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An activity space approach to understanding how food access is associated with dietary intake and BMI among urban, low-income African American women

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Abstract

Inconclusive evidence for how food environments affect health may result from an emphasis on residential neighborhood-based measures of exposure. We used an activity space approach to examine whether 1) measures of food access and 2) associations with diet and BMI differ between residential and activity space food environments among low-income African American women in Atlanta, Georgia (n=199). Although residential and activity space environments differed across all dimensions of food access, being located farther away from ‘unhealthy’ outlets was associated with lower BMI in both environments. Future research should move beyond asking *whether* residential and activity space environments differ, toward examining *if, how, and under what conditions* these differences impact the estimation of health effects.

Keywords

USA; activity space; diet; BMI; food environment; African American; women

Introduction

Ecological models of health recognize that health-promoting behaviors are most likely to occur within supportive and enabling environments.¹ For many residents of socioeconomically disadvantaged and racial minority communities in the United States, their food environments offer limited access to affordable, healthy foods and abundant access to low-cost, nutrient-poor options.^{2–8} These well-evidenced disparities in the food environment

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are theorized to help explain the substantially higher prevalence of poor diet quality and obesity among low-income and racial minority populations.^{9–13}

To facilitate the development of evidence-based solutions that improve food environments and make them more supportive of healthy eating, researchers have spent several decades seeking to identify the specific pathways through which food environments affect health. Despite amassing a considerable body of research, the evidence base remains inconclusive. Recent systematic reviews examining associations between the food environment and health found that 76% of 1937 associations with obesity¹⁴ and 67% of 205 associations with dietary intake¹⁵ were null. While some findings are suggestive of a negative association between supermarket access and obesity, and a positive association between fast food access and obesity, a clear and consistent evidence base has yet to be established.^{14,16}

Like most place-based health research, food environment research relies primarily on residential neighborhoods to delineate the environments to which people are exposed.¹⁵ However, in reality, people encounter multiple environments as they move through their daily lives: going to work, visiting friends and family, shopping, dropping children off at school, and more. As a result, relying on residential neighborhood boundaries to define exposure may substantially misclassify individual experiences of the food environment. This issue, also referred to as the uncertain geographic context problem (UGCoP),¹⁷ the “local” trap,¹⁸ and the “residential” trap,¹⁹ has become a common critique of food environment research.^{20–23} Increasingly, researchers argue for the use of “activity space” approaches, which seek to measure the totality of places people visit on a routine basis thus providing a more accurate characterization of the environments to which they are exposed.^{24–28}

A small, but growing, number of studies demonstrate how using an activity space approach may offer additional insight into the pathways through which food environments affect health. Several studies have compared how features of the food environment differ between residential neighborhood and activity space measurement approaches. Overall, these studies found that activity spaces are substantially larger than residential neighborhoods,^{24,27} and contain a greater number and density of food outlets.^{24,25,27,29} While these studies provide a useful foundation, they are also subject to several limitations, including the use of single measures of the activity space environment (e.g. standard deviational ellipses²⁴ or buffered travel paths^{29,30}); minimal consideration of temporality (e.g. weighting exposures by time spent at each activity location^{31,32}); the use of single measures of food access (e.g. outlet density or counts^{24,27,30}); and examination of a limited number of food sources (e.g. fast food outlets,²⁷ supermarkets,^{24,27,33} or farmer’s markets²⁴). Further, very few studies have examined associations with health behaviors or outcomes, particularly in low-income and racial minority populations.

Findings from the limited number of activity space studies that have examined associations with diet- and weight-related health are mixed. Some identified associations between food environments and dietary intake in activity spaces, but not residential neighborhoods,^{27,29} some observed associations between food environments and body mass index (BMI) in residential neighborhoods, but not activity spaces,³⁰ and still others found no association between food environments and BMI in either residential neighborhoods or activity spaces.

³⁴ Further, with limited exception,³⁴ prior studies did not address issues of selective daily mobility bias, which can occur in the presence of unmeasured factors associated with the locations a person chooses to visit and the health outcomes of interest.²⁸

Just as neighborhood effects researchers have continuously wrestled with how to define and operationalize “neighborhoods” (e.g. census tracts, home address-based buffers),³⁵ activity space researchers now face similar questions regarding which measurement approaches are most suitable and under which conditions. Commonly used activity space measures can produce very different representations of the environment. Summary measures, such as convex hull polygons and standard deviational ellipses, offer information on the overall size, dispersion, and directionality of the activity space, but may also contain a substantial amount of space to which people are not actually exposed.^{36–38} Travel paths and specific activity locations may provide a more precise representation of the environments to which people are exposed, but raise additional operationalization questions, such as the choice of buffer or bandwidth size, the use of road network versus Euclidean distance, and the consideration of temporality.^{36–38} How the choice of measurement approach may affect the quantification of exposures and the estimation of health effects has received little attention.

The present study uses an activity space approach to refine how exposure to the food environment is defined and measured and to examine how features of the food environment are associated with dietary intake and BMI among low-income African American mothers in Atlanta, GA. We focus on low-income African American women given the disproportionate burden of diet- and weight-related disease in this population^{39,40} likely resulting from historical and contemporary forms of structural racism.⁴¹ We additionally focus on women living with children as they commonly hold primary responsibility for household food purchasing and preparation, and play an important role in shaping the diet- and weight-related health of their families.^{42,43}

We begin by comparing multiple definitions of the residential neighborhood and activity space food environment across three dimensions of food outlet access: density, proximity, and quality. We then assess whether food outlet access is associated with dietary intake or BMI, and whether these associations differ by the use of residential neighborhood versus activity space measures. Using multiple definitions of the activity space environment allows us to examine not only whether results differ between residential neighborhood and activity space environments, but also whether any observed differences are sensitive to how the activity space is defined. We strengthen and extend prior activity space research by comparing multiple measures of the activity space environment, including a time-weighted approach, examining several dimensions of food access and multiple types of food outlets, assessing associations with diet- and weight-related health, including objectively measured BMI, and accounting for potential bias due to selective daily mobility.

