Association between Food Swamps and the Diet Quality of Household Food Purchases in a Nationwide Sample

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A thesis

submitted in partial fulfillment of the

requirements for the degree of

Master of Public Health

University of Washington

2020

Committee:

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Program Authorized to Offer Degree: Nutritional Sciences

University of Washington

Abstract

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Background: Food swamp is a term for local food environments where there exists a higher density of unhealthy food retailers selling more energy-dense, nutrient-poor food offerings relative to healthier options. Those living in a food swamp have been found to have higher rates of negative health outcomes compared to those living outside a food swamp, but the mechanism for this relationship is unclear.

Objective: To examine the association between living in a food swamp and the diet quality of household food purchases in a cross-sectional analysis of a nationwide sample.

Methods: Data from the National USDA Household Food Acquisition and Purchase Survey (2012-2013; n = 4,692 households) were analyzed, which included a detailed collection of all foods purchased in the household for one week. The physical food environment index, which we termed the “food swamp score” was calculated for each household as the ratio of the counts of unhealthy food retailers to the counts of all food retailers for a 1-mile radius around the home for urban households and a 5-mile radius around the home for rural households. Healthy eating index (HEI) scores were calculated for the total of each household's food purchasing, providing a 0-100 score of the healthfulness of all foods purchased at food stores and restaurants. Linear regression models were used in the primary analysis to examine the association between quintiles of the food swamp scores and the healthy eating index (HEI) scores for each household, stratifying by urban versus rural census tract and controlling for covariates, including race/ethnicity, education, overall health status, household income, household car ownership, household food security, and supplemental nutrition assistance program (SNAP) participation. Secondary analyses included further stratifying models by car ownership.

Results: The mean household HEI score across all households was 53 (SD = 14), and the mean food swamp score across all households was 89 (SD = 20). No statistically significant associations were found between household food swamp score quintiles and HEI scores of weekly household food purchases when adjusted for covariates for households in either urban or rural census tracts. No statistically significant associations were found when further stratifying these models by car ownership.

Conclusion: We found no association between the food swamp score and the dietary quality of all household food purchases in a nationally representative sample with a detailed collection of all food purchases.

Introduction

While diet quality in the U.S. population has generally been improving in the past decade, overall diet quality is suboptimal.[1] On the population level, Americans are consuming too few fruits, vegetables, and whole grains, and too much sodium, refined grain, added sugar and saturated fat.[2] Additionally, there are noted disparities in diet quality in the U.S. by income and race, with low-income Americans and communities of color reporting lower diet quality compared to higher-income and white communities.[3] Poor diet quality is a major contributor to the national burden of chronic disease, including cardiovascular disease, diabetes, hypertension, obesity, and some cancers.[4] In the U.S., nearly half of Americans have one or more chronic diseases that can be attributed to a suboptimal diet.[5,6] Preventable chronic disease also contributes significantly to excess mortality,[7] and medical costs for treatment of these conditions are a significant portion of total healthcare expenditures, estimated to be approximately one trillion dollars in 2014.[8]

Food choices and diet quality are influenced by a broad array of complex factors. Bleich and colleagues describe how these determinants can be broadly grouped into three levels: individual, local environment, and macro-level. Macro-level factors can include agricultural, environmental, political, and economic systems that broadly shape the overall food supply.[4] Meanwhile, individual-level food choices are thought to be strongly driven by taste, price, and convenience,[9] and food manufacturers have responded to these consumer preferences by increasing the availability and affordability of energy-dense foods in the food supply.[10] However, the local food environment can influence the degree to which an individual is exposed to these macro-level factors. For example, even in the context of a food supply that contains vast amount of less healthy options, modifying the local food environment to make healthy foods more abundant and affordable may be a viable strategy of health promotion to improve population diet quality.[4]

Understanding how the neighborhood food environment affects diet quality and diet-related disease has been an active area of research.[12] Much of the focus of the initial research on the local food environment examined the effects of living in a food desert or the proximity to a grocery store or supermarket.[13] However, natural experiments and quasi-experimental studies measuring the impact of introducing new supermarkets in food deserts have found there are minimal to no effects of new supermarkets on residents' diet quality or health outcomes[14] or any observed improvements in the availability or marketing in nearby food stores outside of the new supermarket.[17] Some evidence suggests that increased density of retailers with generally unhealthy food options, such as fast-food restaurants and convenience stores, in the local food environment has a greater effect on contributing to poor diet quality than the effect of increased access to healthy retailers has on improving diet quality.[18] Additionally, systematic reviews have found that density measurements of the counts of types of retailers have a stronger association with diet quality than proximity measures.[19,20] This suggests that when understanding the effect of the local food environment on diet quality, it is important to consider the relative density of both typically healthy and typically unhealthy food outlets.

