THE ASSOCIATION BETWEEN OBESITY PREVALENCE AND THE FOOD ENVIRONMENT

by

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ABSTRACT

Background: Obesity affects over 40% of adults in the United States. The food environment is thought to be a potential contributing factor to obesity. This present study aimed to explore the association between the food environment and obesity defined by body mass index (BMI) and body fat. **Methods:** A prospective cross-sectional study design was employed with participants nested within income strata. Trained interviewers visited participants' at their place of residence to conduct in-person surveys that included questions about physiological health, neighborhood characteristics, and anthropometrics. The food environment was assessed using the Retail Food Environment Index (RFEI) and the Modified Retail Food Environment Index (mRFEI). Height, weight, and body fat were measured during a visit and used to determine obesity status. Logistic regression was used to examine associations between the food environment indexes and obesity status. **Results:** Analyses were conducted on data from 436 adult participants living in one of 20 U.S. Census block groups located in Kansas City, KS, and MO. The RFEI and the mRFEI were not associated with BMI-defined obesity (OR = 0.96, 95% CI [0.86 – 1.06]) and (OR = 0.81, 95% CI [0.41 – 1.61]), respectively. The RFEI was negatively (OR = 0.83, 95% CI [0.75 – 0.92]), and the mRFEI was positively (OR = 0.83, 95% CI [0.75 – 0.92]) associated with body fat-defined obesity. Lastly, the RFEI (p=0.419) and mRFEI (p=0.543) did not significantly differ in those with or without BMI-defined obesity. **Conclusion:** The relationship between obesity and the food environment is complex. The results of this study suggest the relationship depends on the measure of obesity.

Chapter 1

INTRODUCTION

The obesity epidemic continues to worsen, with rates reaching over 40% in the United States (U.S.).[1] Current projections estimate that by 2030 nearly 50% of Americans will have obesity.[2] Obesity is defined as a body mass index (BMI) of ≥ 30 or a body fat percentage of ≥ 25% or ≥ 30% for males and females, respectively.[3] Obesity is associated with numerous chronic non-communicable diseases, including cardiovascular disease, hypertension, type 2 diabetes, some cancers, and chronic kidney disease.[4] The Centers for Disease Control and Prevention (CDC) reports that almost 173 billion dollars were spent in 2019 on medical costs due to obesity.[1] Obesity puts a significant strain on both the healthcare system and the economy.

Obesity is commonly measured using BMI due to its simplicity and widely accepted cut points. BMI is the ratio of a person's weight in kilograms to their height in meters squared (kg/m^2).[1] However, BMI fails to distinguish between fat and fat-free mass, which can create inappropriate diagnoses of obesity.[5,6] Additionally, BMI has poor sensitivity resulting in obesity diagnoses being misclassified as overweight or normal weight .[5,6] Obesity can also be measured using body fat percentage cut points of ≥ 25% for males and ≥ 30% for females. Body fat percentage may be a better indicator of obesity as it measures adiposity and considers body composition, compared to BMI, which calculates a person's weight relative to height. [5,6] Body fat

percentage measurements require specialized machinery to generate outputs, with various body composition methods being used to measure body fat percentages.[7] Bioelectrical impedance analysis is one method that uses a portable device that measures the resistance of body tissues to an electrical current.[7] This technique can differentiate between fat mass and fat-free mass, providing body fat percent which can be used to classify weight status.[7]

The food environment is the physical presence of food that influences a person's diet; this includes policies, availability, and the presence of food outlets, which are any store where food can be purchased.[8,9] Food environments have the potential to shape health outcomes and dietary behavior through the availability and accessibility of food.[10,11] The food environment is primarily measured by quantifying the frequency as either counts, densities, or ratios of different food outlet types or the proximity to the food outlet.[12,13]