Methods

Population and setting.

Women were recruited between May 2017-July 2018 from two safety-net health care clinics in Atlanta, GA, which primarily serve patients who are covered by Medicaid or uninsured.

Women were eligible to participate if they were between the ages of 18–44, African American, residing with at least one child under the age of 18, and able to comprehend written and spoken English (n=203). Women confirmed as currently pregnant were excluded due to potential differences in dietary intake, weight gain, and routine spatial behavior related to pregnancy. The Emory University Institutional Review Board and the Grady Health System Research Oversight Committee approved all study procedures.

Data sources.

Activity space questionnaire.—Activity space data were collected using the Visualization and Evaluation of Routine Itineraries, Travel destinations, and Activity Spaces (VERITAS) questionnaire.²⁸ VERITAS is an interviewer-administered web-based questionnaire with embedded Google Maps functionality, which enables the interviewer and participant to search for, identify, and input each activity location directly on the map. The first author conducted all interviews, which lasted for approximately 45 minutes to 1 hour. Participants begin by identifying key anchor points in their routine travels, including home, work, and school. Participants then search for the name and address of locations they have visited at least once in the previous month. To facilitate recall, participants are prompted through a series of questions about 21 different types of activity locations, including food-seeking locations, commerce or service locations, social locations, family-related locations, and health services locations. For each location, participants also report visit frequency and average visit duration. The questionnaire used in the present study was minimally adapted from the original VERITAS instrument to include additional child-related locations (e.g. children's school; Women, Infants, and Children (WIC) benefits office). Two recent studies evaluating the validity of VERITAS against GPS tracking found that the majority of GPS locations fell within 1,000 meters of self-reported VERITAS locations (median = 88.5%, IQR = 79.2% - 93.3%; median = 92.6%, IQR = 87.6% - 96.3%).^{44,45}

Retail food environment data.—We obtained retail food outlet data from the Georgia Departments of Public Health (GDPH) and Agriculture (GDA) in November and December 2018. Our data cleaning protocol involved four steps: 1) geocoding address data (99% match rate using Google Maps' Geocoding API), 2) removing outlets deemed ineligible for inclusion (e.g. not open to the public), 3) removing duplicate records, and 4) classifying outlets into one of six categories: supermarkets, grocery stores, convenience stores/pharmacies, discount general merchandise stores (e.g. dollar stores), limited service outlets (e.g. fast food, coffee shops, ice cream parlors), and full service restaurants. We classified outlets using a combination of existing categories present in the GDPH and GDA datasets, prior literature,⁴⁶ additional variables present in the datasets, and local knowledge. In the present study, we examined supermarkets, convenience stores/pharmacies, discount general merchandise stores, and limited service outlets.

Socio-demographic and dietary intake survey.—We collected data on dietary intake and socio-demographic characteristics using an interviewer-administered web-based survey created for the study. We measured dietary intake using the Dietary Risk Assessment (DRA), a 26-item food frequency questionnaire (FFQ).⁴⁷

Electronic medical records.—We abstracted data on BMI and smoking status (“never smoker”, “former smoker”, or “current smoker”) from electronic medical records. Whenever possible, we used the BMI calculated from height and weight measured at the medical appointment on the day of the study visit. Twenty-one participants (11%) did not have their weight and/or height measured on the date of the study visit. For these participants, we recorded the BMI from their most recent appointment, the majority of which were within one month of the study visit.

Measures.

Defining the residential neighborhood and activity space environments.—The residential neighborhood was defined in two ways: 1) the participant’s residential census tract (women were nested within 113 unique census tracts), and 2) the 0.5-mile line-based road network buffer⁴⁸ surrounding the participant’s residential address (a buffer size used in prior food environment research¹⁶ and one that represents a reasonable walking distance) (Figure 1). Although researchers have questioned the use of arbitrary administrative boundaries like census tracts to proxy neighborhood environments, such measures continue to be widely used.²¹ We used a residential census tract measure in the present study to allow for comparison with other definitions of the residential and activity space environments, as well as with the existing literature. We defined the activity space environment in four ways: 1) the convex hull polygon, or the smallest convex polygon containing all of the participant’s activity locations, 2) the unweighted activity space, or the set of points representing each of the participant’s activity locations, 3) the weighted activity space, or the set of points representing each of the participant’s activity locations weighted for the frequency and duration of each visit (calculated as hours per month), and 4) the non-residential activity space, or the set of points representing each of the participant’s activity locations except her residence, also weighted for the frequency and duration of each visit. The VERITAS questionnaire does not ask participants to report the number of hours per day spent at home. We imputed time spent at home using gender- and employment status-specific estimates from the American Time Use Survey (11.7 and 13.5 hours per day for employed and unemployed participants, respectively).

Exposure variables.