"Food swamps" were first described by Rose and colleagues as a spatial metaphor to describe local food environments in New Orleans where there is an excess of retailers providing predominantly energy-dense, nutrient-poor food options that "swamp out" the relatively fewer healthier options.[21] Increased availability of fast-food restaurants and convenience stores have been associated with less consumption of fruits and vegetables,[22] increased intake of fast food,[18,23], and poorer diet quality overall.[18,24,25] Therefore, it is hypothesized that food swamp-like environments with a relative abundance of these types of retailers will affect individual food choices, ultimately impacting diet quality. In a cohort of adolescent girls living in low-income neighborhoods of Baltimore City, Hager and colleagues found that girls living in a food swamp consumed significantly more desserts and snacks compared to girls who were not living in a food swamp.[26]

Food swamps have also been found to be associated with poorer diet-related health outcomes. A nationwide analysis of all counties in the U.S utilizing instrumental variable methods to control for selection into neighborhoods found that food swamps were stronger predictors of county-level obesity rates, suggesting that the relative density of unhealthy food retailers has a stronger effect on county-level obesity rates than just the presence of healthy retailers alone.[27] Counties considered to be food swamps have been associated with higher hospitalization rates among diabetic adults in a nationwide cross-sectional analysis in the U.S., further suggesting that a relatively higher proportion of unhealthy food outlets in a neighborhood is associated with poorer diet-related health outcomes.[28]

Additionally, there have been observed disparities in the types of food retailers in the local food environment by both race and income. Lower-income and predominately minority communities have been found to have lower access to supermarkets[29–31] and higher access to fast-food restaurants.[32] Longitudinal analyses have found that in higher-income communities the concentration of convenience stores decreases over time while it increases over time in lower-income communities,[33] contributing to the disparities in local food environments by income.[34,35] Particularly in the United States, these disparities have been attributed to historically discriminatory local zoning policies, leading to segregated communities by race and class.[36] The observed disparities in healthy food access are a concern for environmental justice and have been hypothesized as a potential contributor for disparities observed in diet-related disease burdens.[37] Understanding how the mix of retailers in the local food environment impact food purchases and ultimately diet quality and health is important to addressing equitable access to nutritious foods.

Objectives

While the relationship between the abundance of unhealthy retailers (food swamps) in the local food environment and diet has been previously examined, there has been no analysis to date examining the intermediate relationship between living in a food swamp and the diet quality of food purchases (figure 1). Additionally, dietary intake is difficult to measure objectively, being subject to recall and social desirability biases,[38] and previous studies of food swamps on dietary outcomes have examined only specific dietary elements rather than overall diet quality.[18,26] The goal of this analysis is to examine the associations between living in a food swamp and the overall diet quality of the objectively measured household food purchases, using a nationwide sample of households in the U.S. We hypothesized that living in a food swamp would be associated with lower diet quality of total food purchased in the household.

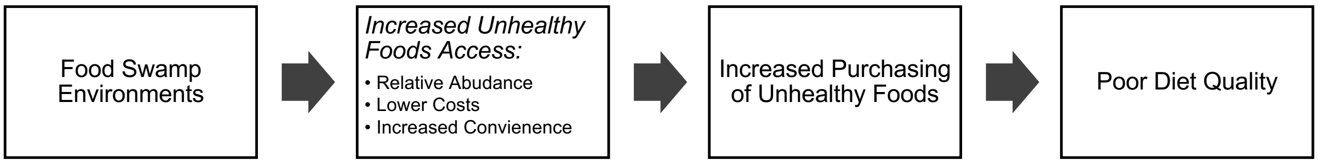

Figure 1. Conceptual model of the hypothesized effects of a food swamp environment on the availability & accessibility of energy-dense, unhealthy foods, and subsequent effects on food purchasing & diet quality.

Methods

Study Population: USDA Food Acquisition and Purchase Survey

The data for this study was obtained from the U.S. Department of Agriculture's (USDA) Food Acquisition and Purchase Survey (Food APS). Food APS is a nationally representative dataset with comprehensive data on food purchasing and acquisitions, along with data on other factors that can influence food purchasing, including the availability of stores and restaurants in participants' neighborhoods. The survey was conducted in 2012 – 2013 and released in 2015. The survey sampling was conducted in a multi-stage design to oversample low-income households, both those participating and not participating in the Supplemental Nutrition Assistance Program (SNAP), but the survey was weighted to be representative of all non-institutionalized households in the contiguous United States. The survey sample included 4,826 households.[39] Data was collected from in-person and phone interviews with a primary household respondent, and detailed information was collected on all individuals in the household, including all foods acquired in 7 days, from both food stores and restaurants. All household members over 11 years of age filled out daily food purchasing booklets, scanned barcodes of packaged foods, and provided food receipts. The receipts from all individuals in the household were combined to create household purchasing measures. The USDA's Economic Research Service (ERS) merged data on foods acquired with data on nutrient content to generate the nutrient content of all household food purchases. Additionally, spatial data for each household's local food environment was merged with USDA databases of SNAP-authorized stores, Store Tracking and Redemption System (STARS) and InfoUSA, a commercial database of store locations.[39]

All households were included in this analysis except those with missing data for the healthy eating index (HEI), food swamp score, or the covariates described below (n = 134). The final analytic sample included 4,692 households. The public-use, de-identified, version of the Food APS dataset was used in the present analysis, so it was exempt from institutional review board (IRB) approval.