The Retail Food Environment Index (RFEI) and the Modified Retail Food Environment Index (mRFEI) can be used to assess the food environment through a ratio.[14,15] The RFEI was created by the California Center for Public Health Advocacy and measures the ratio of unhealthy to healthy food retailers in an area.[14] The RFEI is calculated by dividing the number of fast-food restaurants and convenience stores by the sum of the number of grocery stores and produce vendors.[14] A higher score indicates an unhealthier food environment. However, the RFEI is limited when used to define areas without grocery stores or produce vendors. The CDC created the Modified Retail Food Environment Index (mRFEI) to quantify the food environment

as a single number.[15] The mRFEI is the percentage of healthy food retailers in a given area.[15] The CDC defines healthy food retailers as supermarkets and larger grocery stores and less healthy food retailers as fast-food restaurants, convenience stores, and small grocery stores.[15] The North American Industry Classification Codes were used to define supermarkets, larger grocery stores, smaller grocery stores, convenience stores, and fast-food restaurants.[15] Supermarkets were further defined as stores with fifty or more employees, larger grocery stores had between 10 and 49 employees, and smaller grocery stores had three or fewer employees.[15] The mRFEI is calculated by taking the number of healthy food retailers divided by the sum of the number of healthy and unhealthy food retailers multiplied by 100.[15] The higher the score, the healthier the food environment. A score of zero would indicate that there are no healthy food retailers, whereas a score of 100 would indicate that there are only healthy food retailers.

The purpose of this study is to examine the association between obesity, defined by BMI and body fat and the food environment using RFEI and mRFEI.

Chapter 2

REVIEW OF THE LITERATURE

2.1 Association of Food Retailers and Obesity

Studies that have examined the relationship between BMI-defined obesity and the food environment have yielded inconsistent findings as to what extent the food environment plays.[12] The relationship between BMI-defined obesity and the food environment is typically assessed using individual food outlets rather than a ratio that quantifies the food environment as a whole.[12] Inconsistencies among findings from published studies may be partly due to the variety of methods used to assess the environment. Most studies examine the association between BMI-defined obesity and a specific food retail outlet, such as a supermarket or convenience store.[12] No studies to date have examined the association between body fat percentage and the food environment.

Previous studies have examined the association between BMI-defined obesity and food outlets in a U.S. Census Tract. A 2006 study reported on the association between supermarkets, grocery stores, convenience stores, and BMI-defined obesity.[16] When examining the relationship between supermarkets and BMI-defined obesity, it was found that having at least one supermarket in a U.S. Census Tract lowered the prevalence of BMI-defined obesity regardless of adjustments for covariates.[16] The presence of grocery stores was positively associated with BMI-defined obesity but became null when adjusted for gender, age, race, education, income, and physical

activity.[16] Lastly, the relationship between BMI-defined obesity and the presence of convenience stores was insignificant.[16] A 2009 study that examined the U.S. Census Tract level also found that the presence of at least one supermarket was negatively associated with self-reported BMI-defined obesity, the presence of at least grocery stores was positively associated with BMI-defined obesity, and the presence of at least one convenience store attached to a gas station was insignificant regardless of adjustment.[17] Lastly, at the U.S. Census Tract level, a 2010 study examined the odds of having self-reported BMI-defined obesity against supermarkets, convenience stores, and fast-food restaurants within a census tract with a 2-kilometer (km) buffer from the centroid.[18] It was found that before adjustment, the odds of having BMI-defined obesity were lowered with more supermarkets within the census tract, indicating that living in an area with more access to supermarkets reduces the risk of having BMI-defined obesity.[18] The odds of having BMI-defined obesity were not associated with convenience stores or fast-food restaurants.[18] Upon adjustment for gender, age, race, education level, poverty index ratio, television viewing, moderate physical activity frequency, and the frequency of vigorous physical activity, there was no longer a significant relationship between the odds of having BMI-defined obesity and supermarkets.[18] In all of the unadjusted models, there was a negative association between BMI-defined obesity and supermarkets, a positive association between BMI-defined obesity and grocery stores, and insignificant associations between BMI-defined obesity and convenience stores and fast-food restaurants.[16–18]