Food access. We examined three dimensions of food access: density, proximity, and quality. We calculated density and proximity separately for each outlet category. We used kernel density estimation (KDE), with a one-mile bandwidth (a bandwidth size commonly used in prior food environment research^{49–51}), to create a continuous surface of outlet density per square mile for each outlet category. We then overlaid the participant’s residential census tract, 0.5-mile road network buffer, and activity locations on the continuous surface. For the residential census tract, 0.5-mile road network buffer, and convex hull polygon, we extracted the average outlet density within each polygon. For the unweighted and weighted activity locations, we extracted the outlet density at each point and calculated an average across all of the activity locations for each participant.

We defined proximity as road network distance to the nearest outlet. For the residential census tract we calculated distance from the census tract centroid, for the road network

buffer we calculated distance from the participant's residential address, and for the unweighted and weighted activity locations we calculated distance from each point to the nearest outlet and then calculated an average across all of the activity locations for each participant. There is no conceptually meaningful measure of proximity for the convex hull polygon.

We assessed quality of the food environment using the Centers for Disease Control and Prevention's modified retail food environment index (mRFEI).⁵² We used the KDE approach described above to create continuous mRFEI surfaces and extract values for each residential neighborhood and activity space environment. The mRFEI is calculated as the proportion of healthy food retailers in a given area out of the total number of healthy and unhealthy retailers in the area. The mRFEI classifies supermarkets and large grocery stores (10–49 employees) as healthy, and convenience stores, limited service outlets, and small grocery stores as unhealthy. We also classified discount stores as unhealthy given their limited selection of healthy foods.⁵³ We excluded grocery stores from our mRFEI calculation as our data did not include information on retailer size and we did not have sufficient justification for categorizing them as healthy or unhealthy. To examine the implications of this decision, we ran two sensitivity analyses, the first classifying grocery stores as healthy and the second classifying grocery stores as unhealthy. Overall, our conclusions were unchanged.

Selective daily mobility bias.: Importantly, for all measures of access in the activity space, we addressed the issue of selective daily mobility bias.²⁸ Bias can be minimized by excluding activity points that match the environmental exposure of interest when calculating measures of food access in the participant's activity space. For example, when calculating convenience store density in a participant's activity space, we excluded activity points that were convenience stores (i.e. convenience stores at which the participant reported shopping). In doing so, if we observe an association between convenience store density and obesity, for example, we can be more certain that there is a true association between the environmental exposure and the outcome, rather than a spurious association driven by another factor associated with a woman's propensity to shop at a convenience store and her weight status. We also conducted sensitivity analyses not accounting for potential bias due to selective daily mobility. Overall, results were similar and our overarching conclusions were unchanged. This suggests that in this particular population and setting, this form of bias did not impact findings. However, selective daily mobility bias may occur in other contexts and should be assessed in future studies.

Outcome variables.

Dietary intake.: The DRA is a 26-item FFQ that measures usual intake of foods and beverages associated with cardiovascular disease risk.^{47,54} A single dietary intake score (ranging from 0–52) is obtained by summing the scores from four subsections: 1) nuts, oils, dressings, and spreads; 2) vegetables, fruit, whole grains, and beans; 3) drinks, desserts, snacks, eating out, and salt; and 4) fish, meat, poultry, dairy, and eggs. A higher score represents a healthier dietary pattern. We treated the score as continuous in all analyses. The DRA was validated against the Fred Hutchinson Cancer Research Center FFQ (FHCRC-

FFQ) and serum carotenoids in a sample of low-income, midlife, southern, African American women. Correlations between total DRA score and three FHCRC-FFQ diet quality scores ranged from 0.57 to 0.60 and a DRA fruit and vegetable index was significantly associated with serum carotenoids.⁵⁴

BMI. We abstracted BMI from electronic medical records where it is automatically calculated from the patient's measured weight and height. We treated BMI as a continuous variable in all analyses.

Control variables.—The following control variables were included in adjusted analyses: age (continuous); education (less than high school; high school diploma or GED; some college or technical school; Associate's degree or higher); employment status (full-time; part-time; unemployed, seeking employment; unemployed, not seeking employment); marital status (currently married; not married, living with a partner; never married; divorced, widowed, or separated); household size (continuous); annual income (less than \$5,000; \$5,000-\$9,999; \$10,000-\$19,999; \$20,000-\$29,999; greater than \$30,000); car ownership (yes; no); receipt of Supplemental Nutrition Assistance Program (SNAP) benefits (yes; no); and smoking status (current smoker; former smoker; never smoker). We constructed additional control variables representing the average density and proximity, respectively, of "healthy" (i.e. supermarkets) and "unhealthy" (i.e. convenience stores/pharmacies, discount stores, and limited service outlets) retailers in each environment, to address the possibility that healthy and unhealthy retailers are located next to one another (e.g. in the same strip mall or shopping center). For models estimating the association between supermarket access and dietary intake/BMI, we adjusted for the average density or proximity of "unhealthy" retailers in the same environment, and for models estimating the association between access to each type of "unhealthy" retailer and dietary intake/BMI, we adjusted for the density or proximity of "healthy" retailers in the same environment.

Analysis.

We excluded four participants due to incomplete data or data quality concerns, resulting in a final analytic sample of 199 women. In addition, two women declined to share their residential address. All measures of the residential environment reflect a sample size of 197 women. We excluded seven women who were missing height and/or weight from all models where BMI was the outcome.