Primary Outcome: Weekly Food Purchasing HEI

The primary outcome of this analysis was the total diet quality of all households' weekly foods purchased from both food stores and restaurant outlets as measured by a healthy eating index (HEI) score. The HEI is a measure of diet quality in terms of concordance to federal dietary guidelines, the Dietary Guidelines for Americans. Because Food APS was conducted in 2012-2013, the 2010 Healthy Eating Index was used, which is based on the 2010-2015 Dietary Guidelines. The HEI-2010 is based on 9 adequacy components (total fruit, whole fruit, total vegetables, greens and beans, whole grains, dairy, total protein foods, seafood and plant proteins, fatty acids) and 3 moderations components (refined grains, sodium, and empty calories). The total HEI score is the sum of the 12 component scores and is the nutrient density of a diet (per 1000 kcal) on a continuous scale, from 0 to 100 points with higher scores indicating better diet quality.[40]

Unlike in many other surveys, such as the National Health and Nutrition Examination Survey (NHANES) that use the HEI to quantify the diet quality of foods consumed in 24 hours, the HEI in this study was calculated from Food APS nutrient data for all foods purchased in the 7-day study period by each household. Therefore, the HEI in the present analysis indicates the healthfulness of each household's weekly food purchases. The household HEI-2010 scores were generated from the Food APS nutrient data for each household's reported week's food purchases.

To calculate the densities of each component in the HEI scores, the nutrient content, and food pattern equivalents per 100 grams of each item were obtained from various USDA databases. Food pattern equivalents were used to convert the nutrient content of each item purchased into either cup or ounce equivalents for specific food groups in the various adequacy or moderation components of the HEI scores. The nutrient content and food pattern equivalents were multiplied by the total grams weight of foods purchased. For items purchased in food stores, only the raw, edible portion of foods was used to calculate nutrient content for the HEI score. For example, to calculate the nutrient content of a bunch of bananas, the weight of the inedible peel would be subtracted from the total weight of bananas purchased to get the edible portion of this item for calculating the nutrient content. Additionally, only the raw form of foods purchased in food stores was used to calculate nutrient content rather than assume how cooking or preparation methods could impact the ultimate nutrient content of the foods for consumption. For restaurant items, the total portion of purchased foods was used to calculate the HEI score. Missing quantities of purchased items were imputed by the USDA using methods published previously.[41] Increased food pattern equivalents of adequacy components increase the total HEI score while increased FPEs of moderation components decrease the total HEI score. Weekly total HEI-2010 scores for all foods purchased in each household were generated using a STATA macro developed by the USDA Economic Research Service.[41]

Independent Variable: Food Swamp Score

The primary independent variable of this study is the physical food environment index (PFEI), previously used by Mui and colleagues.[42–44] The PFEI is the relative density of the count of food outlets that typically offer more unhealthy foods out of the total count of food outlets within a straight-line radius of each household's home address, which we termed the "food swamp score" and described in further detail below.

The USDA Food APS data set includes information on the counts of both food stores and restaurants within straight-line distances of each household. The classification of food stores was obtained from the June 2012 version of the USDA Store Tracking and Redemption Subsystem (STARS), a database of all SNAP-authorized retailers, and was classified by the USDA Economic Research Service through a manual review with the STARS, InfoUSA, and Google databases. Food stores were categorized as follows: superstores, supermarkets, medium/large grocery stores, combination grocery/other (defined as drug stores, dollar stores, and general stores), and convenience stores (more detailed definitions of each food outlet category provided in Appendix A). The restaurant outlets were obtained from the InfoUSA database in January 2012 and were categorized by the USDA as a fast-food restaurant or non-fast food restaurant based on a USDA list of known global/U.S. fast-food restaurant names.