When examining the prevalence of self-reported BMI-defined obesity and its relationship with supermarkets using a 1 km radius from the participants' residences, it was found in a 2013 study that BMI-defined obesity decreased at a buffer of 1.0, 1.5, and 3 miles.[19] Convenience stores and fast-food restaurants were not significantly associated with BMI-defined obesity at any buffer.[19] Contrarily, a 2015 study found that supermarkets were only associated with a reduced probability of self-reported BMI-defined obesity at the 1-mile buffer, with null findings at the 0.25, 0.5, 1.5, and 3-mile buffers.[20] Convenience stores were negatively associated with BMI-defined obesity at 0.25, 1, and 3-mile buffers, and fast-food restaurants were positively associated with BMI-defined obesity at a 1-mile buffer.[20]

A 2020 Canadian study found that more grocery stores or markets in a postal code lowered the odds of having BMI-defined obesity.[8] This study examined BMI-defined obesity, defined by a BMI of $\geq 30 kg/m^2$, and abdominal obesity, defined as a waist circumference of ≥ 102 cm for males and ≥ 88 for females.[8] The results remained significant after adjustment for age, sex, education level, sociodemographic deprivation score, neighborhood type, and hours walked per week.[8] The association between BMI-defined obesity, abdominal obesity, and fast-food restaurants was insignificant.[8] This study shows that grocery stores may be a preventive measure against obesity, although causation cannot be determined due to the study's cross-sectional nature.

A 2010 study found that the number of fast-food restaurants using a per capita of 10,000 was negatively associated with self-reported BMI.[21] This indicates that the

more fast-food restaurants are in an area, the lower the BMI. Contrariwise, a 2012 study conducted only on women reported that the availability of fast-food restaurants per 1,000 persons was positively associated with BMI.[22] Neither of these studies reported on fast-food consumption, thus limiting the conclusions that can be drawn.[21,22]

Supermarkets typically are associated with a reduced risk or prevalence of BMI-defined obesity.[16,17,19,20] While grocery stores are associated with mixed findings, with the majority reporting, increased risks of BMI-defined obesity, although, upon adjustment, the results become more skewed.[8,16,17] Convenience stores report primarily null findings regardless of adjustment.[17–19] While fast-food restaurants reported mostly null findings but included some findings that say fast-food restaurants lower BMI-defined obesity risks and findings that say the restaurants increase BMI-defined obesity risk.[8,18–22] The association between BMI-defined obesity and the food environment remains conflicted in their reports.

2.2 The Retail Food Environment Index and Obesity

A 2008 study in California was the first to examine the relationship between self-reported BMI-defined obesity and the food environment using the RFEI to measure the food environment.[14] This study defined the RFEI as the sum of the number of fast-food and convenience stores divided by the number of grocery stores, including supermarkets and produce vendors in a given area.[14] For urban areas, this equated to 0.5 miles from the participant's residence.[14] A radius of 1 mile was used in

smaller cities and suburban areas, and a 5-mile radius was used in rural areas.[14] The RFEI was divided into three categories for analysis: below 3.0, 3.0-4.9, and 5.0 and above.[14] For an RFEI of below three, the BMI-defined obesity prevalence was significantly lower than the other RFEI categories.[14] This study indicates that those with greater access to unhealthy food environments are more likely to have BMI-defined obesity.

A 2009 study in Alberta, Canada, examined the relationship between the prevalence of self-reported BMI-defined obesity and the food environment using the RFEI.[23] The food environment was measured using 800 and 1600-meter (m) buffers around the participants' residences.[23] The RFEI was calculated as the sum of fast-food restaurants plus convenience stores divided by the number of grocery stores.[23] In this study, supermarkets, ethnic markets, and organic markets are also counted as grocery stores.[23] A constant of 1 was added to the denominator if no grocery stores were identified within the buffer.[23] A higher RFEI score means that there are more options for unhealthy food. The RFEI score was divided into three categories for analysis: below 3.0, 3.0-4.9, and 5.0 and above.[23] The logistic regression models were weighted to reflect the age and sex differences and were adjusted for age, sex, education level, and neighborhood socioeconomic factors.[23] It was found that at the 800m buffer, the participants that lived in the lowest RFEI group had the lowest BMI-defined obesity prevalence after adjusting for covariates.[23] At the 1600m buffer, the results between BMI-defined obesity and the RFEI were null.[23] The results of this study indicate a relationship between the food environment and BMI-defined obesity.