To assess whether food access was significantly different across environments, we constructed 'stacked' models where each measure of food access (density, proximity, and mRFEI) in each of the six environments (residential census tract, 0.5-mile road network buffer, convex hull polygon, weighted activity space points, unweighted activity space points, and non-residential activity space points) was nested within women. We used generalized estimating equations (GEE) to control for correlated measures within women and compare values of each food access measure within each environment to the value of the food access measure in the reference environment (residential census tract).

We then used GEE to estimate adjusted associations between food access and 1) dietary intake and 2) BMI, controlling for the correlation of women within residential census tracts.

In adjusted models, supermarket and discount store density variables were scaled to represent an increase of one outlet per 10 square miles. Food outlet proximity variables were scaled to represent a 0.25-mile increase to the nearest outlet for all food outlet categories. We adjusted all models for the control variables listed above. We also sought to adjust for area-level median income, but, due to evidence of multicollinearity, did not include the variable in our final models. Estimates were largely consistent across both sets of models with regard to sign and significance, and our overall conclusions were unchanged. Statistical tests were considered significant at $p < 0.05$. ArcGIS Network Analyst (Version 10.6. Redlands, California: Environmental Systems Research Institute, Inc.) was used to calculate road network distances; all other analyses were conducted in R 3.6.1.

Results

Women were, on average, 32 years of age ($SD=6.7$) (Table 1). The majority had a high school diploma (42.7%) or less (13.6%), over half were employed (full-time=37.2%, part-time=19.6%), and most women earned less than \$30,000 per year. Nearly three quarters of women were single and had never been married, and the mean household size was four people ($SD=1.6$). Over one-third of women did not own a car (36.7%). The mean DRA score was 28.5 ($SD=5.2$; range 13–42), and mean BMI was 34.2 ($SD=9.2$; range 20.6–56.1).

Comparing food access across residential neighborhood and activity space environments.

All measures of food access (i.e. density, proximity, and quality) differed between residential neighborhood and activity space definitions of the food environment (Table 2). The greatest differences were observed between the residential census tract and both the unweighted activity space (i.e. activity points not weighted by frequency or duration of visit) and the non-residential activity space. Overall, food outlet density was higher in the activity space environments than the residential neighborhood environments. For example, compared to the residential census tract, the unweighted activity space included one additional convenience store/pharmacy per square mile ($M=3.60$; $SD=2.58$ vs. $M=4.61$; $SD=1.48$), and over five additional limited service outlets per square mile ($M=5.57$; $SD=8.00$ vs. $M=10.89$; $SD=5.04$).

Distance to the nearest food retailer was shorter in the activity space environments than the residential neighborhood environments. For example, the nearest supermarket was located an average of 1.81 miles ($SD=0.83$) from the residential census tract centroid and an (unweighted) average of 1.20 miles ($SD=0.29$) from the activity space locations, and the nearest limited service outlet was located an average of 0.83 miles ($SD=0.54$) from the residential census tract centroid and an (unweighted) average of 0.28 miles ($SD=0.11$) from the activity space locations. This pattern was the same across all outlet types. The mRFEI was slightly higher (i.e. healthier) in the convex hull polygon compared to the residential census tract.

There were no major differences in food outlet density or mRFEI across the residential neighborhood environment definitions (e.g. census tract and 0.5-mile road network buffer), however, distance to the nearest food outlet was slightly shorter from the residential address than from the census tract centroid. Because the weighted activity space environment

accounted for the time each woman spent at home, the average density, proximity, and mRFEI of food outlets in the weighted activity space environment generally fell between averages for the residential neighborhood and unweighted activity space environments. Mean food outlet density in the convex hull polygon also typically fell between the residential neighborhood and unweighted activity space means.

Associations of food access with dietary intake and BMI among low-income African American mothers.

Food access (i.e. density, proximity, and quality) was not associated with dietary intake in either the residential neighborhood (i.e. census tract or 0.5-mile road network buffer) or activity space environments (i.e. convex hull polygon, unweighted activity space, weighted activity space, or non-residential activity space) (Table 3).

Longer distance to the closest retailer was associated with a lower BMI for all “unhealthy” outlet types (i.e. convenience stores/pharmacies, discount stores, and limited service outlets) in the residential neighborhood and activity space environments (Table 4). For convenience stores/pharmacies, associations were significant in the census tract and unweighted activity space (i.e. activity points not weighted by visit frequency and duration), and for discount stores, associations were only significant in the 0.5-mile road network buffer. For limited service outlets, associations were significant in the census tract, 0.5-mile road network buffer, and weighted activity space. No associations were significant in the convex hull polygon or non-residential activity space.

The magnitude of association varied across environment types. For reference, a beta coefficient equal to -1 can be interpreted as a 1-point decrease in BMI for every 0.25-mile increase in distance to the nearest food outlet. For a woman who is 5'4", a 1-point BMI decrease is equivalent to approximately 6 fewer pounds. For convenience stores/pharmacies, estimates ranged from -1.25 (SE=0.38) in the census tract to -4.44 (SE=1.72) in the unweighted activity space. For limited service outlets, estimates ranged from -0.70 (SE=0.34) in the 0.5-mile road network buffer to -1.30 (SE=0.28) in the census tract. Neither retailer density nor mRFEI was associated with BMI.

