Thus, the present study is unlikely to have been affected by neighborhood socioeconomic-related differential accuracy of the secondary data regarding

the food environment, which has been shown to be present by several studies (Powell et al., 2011; Liese et al., 2013).

Our study, however, is not without limitations. First, our findings will not be generalizable to all study areas and populations. Many studies have characterized urban population areas exclusively (Moore & Diez-Roux, 2006; Zenk et al., 2005; Morland et al., 2002; Franco et al., 2008), which may differ from our study region consisting of both urban and rural characteristics. However, it is possible that our findings may be generalizable to study areas of similar makeup in the Southeastern region of the United States. Second, when constructing the accessibility measures, we did not consider food venues that were outside our eight-county region. Thus, there is a potential for some “edge effects” when conducting calculations for those population-weighted centroids close to the eight-county region boundaries. Last, we did not account for spatial autocorrelation, and thus we cannot assume that the values of observations are independent of one another. Correlation coefficients and ordinary least squares regressions (OLSs) assume that observations have been selected randomly to predict consequence. However, if the observations are spatially clustered in some way, the estimates obtained from the correlation coefficient or OLS estimator will be biased and overly precise. However, our modeling procedures did include a random effect. Moreover, our primary aim was to demonstrate that measures of supermarket availability and accessibility and the corresponding associations can differ based on scale effects. We did not attempt to evaluate supermarket accessibility measures and/or establish causality between the supermarket measures and the existing neighborhood characteristics.

5. Conclusions

The use of food environment measures has increased dramatically over the past decade and has contributed to many public health policies and initiatives (U.S. Department of Agriculture, 2009, 2011; Centers for Disease Control and Prevention, 2009, 2011a, 2011b). In this study, we explored how scale effects can alter the magnitude of associations between predictors and outcomes. Specifically, we found a small increase in the effect size of our associations between supermarket accessibility measures and individual socioeconomic characteristics when using census tract boundaries compared to block groups. In addition, we observed a change in the direction of our association using when using the two difference scales to assess the relationship between neighborhood SES z-score and the supermarket opportunity measure. However, despite our findings, we cannot definitively state whether one scale—census tract or block group—is the most appropriate for all study regions and analyses. Moving forward, researchers should consider carefully their choice of geographic scale. Sensitivity analyses by researchers should serve as an approach to determine what neighborhood boundaries, whether administrative-based (e.g., census tract and block group) or individual level-based, best fit the specific neighborhood experiences (Vallée and Shareck, 2014). Moreover, researchers must be aware that selecting a geographic scale that is either too large or too small in the context of communities and an individual’s actual daily routines and activities can alter measures of association.

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Research Highlights

- Food environment studies rarely address scale effects
- Scale affects analytic results due to the size and number of geographic units
- Our findings demonstrate supermarket measures can differ by choice of scale
- Scale also affect associations between supermarket and socioeconomic measures
- Researchers should consider the scale used in food environment studies carefully

Fig 1.
Neighborhood geographic boundaries

Table 1
Descriptive characteristics of the eight-county South Carolina food environment study area by neighborhood boundaries

	Census tract N=150						Block group N=484					
	Mean	SD	Median	Min	Max		Mean	SD	Median	Min	Max	
Neighborhood demographic and geographic characteristics												
Geographic area (<i>square miles</i>)	37.2	49.8	8.2	0.1	219		11.5	18.1	1.4	0.04	133	
Population size	4,210	2,151	3,872	346	11,655		1,290	994	1,103	23	11,300	
Population density	1,267	1,413	621	14.6	4,440		1,420	1,571	792	8	5,026	
Minority (%)	50.5	25.2	49.8	2.1	99.5		51.3	28.5	48.2	1.2	100	
Neighborhood socioeconomic characteristics												
Median household income (<i>U.S. dollars per year</i>)	34,399	13,190	33,250	0	81,524		35,845	15,701	33,477	0	14,455	
Percentage of the population with at least a high school education (%)	76.0	12.2	73.1	49.9	100		76.1	13.5	75.0	31.2	100	
Poverty (%)	17.7	11.7	16.4	0	61.9		17.6	13.2	14.7	0	80.7	
Neighborhood SES z-score	0	1	-0.3	-1.3	4.0		0	1	-0.2	-2.1	4.5	
Availability measures												
Supermarket density	0.23	0.45	0.01	0	1.6		0.04	0.13	0	0	0.54	
Accessibility measures												
Supermarket cumulative opportunity	10.5	5.6	9.2	3.3	20.9		0.3	0.7	0	0	2.3	
Distance to nearest supermarket (<i>miles</i>)	2.8	2.5	1.7	0.1	9.2		2.3	2.2	1.5	0.1	8	
SES, Socioeconomic												

Table 2

Regression analyses for the relationships between neighborhood socioeconomic characteristics and supermarket density and cumulative opportunity measures by neighborhood boundaries