A 2010 study in North Carolina used the RFEI to examine the relationship between self-reported BMI and the food environment.[21] The RFEI was defined in two different ways.[21] The RFEI 1 was calculated as the sum of the number of fast-food restaurants, grocery, and convenience stores divided by the sum of the number of supermarkets and produce stands in a county.[21] The RFEI 2 was calculated as the number of fast-food restaurants divided by the sum of the number of supermarkets and produce stands in a county.[21] Data was analyzed using linear regression models; in the unadjusted model, only RFEI 1 was significantly positively associated with BMI.[21] After adjusting for the percent below the poverty level, percent rural, and diverse index, the relationship between BMI and RFEI 1 was null.[21] This study has mixed results, furthering the theory that the food environment may not influence BMI.

A 2012 study conducted in Kentucky examined the relationship between self-reported BMI-defined obesity and the food environment using the RFEI.[24] The RFEI was defined as the sum of fast-food restaurants plus convenience stores divided by the sum of supermarkets plus fruit and vegetable markets.[24] A Euclidean buffer of 0.5 miles was around each participant's three-day GPS track line.[24] Adjusted odds ratios were used to assess if BMI-defined obesity was associated with the RFEI.[24] This study found that after adjusting for gender, age group, race, income, education, marriage status, and employment status, the relationship was not significant.[24]

The RFEI is positively associated with BMI-defined obesity when using categories to analyze the RFEI.[14,23] When adjusted, the RFEI and BMI-defined obesity became null in 50% of the studies.[21,24] However, the RFEI was inconsistently defined,

which limits the conclusions that can be made about its relationship with BMI-defined obesity. The RFEI, as an indicator of the food environment, suffers due to the different ways studies utilize the method.

2.3 The Modified Retail Food Environment Index and Obesity

A 2018 study in St. Louis and Kansas City, MO, examined the relationship between the food environment and self-reported BMI-defined obesity using the mRFEI.[25] In this study, the mRFEI was calculated for six U.S. Census tracts.[25] This study did not specify how the mRFEI was calculated but stated that the higher the mRFEI percentage was, the healthier the food retailers in that tract.[25] The study did include what a healthy food retailer and a less healthy food retailer were, according to the mRFEI.[25] Healthy food retailers included supermarkets, large grocery stores, produce stores, and superstores.[25] Less healthy food retailers include convenience stores, fast-food restaurants, and grocery stores with at most three employees.[25] The mRFEI increased as BMI decreased, indicating that the healthier the food environment, the lower the BMI.[25] This was attenuated as insignificant upon adjustment for entropy, correlation ratio, segregation measures, and the isolation index.[25]

A 2019 study across the U.S. used the mRFEI to examine the relationship between the food environment and BMI-defined obesity in adults aged 45 and older.[26] This study uses the percentage of healthy food retailers out of the number of all food retailers to figure out how healthy the food environment is in that census tract.[26]

Healthy food retailers included large grocery stores, supermarkets, supercenters, and produce stores.[26] Less healthy food retailers were undefined.[26] Ordinary least squares regression showed that the mRFEI was significantly negatively correlated with BMI.[26] Adjustments for sociodemographic, lifestyle, and community feature covariates rendered this relationship insignificant.[26]

A 2022 Canadian study examined the relationship between the food environment and a self-reporting of having overweight or BMI-defined obesity using data using the mRFEI to quantify the food environment.[27] The mRFEI was calculated as the sum of healthy food retailers divided by the sum of unhealthy food retailers plus the sum of healthy food retailers multiplied by 100, where healthy food retailers were defined as grocery stores, chain supermarkets, and fruit and vegetable markets.[27] Less healthy food retailers consisted of fast-food restaurants, convenience stores, and convenience stores at gas stations.[27] This study reported that mRFEI was significantly negatively correlated with a BMI over 25kg/m^2.[27]

Overall, studies show that a higher mRFEI or higher percentage of healthy food outlets was associated with a lower BMI.[25–27] Although in all studies, that reported adjustment for covariates rendered the association insignificant.[25–27] Therefore, the association between BMI and the mRFEI may be attributed to confounding factors. Also, the studies classified unhealthy food retailers differently, limiting the studies' generalization. Additionally, only one of the studies used measured height and weight to calculate BMI.