Both definitions of the residential neighborhood environment (i.e. census tract and 0.5-mile road network buffer) produced similar estimates of the association between retailer density and BMI. In contrast, estimates of the association between retailer density and BMI in the activity space environment differed from those in the residential neighborhood environment as well as from one another, primarily in regard to the magnitude of association. Overall, coefficient sign and significance were similar across the residential neighborhood and activity space environments, with the exception of the non-residential activity space; coefficients for supermarket and discount store density were positive in all environments (i.e. census tract, 0.5-mile road network buffer, convex hull polygon, unweighted activity space, and weighted activity space) except the non-residential activity space. For retailer proximity and mRFEI, the magnitude of association differed between the residential neighborhood and activity space environments as well as among the respective residential neighborhood and activity space definitions. While coefficient sign was consistent across all environments,

magnitude was generally greatest in the unweighted activity space and smallest in the 0.5-mile road network buffer.

Discussion

This study used an activity space approach to examine how food access is associated with dietary intake and BMI among low-income African American mothers in Atlanta, GA. Residential neighborhood and activity space environments differed across all three dimensions of food access—density, proximity, and quality—suggesting that the measurement of food access is sensitive to how the food environment is defined. Despite these differences, activity space measures did not help clarify the pathways through which food environments may affect diet- and weight-related health. Being located farther away from ‘unhealthy’ outlets was associated with lower BMI using both residential neighborhood and activity space definitions of the environment, while food access was not associated with dietary intake in either environment. Further, all observed associations would have been captured by solely examining the residential neighborhood environment: one association was only observed in the residential neighborhood, and no associations were observed in the purely non-residential activity space. The magnitude and significance of associations varied depending on how we defined the activity space environment. Our results highlight the need for additional research that moves beyond describing differences between residential and activity space environments to explore how the respective health effects of residential neighborhoods and activity spaces may vary across populations and places, and how the use of different definitions of the activity space may affect results.

Similar to previous studies, we found that residential neighborhood measures underestimated the density of food retailers to which women were routinely exposed.^{24,25,55} These findings can likely be explained by conventional urban zoning ordinances that separate residential and commercial land use, resulting in higher retail density in non-residential areas. Similarly, women’s routine activity destinations were located in closer proximity to food outlets than were their homes. Ongoing zoning reforms in Atlanta and other cities, which aim to prioritize regulation of the physical form and design of new developments, rather than strict land use requirements (e.g. mixed use development),⁵⁶ may affect future findings. Less pronounced differences in the mRFEI across the residential and activity space environments may reflect the measure’s limited variability in the study area.

Notably, differences between residential neighborhood and activity space environments did not substantively affect our conclusions regarding how food access may affect dietary intake and BMI. Although activity space measures provided a more comprehensive picture of the environments to which women were routinely exposed, residential neighborhoods appeared to be particularly salient areas of exposure. This finding is consistent with results from a study of low-income housing residents in New York City, which found that higher grocery store density in the residential neighborhood, but not the activity space, was associated with a lower BMI.³⁰ However, other studies conducted with adolescents in Nova Scotia, Canada and predominantly low-income African American and Latina women in Detroit, identified associations between food environments and dietary intake in activity spaces, but not residential neighborhoods,^{27,29} while no associations with BMI were found in either

residential neighborhoods or activity spaces among children in North Carolina.³⁴ Importantly, the studies that identified associations between activity space food environments and dietary intake/BMI were unable to address potential bias due to selective daily mobility given their use of GPS-defined activity spaces, which provide spatial and temporal data on locations visited, but typically do not provide information on the *type* of location visited (e.g. whether a location was a supermarket, worksite, doctor's office, etc.).

Our findings may be explained by the fact that people spend a considerable amount of time in their residential neighborhoods, which often serve as a hub around which many activities of daily life revolve. As such, the food-related behaviors and norms that dominate in the residential neighborhood may be particularly influential in patterning diet- and weight-related behaviors and outcomes even for women who shop outside of their immediate residential neighborhoods.²⁰ The residential neighborhood may have been especially relevant for the women in our sample, nearly half of whom were unemployed and over one third of whom did not own a car. Research conducted by Inagami et al. in Los Angeles identified a stronger association between neighborhood restaurant density and BMI among residents who did not own a car.⁵⁷ Further, Kestens et al.'s finding that residential neighborhoods were more strongly associated with weight outcomes among women, while activity space environments were more strongly associated with weight outcomes among men,⁵⁸ suggests that gender differences in time use and mobility may benefit from further study. However, it is also possible that our findings reflect residual confounding due to neighborhood selection processes, or limitations of our approach to measuring activity space, which we discuss further below.

Acknowledging the multidimensionality of food access is also critical to understanding how food environments affect health.^{21,59,60} Of the three dimensions of food access measured, proximity was the most consistently associated with BMI. Because the saliency of each dimension likely depends upon the reasons for using a particular outlet, it is unsurprising that being located farther away from "unhealthy" outlets, including convenience stores/pharmacies, discount stores, and limited service outlets, was associated with lower BMI, while there was no association between supermarket proximity and BMI. Convenience is one of the most frequently cited reasons for using limited service outlets and convenience stores.^{61,62} If women are not located in close proximity to such outlets, they may be unlikely to go out of their way to find one. The use of convenience stores/pharmacies, discount stores, and limited service outlets may also be triggered by exposure to the outlet in the first place through advertisements, price promotions, product placement, and the availability of single serving or pre-packaged drinks and snacks.⁶³ In contrast to "unhealthy" outlets, supermarket trips are often pre-planned and influenced by numerous factors beyond convenience including affordability, family friendliness, acceptance of SNAP benefits, availability of culturally relevant foods, and more, and women are often willing to travel beyond their immediate environments to find a supermarket that fulfills these criteria.^{64–67}