Following previous studies using the PFEI and the USDA definitions of food outlets, food retailer types were categorized depending on whether they were hypothesized to typically sell more unhealthy food options or more healthy food options.[27,42,44] Unhealthy retailer types included convenience stores, combination grocery/other stores, fast food restaurants, and non-fast food restaurants. Healthy food retailers included superstores, supermarkets, and medium/large grocery stores. Therefore, the food swamp score used in this analysis is operationalized as the relative density of unhealthy retailers over the count of total retailers within a certain straight-line distance from participants' homes multiplied by 100, or:

$$PFEI = \frac{Counts\ of\ Convenience\ Stores + Combination\ Stores + \ Fast\ Food + Non\ Fast\ Food\ Restaurants}{Total\ Count\ of\ all\ Food\ Outlets} * 100$$

Previous studies using the PFEI and similar retail food environment index (RFEI) have used a variety of distances around households to measure food swamp status, from 0.25 miles to county-level indices.[45,46] Because we hypothesized that the effect of food swamps would differ based on households being in rural or urban census tracts, we calculated the food swamp score using the straight line distance of 1-mile for all urban households and 5-miles for all rural households for the primary analyses. A census tract was designated as urban if the geographic centroid of the tract is in an area with more than 2,500 people, and all other tracts are considered rural. Additional sensitivity analyses were conducted to test smaller straight-line distances. The resulting food swamp score for each household was a continuous variable from 0 to 100, with higher scores indicating a higher relative density of unhealthy food stores within the specified distance around a household. Once the food swamp score was calculated, the sample was grouped into quintiles based on the distribution of the food swamp score. Therefore, households in the 1st quintile would be considered to have the lowest quintile of food swamp scores or their neighborhood food environment would be the least like a food swamp, and households in the 5th quintile would be considered to have the highest quintile of food swamp scores or their neighborhood food environment would be the most like a food swamp.

Covariates

Chosen covariates for this analysis were variables that were hypothesized *a priori* to influence both the food swamp score of one's neighborhood and the diet quality of foods purchased but did not fall along the causal pathway between food swamp score and household diet quality. These factors include race/ethnicity, educational attainment, health status, household income, car ownership, food security status, and SNAP participation. To adjust for demographic characteristics and to avoid the complication of combining individuals in the household, only the household's primary respondent’s data were used to represent the entire household on individual-level characteristics such as race/ethnicity, education, and health status.

The race/ethnicity categories were White/non-Hispanic, Black/non-Hispanic, Hispanic, Asian/Native Hawaiian or Pacific Islander, Native American or Alaskan Native, other, and multiple races/ethnicities. Educational attainment categories were less than high school, high school completion/equivalent, some college, and college completion or higher. Self-reported general health was determined by asking the household’s primary respondent to rate their general health as either “excellent”, “very good”, “good”, “fair” or “poor”.

Total household income was reported by the primary respondent, and the 2012 federal poverty guideline for a household of the same size was used to calculate a continuous variable of income as a percentage of the federal poverty guideline. Car ownership was defined as either owning or leasing a vehicle. Household food security was determined by asking the household’s primary respondent the 10-question USDA 30-day Adult Food Security questionnaire, which categories households as “highly food secure, marginally food secure, low food security, and very low food security.”[47] SNAP participation indicated if any household members were receiving SNAP benefits at the time of the survey. SNAP participation was initially self-reported by participants but later confirmed by the USDA using SNAP administrative data.

Statistical Analysis

Descriptive characteristics were calculated for all households included in the analytic sample. Multiple linear regression models were used to estimate the association between the household's food swamp score and the HEI for the reported weekly food purchases, controlling for covariates described previously. It was hypothesized that the association between HEI of weekly food purchases and food swamp scores may vary by living in an urban or rural census tract, so the primary models were stratified by living in a rural or urban census tract. Secondary analyses further stratified these models by car ownership, producing four multiple linear regression models: urban and car access, rural and car access, urban and no car access, and rural and no car access. An alpha (α) of 0.05 was the level used to determine significance.

All statistical analyses were weighted, using survey weights provided by the USDA and accounted for the multistage stratified sampling design through the use of stratum and primary sampling unit identifiers, and Taylor series linearized standard errors were employed. Data analysis was performed using the svy package in Stata v.16 (StataCorp LP, College Station, TX).

Sensitivity Analyses

Additional sensitivity analyses were conducted to test shorter straight-line distances of the food swamp variable: 0.25 miles and 0.5 miles straight-line distances around the home. Because the distribution of these shorter distances was bimodal at the extremes with most households scoring either 0 or 100, the median of these variables was used to create a dichotomous variable categorizing each household as having a high or low food swamp score based on these shorter distances. Additional multiple linear regression models were used to test the associations of dichotomous food swamp scores for the 0.25-mile and 0.5-mile distances around participants' homes for only urban households, controlling for the same covariates used in the primary models.

Results

Table 1 summarizes the descriptive characteristics of households included in the analytic sample (N = 4,692), stratified by quintiles of the main food swamp independent variable. The mean household HEI score across all households was 53 (SD = 14), and the mean food swamp score across all households was 89 (SD = 20). Notably, some covariates do not appear to be distributed across the quintiles as would be expected. The proportion of college or more educational attainment and excellent health appears to be highest in the highest quintile of food swamp score.

The results of the adjusted association between the quintile of food swamp score and household dietary quality are summarized in Table 2. No statistically significant associations were found between household food swamp score quintiles and HEI scores of weekly household food purchases when adjusted for covariates for households in either urban or rural census tracts (highest quintile - urban: $\beta = 0.75$, 95% CI -1.47, 2.96; rural: $\beta = -1.70$, 95% CI -5.60, 2.19).