	Supermarket density ^a			Supermarket cumulative opportunity ^b		
	Census tract N=150	Block group N=484	Census tract N=150	Block group N=484	Census tract N=150	Block group N=484
	<i>B</i> (SE)	<i>p</i> -value	<i>B</i> (SE)	<i>p</i> -value	<i>B</i> (SE)	<i>p</i> -value
Median household income (<i>U.S. dollars per year</i>) ^c	-0.25 (0.12)	0.04	-0.04 (0.02)	0.04	-2.21 (0.76)	<0.01
Population density	--	--	--	--	1.73 (0.20)	<0.01
Minority (%)	-0.21 (0.17)	0.23	-0.02 (0.03)	0.45	-3.40 (1.07)	<0.01
Urbanicity	0.32 (0.07)	<0.01	0.02 (0.01)	0.05	4.74 (0.72)	<0.01
Model R²	0.13		0.01		0.80	0.32
Percentage of population with at least a high school education (%)	-0.40 (0.45)	0.37	-0.05 (0.06)	0.42	-0.67 (2.90)	0.82
Population density	--	--	--	--	1.72 (0.20)	<0.01
Minority (%)	-0.11 (0.18)	0.54	-0.001 (0.03)	0.98	-2.0 (1.18)	0.09
Urbanicity	0.35 (0.10)	<0.01	0.03 (0.02)	0.09	4.66 (0.82)	<0.01
Model R²	0.13		0.01		0.77	0.31
Poverty (%)	0.72 (0.36)	0.04	0.07 (0.05)	0.22	8.23 (2.29)	<0.01
Population density	--	--	--	--	1.62 (0.20)	<0.01
Minority (%)	-0.19 (0.17)	0.25	-0.01 (0.02)	0.83	-3.86 (1.05)	<0.01
Urbanicity	0.29 (0.07)	<0.01	0.02 (0.01)	0.11	4.86 (0.69)	<0.01
Model R²	0.11		0.01		0.79	0.34
Neighborhood SES z-score	0.02 (0.06)	0.73	-0.01 (0.01)	0.40	0.97 (0.38)	0.01
Population density	--	--	--	--	1.61 (0.20)	<0.01
Minority (%)	0.04 (0.2)	0.84	-0.01 (0.03)	0.82	0.5 (1.30)	0.68
Urbanicity	0.27 (0.1)	<0.01	0.03 (0.02)	0.09	3.79 (0.77)	<0.01
Model R²	0.11		0.01		0.78	0.03

SES, Socioeconomic

^aLinear regression model adjusted for minority and urbanicity

^bLinear regression model adjusted for population density, minority and urbanicity

c₁ Median household income log transformed

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Regression analyses for the relationships between neighborhood socioeconomic characteristics and distance to the nearest supermarket by neighborhood boundaries

	Distance to nearest supermarket (miles) ^a			
	Census tract-based centroid		Block group-based centroid	
	<i>B</i> (SE)	<i>p</i> -value	<i>B</i> (SE)	<i>p</i> -value
Median household income (U.S. dollars per year) ^b	0.59 (0.17)	<0.01	0.40 (0.08)	<0.01
Population density	-0.40 (0.04)	<0.01	-0.38 (0.02)	<0.01
Minority (%)	0.49 (0.24)	0.04	0.21 (0.12)	0.07
Urbanicity	-0.06 (0.16)	0.72	0.05 (0.08)	0.54
Model R²	0.64		0.58	
Percentage of population with at least a high school education (%)	1.46 (0.63)	0.02	0.88 (0.29)	<0.01
Population density	-0.41 (0.04)	0.01	-0.4 (0.02)	<0.01
Minority (%)	0.41 (0.26)	0.11	0.09 (0.12)	0.46
Urbanicity	-0.20 (0.18)	0.26	0.03 (0.09)	0.73
Model R²	0.61		0.57	
Poverty (%)	-1.86 (0.50)	<0.01	-0.96 (0.25)	<0.01
Population density	-0.38 (0.04)	<0.01	-0.39 (0.02)	<0.01
Minority (%)	0.50 (0.23)	0.03	0.12 (0.12)	0.31
Urbanicity	-0.07 (0.15)	0.66	0.12 (0.08)	0.14
Model R²	0.63		0.57	
Neighborhood SES z-score	0.11 (0.09)	0.20	0.07 (0.05)	0.10
Population density	-0.42 (0.04)	<0.01	-0.40 (0.02)	<0.01
Minority (%)	0.31 (0.29)	0.29	0.05 (0.14)	0.72
Urbanicity	-0.09 (0.17)	0.59	0.08 (0.09)	0.35
Model R²	0.60		0.56	

SES, Socioeconomic

^aLinear regression model adjusted for population density, minority and urbanicity

^bMedian household income log transformed