Surprisingly, proximity to "unhealthy" outlets, while associated with BMI, was not associated with dietary intake. BMI is a more distal outcome than diet, and it is possible that food access is correlated with other features of the environment, such as green space or walkability (and thus, physical activity), that also affect BMI.²² In other words, features of

the food environment may be one element in a complex and synergistic network of environmental influences on BMI, rendering it more difficult to detect precise intermediary pathways. It is also possible that our measure of dietary intake did not adequately capture women's usual diets. Self-report dietary assessments are notoriously prone to measurement error and using more rigorous instruments such as 24-hour dietary recalls may be necessary.⁶⁸

Unlike proximity, food outlet density was not consistently associated with BMI or dietary intake. Understanding this finding requires consideration of the hypothesized pathways through which food outlet density affects diet- and weight-related behaviors. Do we believe that exposure to a higher density of unhealthy outlets triggers more cravings or leaves us more susceptible to marketing techniques? Is there a threshold at which higher densities no longer matter? For example, is exposure to seven fast food outlets over the course of a day less influential than exposure to ten? Given that the majority of Americans shop at a supermarket,⁶⁹ do we believe that exposure to a higher density of supermarkets will increase shopping frequency or prompt the purchase of healthier items? Because our study was conducted in a large metropolitan area with many food outlets, it is possible that density was less salient because women were already exposed to a high number of unhealthy food outlets, and able to shop at supermarkets aligned with their preferences. In contrast, density may be more meaningful in rural or less densely populated areas where the range of densities differentiates areas with very few options from those with much greater availability.

Our results indicate that activity space researchers must be mindful of how they choose to define the activity space environment. The magnitude, significance, and, at times, direction of the associations between food access and BMI differed across activity space definitions. The non-residential activity space, the only measure that did not include the participant's home, differed most from the other activity space measures: some coefficients differed in direction from all other residential and activity space definitions and we observed no significant associations between food access and BMI in the non-residential activity space. These results are consistent with the observed salience of the residential environment in our sample. However, in other more mobile populations—those in which people are more likely to work or attend school, have access to a car, or live in areas with robust public transit options—the non-residential environment may be an important source of exposure. Our findings also raise questions about the utility of the convex hull polygon as a representation of the activity space environment. Food access in the convex hull polygon was not associated with dietary intake or BMI. Consistent with our findings, Zenk et al. found that fast food outlet density in participants' daily path areas was associated with dietary intake, while density in their standard deviational ellipses was not.²⁷ Still, additional research is needed to clarify when and how these measures may be useful in food environment research, for example, by offering insight into the overall size, dispersion, and directionality of activity spaces.

Our comparison of weighted and unweighted activity spaces underscores the complexity of defining what it means to be 'exposed' to an environment. Our choice to weight by visit frequency and duration assumes that the longer a woman spends in a given place, the more

likely it is to affect her. However, this is not necessarily true. While the home address typically carried the most weight in our analyses, a not insignificant proportion of time at home may have been spent sleeping. Is a woman ‘more exposed’ to the food environment around her home because she sleeps next to it each night? Is she ‘less exposed’ to the food environment around her child’s school where she goes every morning and afternoon, but only for five minutes? Decisions regarding the use of unweighted or weighted measures and various approaches to weighting will likely depend on the dimensions of access and types of food outlets in question, as well as characteristics of the study population and setting, and require further study.

Our study makes several important contributions to the small, but growing, body of literature comparing residential neighborhood and activity space measures of the food environment and their effect on diet- and weight-related health. Our study is one of very few to examine both dietary intake and BMI and is further strengthened by our use of objectively measured BMI. Importantly, we explicitly addressed potential biases due to selective daily mobility, which few prior studies have been able to do. An additional strength of our study was the examination of multiple dimensions of food access across multiple types of food outlets. Our results demonstrate that food access is a multidimensional construct, and that the saliency of each dimension may vary by outlet type. Understanding where, when, and how food access affects health, can strengthen the design and implementation of interventions seeking to make food environments more supportive of healthy eating. Further, by focusing our study on low-income African American women, we were able to highlight that important differences in food access exist even within socio-demographically similar populations. This should serve as a reminder that interventions cannot treat low-income or racial minority communities as monolithic entities.

Despite these strengths, our study was subject to several limitations. We acknowledge that residential self-selection is an important source of bias in studies examining the association between neighborhoods and health. Because one of the dominant forces sorting people into neighborhoods in the U.S. is residential segregation by race and class, we anticipate that neighborhood self-selection is less of an issue in our racially and socioeconomically homogeneous sample. Still, longitudinal and quasi-experimental study designs that capture changes in the food environment and residential mobility are necessary to fully address these potential biases. Next, the VERITAS questionnaire collects self-reported data, which are subject to recall, social desirability, and other attendant biases. Further, VERITAS only assesses a subset of all locations visited by the participant and does not capture the routes used to travel between locations. As a result, there may be additional areas of exposure relevant to dietary intake or BMI that were not assessed. The errors present in most secondary retail food environment data sources have been widely discussed and may have resulted in some misclassification of our exposure measures, including retailer openings and closings that may have occurred in the months between data collection and the acquisition of secondary data.⁷⁰ That said, government sources are among the most accurate,⁷⁰ our timeframes for data collection and secondary data acquisition were well-aligned, and we subjected our data to a rigorous cleaning protocol. Finally, our sample was not randomly selected and results are not intended to generalize to the broader population of low-income African American mothers in Atlanta, GA or other cities across the US.