Table 3 summarizes the results of the secondary analyses further stratifying the multiple linear regression models between household food swamp score quintiles and HEI scores of weekly household food purchases by both urban or rural status and car access. There was no statistically significant association between household food swamp score quintiles and HEI scores of weekly household food purchases when adjusted for covariates in any of the four models (highest quintile - urban/car: β = 0.89, 95% CI -1.40, 3.19; urban/no car: β = -1.06, 95% CI -4.77, 2.66; rural/car: β = -1.81, 95% CI -6.09, 2.48; rural/no car: β = 3.34, 95% CI -2.88, 9.56).

The results of the sensitivity analyses are summarized in table 4. Calculating food swamp scores with smaller straight-line distances around urban households were not found to be significantly associated with the HEI scores of household food purchases (0.25-mile: β = 0.34, 95% CI -1.36, 2.05; 0.5-mile: β = -0.65, 95% CI -2.40, 1.10).

Discussion

Our study adds to the existing literature on the local food environment by examining the association of food swamps on the healthfulness of household food purchasing. To our knowledge, this is the first study to examine the cross-sectional relationship between living in a food swamp and the diet quality of household food purchases. While previous work has found associations between living in a food swamp, some dietary behaviors, and county-level obesity rates,[26,27] we found no evidence of an association between food choices at the household food purchasing level and food swamps at a smaller geographic scale than the county level. We found no association between the HEI score of household food purchases and the food swamp score for the 1-mile area around a household in an urban area or a 5-mile area around a household in a rural area. We also did not find an association when further stratifying analyses by car ownership or when examining food swamp scores for urban households using smaller areas, including a 0.25-mile and 0.5-mile straight-line distance around the household.

Our results are inconsistent with prior studies of the relationship of food swamps with diet quality on these smaller geographic scales. Using a definition of a food swamp as having four or more corner or convenience stores within 0.25-miles of home, Hager and colleagues found a significant relationship between living in a food swamp and consumption of snacks and desserts in a cross-sectional study of adolescent girls living in an urban neighborhood.[26] Our analysis considered the entire diet quality of a week of a household's food purchases. This could suggest that the association of food swamps with diet quality is lower when considering a broader measure of diet quality than the purchase or consumption of particular foods or food groups.

These results are also inconsistent with prior cross-sectional studies examining the relationship between food swamps and obesity rates. Cooksey-Stowers et al. found that using county-wide measures of food swamp scores was associated with county-level obesity rates. Further, they used an instrumental variable (IV) approach that accounts for the possibility of neighborhood self-selection.[27] Other studies have compared IV estimates to estimates generated with an ordinary least squares regression and found that estimates generated with an IV approach find stronger estimates of the relationship between environments and health outcomes.[48] Our null results could be due to unmeasured neighborhood self-selection that could bias estimates towards the null. Additionally, our analysis examined diet quality versus obesity as an outcome, and our food swamp score examined the local food environment at a smaller geographic scale than the county-level.

In a longitudinal analysis of the association between diet quality and access to food stores and fast-food restaurants, Boone-Heinonen and colleagues also found that there was no association between overall diet quality and the counts of grocery stores or supermarkets within 0.5-mile to 5-mile distances around households. However, they did find a significant positive association between counts of fast-food restaurants within 1 to 2 miles of home with fast food consumption, specifically only in low-income men.[18] However, in our analysis when considering the association of the relative density of unhealthy food retailers to the overall diet quality of all household members' food purchases, we found no significant relationship. Again, our results suggest that the association of food swamps to diet quality may be lower when examining overall diet quality. However, the lack of relationship observed in our analysis may also be due to the use of a measure of the relative density of unhealthy retailers to characterize the food environment instead of a single count of one type of food retailer. Counts of food retailers have been found in systematic reviews to find more positive associations and relatively larger effect sizes than the use of proximity measures, such as the distance to the nearest food retailer, to measure the local food environment. In contrast, relative density measures, such as our measure of food swamps, have been used much less often in prior food environment research. Additionally, similar to our results, the overall effect sizes found in much of the food environment literature have been either small or null.[19]

This analysis builds upon the existing literature of local food environments, particularly the literature on food swamps by analyzing the relationship between food swamps and the diet quality of household food purchasing in a nationwide sample. Using a nationwide sample makes the results more generalizable to the entire U.S. population compared to the prior analyses of food swamps that have focused on a single geographic area.[26,42,43,49] Additionally, this dataset provided a robust, relatively objective collection of all foods purchased in households to measure the overall diet quality. While we cannot assume that all foods purchased will be consumed, previous research has found that objectively documented household food purchases can reflect a reasonably accurate measure of diet quality when compared to 24 hour recalls.[50] This dataset also included measures of the local food environment on a smaller geographic scale than prior ecologic studies,[27] allowing us to examine the effects of micro-food swamp environments on individual household-level food purchasing behavior.