Chapter 3

MANUSCRIPT

3.1 Introduction

Obesity is a global health issue associated with numerous chronic non-communicable diseases such as hypertension, type 2 diabetes, cardiovascular disease, chronic kidney disease, and some cancers and an increased mortality risk.[4] Over one-third of adults in the United States (U.S.) has obesity, with current trends predicting that by 2030 nearly 50% of adults in the U.S. will have obesity.[1,2] Factors contributing to obesity include genetic, environmental, and behavioral factors.[16] The Centers for Disease Control and Prevention (CDC) reports that almost 173 billion dollars were spent in 2019 on medical costs due to obesity.[1] Obesity puts a significant strain on both the healthcare system and the economy.

The food environment is the physical presence of food that influences a person's diet; this includes policies, availability, and the presence of food outlets, which are any store where food can be purchased.[8,9] Food environments have the potential to shape health outcomes and dietary behavior through the availability and accessibility of food.[10,11] Findings from studies examining the relationship between obesity and the food environment are inconsistent concerning the food environment's role in obesity.[12] These inconsistencies among studies that examined the relationship between obesity and the food environment may be partly due to various methods used to assess the environment. Although it has been speculated that a ratio of unhealthy

food outlets to healthy food outlets may result in more consistent findings than individual store counts, few studies have used a ratio to examine obesity and food environments.[12]

The Retail Food Environment Index (RFEI) and the Modified Retail Food Environment (mRFEI) are used to measure the food environment as a single number allowing for the food environment to be assessed more efficiently than its individual components of fast-food restaurants, convenience stores, grocery stores, and produce vendors.[14,15] The RFEI is the ratio of fast food and convenience stores to grocery stores, while the mRFEI is the percentage of healthy food retailers in a given area.[14,15] Previous studies have concluded that obesity and the RFEI were positively correlated.[14,23,24]. Studies have found that BMI and mRFEI were negatively correlated, indicating that the higher the mRFEI, the lower the BMI.[25–27]

Currently, no studies have examined the association between obesity, defined by body fat percentage, and the food environment. As body fat percentage may be a better indicator of obesity due to its ability to measure body composition, it is imperative that the association be examined using body fat percentage. The present study aimed to enhance the understanding of the association between obesity using BMI and body fat and the food environment using the RFEI and the mRFEI. We hypothesized that a higher RFEI would be associated with higher BMI and body fat- and that mRFEI would be associated with a lower BMI and body fat.

3.2 Methods

3.2.1 Study Design and Participants

The data for this study is part of a more extensive multi-level study that examined environmental risk factors for obesity.[28–30] This study used a prospective cross-sectional, three-group nested design which ensured that there was a high variance between households' incomes. Trained interviewers conducted 60-minute face-to-face interviews and took anthropometric measurements for 20 U.S. Census block groups in Kansas City, KS, and Kansas City, MO, from 2003 to 2009. The survey included sociodemographic characteristics, physiological health, and health behaviors, which were measured using the Behavior Risk Factor Surveillance System, as well as neighborhood perceptions which were measured using the International Physical Activity Prevalence Study Questionnaire. Sociodemographics of interest from the Behavior Risk Factor Surveillance System included age, sex, ethnicity, race, educational level, and household income. In addition, race was dichotomized into non-minority, which included white, and minority which included black, Asian, Pacific Islander, Hawaiian, Native American, Alaskan Native, and other.

Individuals were eligible to participate if they were between 17 and 84 years of age, if they were the primary person responsible for making the household's food decisions, if they lived in the area for a minimum of 12 months, and if they were able to read and understand surveys in English. Participants were excluded if they were

pregnant or had any chronic health problems or disabilities that prevented them from participating in physical activity. A total of 436 participants were analyzed.