Conclusion.

Although activity space approaches can more precisely represent the environments to which people are exposed, they do not offer a magic bullet for understanding the complex pathways through which food environments affect diet- and weight-related health. Future studies will likely continue to find differences between residential neighborhood and activity space environments due to land use restrictions and other elements of urban design. As such, an important question becomes not only *whether* environments differ, but *if, how, and under what conditions* these differences impact the estimation of health effects. Future research will need to incorporate rigorous measures of health behavior and outcomes, recruit samples or utilize existing data that allow for stratified and interaction analyses, and intentionally choose measures of activity space that are conceptually aligned with what is known about spatial behavior in the population of interest. A wide array of study designs and methods can assist in accomplishing these tasks: for example, researchers can leverage large datasets from transport and travel surveys to examine differences across populations and places; examine natural changes in the food environment to capture the spatial and temporal dimensions of food access and their impact on health; use systems science tools, such as simulations and modeling, to test diverse approaches to defining, measuring, and altering activity space environments, and apply mixed methods approaches, like geo-ethnography,⁷¹ to enhance our understanding of the dynamic relationships between people and place.

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Highlights

- Food access differed between residential neighborhood and activity space measurement approaches
- Lower unhealthy food access was associated with lower BMI regardless of measurement approach
- The magnitude and significance of associations varied depending on how the activity space was defined

Figure 1.

Visual representations of the residential neighborhood and activity space environments

Notes. Average outlet density (outlets per square mile) within each polygon extracted for residential census tract, 0.5-mile road network buffer, and convex hull polygon. For weighted and unweighted activity space points, outlet density at each point extracted and averaged across all activity locations for each participant. Same approach used to calculate modified Retail Food Environment Index (mRFEI). Proximity (i.e. road network distance) to nearest outlet calculated from residential census tract centroid and participant's residential address: no measure of proximity calculated for convex hull polygon. For weighted and unweighted activity space points, distance from each point to nearest outlet calculated and averaged across all activity locations for each participant.

Table 1.

Characteristics of low-income African American mothers in Atlanta, GA (n=199)

	N or Mean	% or SD
Age (<i>mean, SD</i>)	32	6.7
Education (<i>n, %</i>)		
Less than high school	27	13.6
HS diploma or GED	85	42.7
Some college/technical school	54	27.1
Associate's degree or higher	33	16.6
Employment status (<i>n, %</i>)		
Full-time	74	37.2
Part-time	39	19.6
Unemployed, seeking employment	49	24.6
Unemployed, not seeking employment	37	18.6
Marital status (<i>n, %</i>)		
Currently married	22	11.1
Not married, living with partner	21	10.6
Never married	143	71.9
Divorced/separated/widowed	13	6.5
Household size (<i>mean, SD</i>)	4.1	1.6
Income (annual) (<i>n, %</i>)		
Less than \$5,000	55	27.6
\$5,000-\$9,999	31	15.6
\$10,000-\$19,999	47	23.6
\$20,000-\$29,999	32	16.1
Greater than \$30,000	34	17.1
Car ownership (<i>n, %</i>)		
Yes	126	63.3
No	73	36.7
SNAP benefits (<i>n, %</i>)		
Yes	157	78.9
No	42	21.1
Smoking status (<i>n, %</i>)		
Current	41	20.6
Former	23	11.6
Never	135	67.8
Dietary quality (0–52) (<i>mean, SD</i>)	28.5	5.2
BMI (<i>mean, SD</i>)	34.2	9.2

Table 2.

Comparing food access in the residential neighborhood and activity space environments (n=199)

	Residential neighborhood ^a			Activity space		
	<i>Census tract (ref)</i> ^b	<i>Road network (0.5-mile)</i> ^c	<i>Convex hull polygon</i>	<i>Full activity space points, weighted (hours/month)</i>	<i>Full activity space points, unweighted</i>	<i>Non-residential activity space points, weighted (hours/month)</i>
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
<i>Supermarkets</i>						
Density (retailers/mi ²)	0.16 (0.12)	0.17 (0.13)	0.22 (0.08)	0.19 (0.12)	0.25 (0.08)	0.25 (0.16)
Proximity (distance to closest retailer) (miles)	1.81 (0.83)	1.66 (0.94)		1.60 (0.77)	1.20 (0.29)	1.35 (0.82)
<i>Convenience stores</i>						
Density (retailers/mi ²)	3.60 (2.58)	3.64 (2.52)	3.62 (1.30)	3.77 (2.13)	4.61 (1.48)	4.16 (2.49)
Proximity (distance to closest retailer) (miles)	0.69 (0.45)	0.52 (0.44)		0.48 (0.36)	0.26 (0.10)	0.37 (0.38)
<i>Discount stores</i>						
Density (retailers/mi ²)	0.42 (0.16)	0.45 (0.17)	0.39 (0.08)	0.43 (0.14)	0.43 (0.08)	0.40 (0.14)
Proximity (distance to closest retailer) (miles)	1.25 (0.82)	1.08 (0.77)		1.07 (0.59)	0.90 (0.26)	1.02 (0.62)
<i>Limited service outlets</i>						
Density (retailers/mi ²)	5.57 (8.00)	5.54 (7.84)	7.10 (3.37)	6.73 (6.70)	10.89 (5.04)	9.69 (8.38)
Proximity (distance to closest retailer) (miles)	0.83 (0.54)	0.67 (0.55)		0.60 (0.46)	0.28 (0.11)	0.40 (0.44)
<i>mRFEI</i> (% healthy out of total)	2.30 (1.48)	2.28 (1.67)	2.63 (0.92)	2.29 (1.38)	2.33 (0.82)	2.41 (1.58)

^an=197 for residential neighborhood environments because 2 participants did not share their residential address^bFor proximity measures, this column displays distance from the residential census tract centroid to nearest outlet^cFor proximity measures, this column displays distance from the residential address to nearest outlet*Notes.* Residential census tract is the reference category for all comparisons; mRFEI = modified Retail Food Environment Index; bolded text indicates p<.05.