This study has several limitations. First is the possibility of unmeasured confounding from neighborhood-level contextual variables, such as median household income or neighborhood racial segregation. Low-income neighborhoods and communities of color have been found to have higher exposure to fast-food restaurants and convenience stores and less access to supermarkets in their neighborhood food environment compared to higher-income and predominately white neighborhoods.[30,37] Because of this relationship, the food swamp score measures these neighborhood contextual variables to some degree, but would not control for other downstream effects of neighborhood segregation or income level, such as stressors, that could be correlated with diet quality. Our analysis also did not account for food prices, which can vary regionally and are known to influence food purchasing, diet quality, and health outcomes.[51,52]

The cross-sectional design of this analysis limits our ability to draw inferences on causal relationships of the effects of food swamps on household food purchasing. The present analysis cannot eliminate the possibility that households with generally the healthiest food purchasing patterns could prefer and self-select to live in neighborhoods with the least food-swamp-like characteristics. This design also limits our ability to understand the effect of reverse causality on the relationship between the food environment and purchasing. Our conceptual model (figure 1) assumes a uni-directional relationship from the local food environment on an individual's food purchasing, but in actuality, consumer demand and food purchasing can also influence the food supply in their local environment.[53]

Another potential limitation of the use of the food swamp score as an index to measure the local food environment is that it requires food stores and restaurants to be broadly characterized as either "healthy" or "unhealthy" based on typical definitions of these retailers and the food they generally offer. While convenience stores and restaurants typically sell more energy dense-nutrient poor foods, similar energy-dense foods can also be purchased in supermarkets and superstores. Additionally, there are increasing public health efforts to improve the availability of healthy options in convenience stores and corner stores in food swamps.[54,55] While the food swamp score can give an estimated measure of the density of unhealthy food access, the true accessibility of healthy foods in the local food environment may be either higher or lower than our exposure measure assumes. A prior systematic review has highlighted the importance of looking beyond store types when characterizing the local food environment to instead focus more granularly on food access within stores.[56]

Conclusions

Our analysis contributes to the food environment literature by examining the association between food swamps and objectively measured household-level food purchasing. We found no relationship between living in a food swamp and the healthfulness of household food purchasing, either in rural or urban households. There also was no observed relationship when restricting analyses in urban or rural households by car access, or when examining smaller geographic areas around the household. Because the existing literature on food swamps is mixed and mainly cross-sectional, further longitudinal and experimental research on the effects of food swamps and diet quality are needed to better understand the relationship of food environments and health behaviors.

Tables

Table 1. Descriptive characteristics of key variables, stratified by quintiles of food swamp scores with the highest food swamp score quintile indicating the most food swamp-like characteristics.

	Lowest Quintile (n = 956)	**Low-Middle Quintile (n = 929)**	**Middle Quintile (n = 931)**	**High-Middle Quintile (n = 941)**	**Highest Quintile (n = 945)**	**All (N = 4,692)**
Food Swamp Scores (Min – Max)	0-89	89-93	93-95	95-98	98-100	
Age (Mean, SD)	50 (16)	48 (18)	48 (17)	49 (19)	52 (16)	50 (17)
Sex (n, %)						
Male	241 (32%)	210 (28%)	248 (32%)	267 (33%)	266 (35%)	1232 (32%)
Female	715 (68%)	719 (72%)	683 (68%)	674 (67%)	669 (65%)	3460 (68%)
Race/Ethnicity (n, %)						
White, non-Hispanic	601 (71%)	460 (57%)	463 (56%)	570 (72%)	675 (83%)	2769 (69%)
Black, non-Hispanic	130 (12%)	162 (18%)	137 (15%)	128 (11%)	85 (6%)	642 (12%)
Hispanic	169 (12%)	232 (16%)	237 (19%)	147 (11%)	128 (7%)	913 (13%)
Asian, Native Hawaiian or Pacific Islander	8 (0%)	7 (0%)	5 (0%)	7 (0%)	6 (1%)	33 (0%)
Native American or Alaskan Native	27 (3%)	33 (5%)	64 (8%)	62 (4%)	16 (2%)	202 (4%)
Other	3 (0%)	11 (1%)	11 (1%)	5 (1%)	5 (1%)	35 (1%)
Multiple	18 (2%)	24 (3%)	14 (1%)	22 (1%)	20 (1%)	98 (2%)
Education (n, %)						
Less than High School	161 (8%)	200 (13%)	165 (11%)	156 (10%)	115 (6%)	797 (9%)
High School	297 (26%)	274 (25%)	266 (27%)	234 (20%)	277 (25%)	1348 (25%)
Some College	325 (39%)	283 (32%)	302 (30%)	306 (33%)	326 (33%)	1542 (34%)
College or More	173 (26%)	172 (31%)	198 (33%)	245 (36%)	217 (37%)	1005 (33%)
Overall Health (n, %)						
Excellent	100 (12%)	96 (11%)	97 (12%)	91 (14%)	121 (16%)	505 (13%)
Very Good	259 (35%)	217 (30%)	223 (29%)	253 (36%)	263 (35%)	1215 (33%)
Good	374 (35%)	349 (37%)	368 (39%)	383 (33%)	351 (34%)	1825 (35%)
Fair	184 (16%)	207 (18%)	190 (16%)	175 (13%)	165 (13%)	921 (15%)
Poor	39 (3%)	60 (3%)	53 (4%)	39 (3%)	35 (2%)	226 (3%)
Urban vs. Rural (n, %)						