3.2.2 Measures

3.2.2.1 Obesity

Both BMI and body fat percentage were used to determine obesity status. Cut-off points for BMI-defined obesity and body fat-defined obesity are a BMI of ≥ 30 or a body fat percentage of ≥ 25% or ≥ 30% for males and females, respectively.[3] BMI (kg/m^2) was calculated using the participant's height and weight measured during the interview. Height was measured using a portable stadiometer (Charder HM200P Portstad Portable Stadiometer, USA) and rounded to the nearest 0.1 inch before being converted into meters. Weight was measured using a portable scale (Tanita TBF-300, Tokyo, Japan) and rounded to the nearest 0.1 pound before being converted to kilograms. Body fat percentage was also assessed during the interview using foot-to-foot bioelectrical impedance analysis (Tanita TBF-300, Tokyo, Japan). Trained investigators followed standard procedures for the device, and measurements were triplicated and averaged.

3.2.2.2 The Food Environment

The RFEI and the mRFEI were used to assess the community food environment. [14] First, the food environment was evaluated using the RFEI. It was

calculated as the sum of fast-food restaurants and convenience stores divided by the sum of grocery stores for each U.S. Census block group. The RFEI is the ratio of unhealthy food retailers to healthy food retailers in an area. A higher RFEI score is indicative of a less healthy food environment. The RFEI is limited in its ability as it can only score food environments with grocery stores. Secondly, the mRFEI was used to examine the food environment and was calculated by dividing the number of healthy food retailers by the sum of the number of healthy and less healthy food retailers multiplied by 100 for each U.S. Census block group. The CDC defines healthy food retailers as supermarkets and larger grocery stores and less healthy food retailers as fast-food restaurants, convenience stores, and small grocery stores. Supermarkets were further defined as stores with fifty or more employees, larger grocery stores had between 10 and 49 employees, and smaller grocery stores had three or fewer employees. The mRFEI is the percentage of healthy food retailers in an area. The mRFEI ranges from 0 to 100; the closer the number is to 100, the healthier the food environment. The count of grocery stores, convenience stores, and fast-food restaurants per U.S. Census block group were measured to assist in examining the food environment.

3.2.3 Statistical Analysis

Descriptive data are expressed in frequencies and percentages (%) for categorical variables and as means and standard deviations (SD) for continuous variables. Comparisons using Chi-square for categorical variables and t-test for

continuous variables were used to examine the differences between obese and non-obese groups. Binary logistic regression was used to analyze the association between the food environment indexes and obesity defined by BMI and body fat and between BMI-defined obesity and body fat-defined obesity for grocery stores, convenience stores, and fast-food restaurants. Based on bivariate analysis, the model was adjusted for sex, race, and educational level, which were found to be associated with either BMI-defined obesity or body fat-defined obesity. A *p*-value of < 0.05 was considered statistically significant. All statistical analyses were conducted using SPSS Statistics version 28.0 (IBM Corp., Armonk, New York).

3.3 Results

Presented in Table 1 are participant characteristics (n=436). The mean age was 44.1 ± 14.0 years, and the sample was comprised mainly of females (n=310, 71.1%). The average BMI was (28.5 ± 7.8) and 34.4% (n=150) had BMI-defined obesity. The average body fat percentage was (33.1% ± 11.3) and 63.8% (n=278) body fat-defined obesity.

The RFEI and the mRFEI were significantly negatively correlated ($r(434) = -.81$, $p < .001$). Table 2 shows no significant difference between BMI-defined obesity status, age, gender, and household income. Chi-square analysis showed a significant difference between BMI-defined obesity status and race and education ($X^2(1,436) = 11.6$, $p<.001$) and ($X^2(3,436) = 18.7$, $p<.001$), respectively. No

statistically significant difference was observed between the RFEI or the mRFEI based on BMI-defined obesity.