Table 3.

Adjusted associations between food access and diet quality among low-income African American mothers in Atlanta, GA (n=199)

	Residential neighborhood ^a						Activity space						Non-residential activity space points, weighted (hours/ month)					
	Census tract ^b			Road network (0.5-mile) ^c			Convex hull polygon			Full activity space points, weighted (hours/month)						Full activity space points, unweighted		
	β	SE	p	β	SE	p	β	SE	p	β	SE	p	β	SE	p	β	SE	p
Supermarkets																		
Density (retailers/10 mi ²)	0.05	0.36	0.88	-0.07	0.39	0.86	-0.06	0.46	0.90	0.06	0.57	0.91	0.35	0.54	0.51	0.18	0.22	0.41
Proximity (distance to closest retailer) (miles)	0.08	0.12	0.50	-0.05	0.12	0.70				0.002	0.59	1.00	-0.14	0.35	0.69	-0.03	0.15	0.84
Convenience stores																		
Density (retailers/mi ²)	-0.02	0.16	0.89	-0.03	0.18	0.87	0.16	0.27	0.54	0.04	0.33	0.91	0.04	0.31	0.89	0.20	0.17	0.23
Proximity (distance to closest retailer) (miles)	-0.14	0.30	0.64	0.38	0.27	0.16				0.17	0.40	0.67	0.66	1.00	0.50	-0.29	0.37	0.44
Discount stores																		
Density (retailers/10 mi ²)	0.003	0.41	0.99	-0.20	0.17	0.23	0.45	0.50	0.36	-0.02	0.28	0.94	0.15	0.58	0.79	-0.12	0.32	0.71
Proximity (distance to closest retailer) (miles)	-0.08	0.15	0.59	0.02	0.47	0.97				-0.04	0.14	0.78	-0.02	0.32	0.96	-0.08	0.15	0.58
Limited service outlets																		
Density (retailers/mi ²)	-0.01	0.10	0.89	-0.01	0.08	0.91	0.04	0.10	0.67	0.02	0.14	0.91	0.03	0.07	0.64	0.07	0.05	0.15
Proximity (distance to closest retailer) (miles)	-0.29	0.23	0.21	0.23	0.20	0.24				0.10	0.32	0.75	-0.31	0.87	0.72	-0.32	0.33	0.33
mRFEI	0.12	0.28	0.67	0.10	0.36	0.78	0.05	0.38	0.89	-0.03	0.42	0.94	-0.39	0.57	0.49	-0.24	0.22	0.28

^a n=197 for residential neighborhood environments because 2 participants did not share their residential address^b For proximity measures, this column displays distance from the residential census tract centroid to nearest outlet^c For proximity measures, this column displays distance from the residential address to nearest outlet

Table 4.

Adjusted associations between food access and BMI among low-income African American mothers in Atlanta, GA (n=192)^a

	Residential neighborhood ^b						Activity space					
	Census tract ^c			Road network (0.5-mile) ^d			Convex hull polygon			Full activity space points, weighted (hours/month)		
	β	SE	p	β	SE	p	β	SE	p	β	SE	p
<i>Supermarkets</i>												
Density (retailers/10 mi ²)	0.51	0.68	0.45	0.53	0.61	0.39	0.01	1.00	0.99	0.19	0.72	0.79
Proximity (distance to closest retailer) (miles)	0.32	0.23	0.17	0.09	0.22	0.65				0.33	0.29	0.25
<i>Convenience stores</i>												
Density (retailers/mi ²)	0.48	0.25	0.05	0.40	0.24	0.10	0.26	0.53	0.62	0.52	0.30	0.09
Proximity (distance to closest retailer) (miles)	-1.25	0.38	0.001	-0.69	0.41	0.09				-0.96	0.54	0.08
<i>Discount stores</i>												
Density (retailers/10 mi ²)	0.30	0.45	0.51	0.31	0.41	0.45	1.30	0.91	0.15	0.33	0.44	0.46
Proximity (distance to closest retailer) (miles)	-0.19	0.25	0.43	-0.51	0.24	0.04				-0.65	0.33	0.05
<i>Limited service outlets</i>												
Density (retailers/mi ²)	0.06	0.09	0.51	0.06	0.10	0.55	0.01	0.20	0.96	0.11	0.13	0.37
Proximity (distance to closest retailer) (miles)	-1.30	0.28	<.001	-0.70	0.34	0.04				-0.90	0.40	0.02
<i>mRFEI</i>	-0.68	0.48	0.15	-0.34	0.42	0.41	-1.21	0.73	0.10	-0.54	0.58	0.35
										-1.32	0.89	0.14
										-0.24	0.47	0.61

^a n=192 because 7 participants were missing BMI measures^b n=190 for residential neighborhood environments because 2 participants did not share their residential address

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For proximity measures, this column displays distance from the residential census tract centroid to nearest outlet
For proximity measures, this column displays distance from the residential address to nearest outlet