Urban	682 (64%)	684 (72%)	695 (66%)	705 (68%)	650 (61%)	(66%)
Rural	274 (36%)	245 (28%)	236 (34%)	236 (32%)	285 (39%)	1276 (34%)
Household Income as % FPL (Mean, SD)	372% (279%)	313% (258%)	373% (361%)	419% (393%)	388% (256%)	374% (309%)
Car Access (n, %)						
No	138 (8%)	189 (15%)	141 (12%)	153 (11%)	111 (8%)	732 (11%)
Yes	818 (92%)	740 (85%)	790 (88%)	788 (89%)	824 (92%)	3960 (89%)
Household Food Security Status (n, %)						
High	486 (71%)	435 (62%)	479 (64%)	519 (73%)	549 (76%)	2468 (70%)
Marginal	197 (14%)	200 (18%)	192 (18%)	174 (12%)	174 (13%)	937 (15%)
Low	149 (8%)	178 (12%)	160 (10%)	142 (10%)	127 (6%)	756 (9%)
Very Low	124 (7%)	116 (7%)	100 (8%)	106 (5%)	85 (5%)	531 (6%)
SNAP Participation (n, %)						
No	636 (85%)	576 (83%)	619 (83%)	658 (89%)	694 (92%)	3183 (87%)
Yes	320 (15%)	353 (17%)	312 (17%)	283 (11%)	241 (8%)	1509 (13%)
Healthy Eating Index (Mean, SD)	53 (13)	53 (15)	53 (15)	53 (15)	53 (12)	53 (14)

Notes: Subpopulations numbers (n) are unweighted, raw totals. The calculated proportions, means, and standard deviations are survey-weighted to account for the complex sampling design. Descriptive variables are stratified by quintiles of food swamp scores with the distributions of the continuous food swamp scores by quintiles (minimum-maximum): lowest quintile (0-89), low-middle quintile (89-93), middle quintile (93-95), high-middle quintile (95-98), and highest quintile (98-100). The highest food swamp score quintiles indicate households in areas with the highest food swamp-like characteristics.
Abbreviations: FPL – federal poverty limit; PR – primary respondent. SNAP – Supplemental Nutrition Assistance Program.

Table 2. Primary statistical analyses of the multiple linear regression analysis between food swamp quintile and HEI score of weekly household food purchases, stratified by urban versus rural status of households.

	Urban		***Rural***	
Food Swamp Score Quintile	**β (95% CI)**	**P-value**	**β (95% CI)**	**P-value**
Lowest Quintile	Referent		Referent	
Low-Middle Quintile	2.11 (-0.81, 5.03)	0.150	-2.11(-5.81, 1.59)	0.249
Middle Quintile	0.10 (-2.13, 2.32)	0.930	0.46 (-4.08, 4.99)	0.837
High-Middle Quintile	0.76 (-1.92, 3.44)	0.568	-1.26 (-5.85, 3.32)	0.575
Highest Quintile	0.75 (-1.47, 2.96)	0.497	-1.70 (-5.60, 2.19)	0.376

The primary models are multiple linear regression models for the association between food swamp score quintile and healthy eating index (HEI) score for weekly household food purchases, adjusted for covariates, and stratified by household being in an urban or rural census tract. All models were adjusted for the following covariates: educational attainment, race/ethnicity, overall health, income (as a percent of federal poverty limit), car access, food security status, and SNAP participation. Food swamp score was defined as the relative density of unhealthy food outlets to total food outlets for a 1-mile straight-line distance around the household for all urban households and a 5-mile straight-line distance for all rural households. Quintiles of food swamp scores in the analytic sample were calculated for all households, with the highest food swamp score quintiles indicating households in areas with the most food swamp-like characteristics.

Table 3. Secondary models of the association between food swamp quintiles and HEI score of weekly household food purchases, stratified by urban versus rural status and car access of households.