No significant associations were observed between BMI-defined obesity and the food environment using logistic regression (Table 3). Table 4 presents the association between body fat-defined obesity and the food environment. In the unadjusted model for the RFEI, the odds of having body fat-defined obesity decreased by 17% (95% CI: 0.75-0.92) for every one-unit increase in the RFEI. This indicates that as the ratio of convenience stores and fast-food restaurants to grocery stores increases, the risk of body fat-defined obesity decreases. The adjusted model discovered that the odds of having body fat-defined obesity decreased by 17% (95% CI: 0.74 – 0.92). In the unadjusted model for the mRFEI, it was observed that the odds of having body fat-defined obesity decreased by 1% (95% CI: 1.00 – 1.02) for every one-unit decrease in the mRFEI. As the percentage of healthy food retailers increases, the odds of having body fat-defined obesity increase. In the adjusted model for the mRFEI, the odds of having body fat-defined obesity decreased by 1% for every one-unit decrease in the mRFEI. (95% CI: 1.00 – 1.02).

Table 5 presents the associations between BMI-defined obesity, body fat-defined obesity, and food outlets. Grocery and convenience stores were not significantly correlated with BMI-defined obesity. In contrast, fast-food restaurants were significantly negatively correlated with BMI-defined obesity. Grocery stores were not significantly correlated with body fat-defined obesity. Convenience stores and fast-food restaurants were significantly correlated with body fat-defined obesity.

Specifically, an increase in the number of convenience stores and fast-food restaurants within the census block group was negatively associated with body fat-defined obesity.

3.4 Discussion

This study examined whether having increased access to food outlets was associated with BMI-defined obesity and body-fat-defined obesity in a metropolitan area. We hypothesized that a higher ratio of fast-food restaurants and convenience stores to grocery stores would be associated with a higher prevalence of BMI-defined obesity and body-fat-defined obesity. Similarly, a higher percentage of healthy food retailers would be associated with a lower prevalence of BMI-defined obesity and body-fat-defined obesity. To our knowledge, this is the first study that used body fat-defined obesity to examine the association between obesity and the food environment.

This study found that adults living in a U.S. Census block group with a higher ratio of unhealthy food retailers to healthy food retailers, as denoted by a higher RFEI, did not significantly affect the odds of BMI-defined obesity. These findings are not consistent with prior studies that found that a higher RFEI is associated with higher BMI-defined obesity.[14,23,24] Nor are they supported by Jilcott, who found that a higher RFEI is associated with a higher BMI.[21] A high RFEI decreased the odds of having body fat-defined obesity. A possible reason for this negative correlation between body fat-defined obesity and the RFEI is that it was driven by the significant negative correlation between fast-food restaurants and body fat-defined obesity.

This study determined that those living in U.S. Census block groups with a higher percentage of healthy food retailers, denoted by a higher mRFEI, had no significant effect on BMI-defined obesity risk. These findings are not consistent with other studies that found that a higher mRFEI was associated with a lower BMI.[25–27] However, they align with the studies that adjusted their statistical models for covariates.[25,26] While a higher mRFEI was not associated with a significant decrease in BMI-defined obesity risk, it was in the expected direction. A higher mRFEI was associated with an increased risk of body fat-defined obesity. This may be due to the grocery stores being misclassified into healthy food retailers as information on store size was unavailable and may have included grocery stores with three or fewer employees. The lack of significant results for BMI-defined obesity may be due to under-classifying people as obese because of BMI's limited ability to classify BMI-defined obesity correctly.[3]

The absence of a significant difference between BMI-defined obesity status with the RFEI and the mRFEI suggests that other factors besides the food environment play a major role in BMI-defined obesity status. Other contributors to BMI-defined obesity include genetic factors, diet, physical activity, and the built environment.[31] Adjusting for covariates did not significantly alter the model, suggesting that the food environment plays a larger role in BMI-defined obesity status than sex, race, and educational level. This may be due to the study's inclusion criteria, which resulted in most participants being female, and the study's design, which prevented any one income group from being overly represented.

This study found that each extra grocery store added to a U.S. Census block group did not affect BMI-defined obesity risk but increased the body fat-defined obesity risk. These findings align with the mRFEI results, which stated that the higher the percentage of healthy food retailers, the lower the odds of BMI-defined obesity and the higher odds of body fat-defined obesity. Therefore, indicating that the prevalence of a healthier food outlet is associated with an increase in body fat-defined obesity prevalence. These findings are supported and contradicted by previous studies that found mixed findings between grocery stores and BMI-defined obesity.[8,16,17] One study examined the effect on BMI after opening a new grocery store and found no significant differences in BMI between the intervention and control neighborhoods.[32] This may suggest that the addition of healthy food retailers does not play a prominent role in BMI-defined obesity status.