	Urban			
	Car Access		*No Car Access*	
Food Swamp Score Quintile	**β (95% CI)**	**P-value**	**β (95% CI)**	**P-value**
Lowest Quintile	Referent		Referent	
Low-Middle Quintile	1.96 (-1.37, 5.29)	0.239	2.71 (-1.42, 6.85)	0.191
Middle Quintile	0.66 (-1.51, 2.83)	0.540	-1.76 (-5.41, 1.89)	0.333
High-Middle Quintile	0.85 (-1.72, 3.43)	0.505	0.44 (-5.59, 6.46)	0.884
Highest Quintile	0.89 (-1.40, 3.19)	0.433	-1.06 (-4.77, 2.66)	0.567
	Rural			
	Car Access		*No Car Access*	
Food Swamp Score Quintile	**β (95% CI)**	**P-value**	**β (95% CI)**	**P-value**
Lowest Quintile	Referent		Referent	
Low-Middle Quintile	-2.14 (-6.03, 1.76)	0.268	0.45 (-6.14, 7.04)	0.888
Middle Quintile	0.73 (-3.70, 5.16)	0.737	-5.24 (-14.58, 4.09)	0.255
High-Middle Quintile	-1.83 (-7.26, 3.60)	0.493	6.21 (-1.22, 13.64)	0.097
Highest Quintile	-1.81 (-6.09, 2.48)	0.393	3.34 (-2.88, 9.56)	0.276

The secondary models are multiple linear regression models for the association between food swamp score quintile and healthy eating index (HEI) score for weekly household food purchases, adjusted for covariates, and stratified by household being in an urban or rural census tract and car access. All models were adjusted for the following covariates: educational attainment, race/ethnicity, overall health, income (as a percent of federal poverty limit), food security status, and SNAP participation. Food swamp score was defined as the relative density of unhealthy food outlets to total food outlets for a 1-mile straight-line distance around the household for all urban households and a 5-mile straight-line distance for all rural households. Quintiles of food swamp scores in the analytic sample were calculated for all households, with the highest food swamp score quintiles indicating households in areas with the most food swamp-like characteristics.

Table 4. Sensitivity Analyses of the association between 0.25-mile and 0.5-mile food swamp scores and HEI scores of weekly household food purchases in urban households (n = 3,416)

Food Swamp Score	0.25-mile Food Swamp Score β (95% CI)	P-value	0.5-mile Food Swamp Score β (95% CI)	P-value
Low Food Swamp Score	Referent		Referent	
High Food Swamp Score	0.34 (-1.36, 2.05)	0.684	-0.65 (-2.40, 1.10)	0.454

The models in the sensitivity analyses are multiple linear regression models for the association between 0.25-mile and 0.5-mile food swamp scores and healthy eating index (HEI) score for weekly household food purchases, adjusted for covariates and only for households in urban census tracts. All models were adjusted for the following covariates: educational attainment, race/ethnicity, overall health, income (as a percent of federal poverty limit), car access, food security status, and SNAP participation. Food swamp score was defined as the relative density of unhealthy food outlets to total food outlets for either a 0.25-mile or 0.5-mile straight-line distance around the household. Using the median of each food swamp score variable as a cut-off, a dichotomous version of the 0.25-mile and 0.5-mile distances to indicate each household as having a high or low food swamp score, with the high food swamp score indicating households in areas with the most food swamp-like characteristics

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Appendix A – Classification of Food Stores by USDA Store Type Definitions

The USDA classified food store types in the Food APS dataset based on the definitions below from the USDA Food and Nutrition Service.[39] For calculating the food swamp scores in the present analysis, we classified the following store types as selling relatively unhealthy items: convenience stores and combination grocery stores and the following stores as having relatively healthier items: medium/large grocery stores, supermarkets, and superstores.

Unhealthy

Convenience Store: "Self-service stores that offer a limited line of convenience items and are typically open long hours to provide easy access for customers. Primarily engaged in the retail sale of a variety of canned goods, dairy products, pre-packaged meats, and other grocery items in limited amounts. Usually sell a large variety of ineligible products; such as hot coffee, alcohol, or tobacco products."

Combination Grocery/Other: "Primary business is the sale of general merchandise but also sells a variety of food products. Such stores include independent drug stores, dollar stores, and general stores."

Healthy

Large Grocery Store: "A store that carries a wide selection of all four staple food categories. They may sell ineligible items as well, but their primary stock is food items."

Medium Grocery Store: "A store that carries a moderate selection of all four staple food categories. They may sell ineligible items as well, but their primary stock is food items."

Supermarket: "Establishments commonly known as supermarkets, food stores, grocery stores, and food warehouses primarily engaged in the retail sale of an extensive variety of grocery and other store merchandise. This store typically has ten or more checkout lanes with registers, bar code scanners, and conveyor belts."

Super Store/Chain Store: "Very large supermarkets, 'big box stores, superstores and food warehouses primarily engaged in the retail sale of a wide variety of grocery and other store merchandise. Includes stores that are large food/drug combo stores and mass merchandisers under a single roof, and membership retail/wholesale hybrids offering a limited variety of products in a warehouse-type environment."