The number of convenience stores within a U.S. Census block group was not associated with BMI-defined obesity but significantly decreased the odds of body fat-defined obesity. This was in line with most studies that found no significant relationship between BMI-defined obesity and convenience stores.[17–19] Although convenience stores are perceived as unhealthy, it has been found that most calories from sugar-sweetened beverages and energy-dense, nutrient-poor foods are purchased at grocery stores and supermarkets, followed by fast-food restaurants, and then convenience stores.[33]

An increase in fast-food restaurants within a U.S. Census block group is associated with significantly decreased odds of body fat-defined obesity and BMI-

defined obesity. It is important to note that this does not factor in whether the individual consumes fast food. These findings are supported by Jilcott, who found that the more fast-food restaurants there were for a per capita 10,000 people, the lower the BMI.[21] However, the findings contradict other studies that concluded that the availability of fast-food restaurants increases BMI-defined obesity risk.[20,22]

A possible reason for the unexpected findings for the RFEI is that, on average, people travel almost five miles to obtain fast food.[34] Traveling to grocery stores varies, with one study in Seattle reporting an average of just over three miles and another in Atlanta averaging just over four and a half miles.[34,35] These distances may mean people traveling outside their block group to purchase food. A block group consists of 600 to 3,000 people; therefore, in a metropolitan area, a block group may not be an adequate unit to measure the food environment.[36]

This study is limited because it is cross-sectional; therefore, no causal relationships can be implied. No information was reported on the size of the grocery stores used to calculate the mRFEI, which may mean that some of the grocery stores were small grocery stores with three or fewer employees, which the CDC classifies as less healthy food retailers. Therefore, the percentage of healthy food retailers may have been less than reported skewing the results towards a decreased body fat-defined obesity prevalence. This study utilized U.S. Census block groups to measure the mRFEI, which is designed to be used at the Census tract level; this may have resulted in the food environment being underrepresented with participants traveling beyond their block group. Lastly, this study did not factor in diet, which is a contributing factor to obesity

and may potentially play a larger role in obesity status compared to the food environment.

3.5 Conclusion

The present study concludes that a greater availability of healthier food retailers is associated with a significantly higher body fat-defined obesity prevalence. At the same time, the higher availability of convenience stores and fast-food restaurants compared to grocery stores is associated with a higher body fat-defined obesity prevalence. Other than fast-food restaurants, food outlets were not significantly associated with BMI-defined obesity. Body fat-defined obesity was not associated with grocery stores but was significantly associated with convenience stores and fast-food restaurants.

Further studies should assess the built environment in addition to the food environment, as certain parts of the built environment are known to play a role in weight, such as parks, gyms, and sidewalks.[37] This may provide more insight into the relationship between obesity and the food environment. Furthermore, more studies that examine the food environment and body fat-defined obesity are needed before a consensus can be made regarding whether a healthier food environment is associated with heightened body fat-defined obesity risk, as shown in the current study.

CONCLUSION

The findings from this study suggest that when assessing the food environment using indices, there is no association with BMI-defined obesity, but there is with body fat-defined obesity. Other studies have found the opposite, with the food environment indices associated with BMI-defined obesity. [14,21,23–27]Although, when using its' individual components, convenience stores, and fast-food restaurants were negatively associated with body fat-defined obesity. While only fast-food restaurants were significantly negatively associated with BMI-defined obesity. Grocery stores were neither significantly associated with BMI-defined obesity nor body fat-defined obesity. To date, no studies have examined the food environment using body fat-defined obesity.

Further studies should include the built environment and the food environment; the built environment can be defined as the human-made environment in which people work, live, and engage in physical activity, land use, transportation, and infrastructure.[37] Certain parts of the built environment are known to play a role in weight and may be able to provide more insight into the relationship between obesity and the environment. Furthermore, more studies that examine the food environment and body fat-defined obesity are needed before a consensus can be made regarding whether a healthier food environment is associated with heightened body fat-defined obesity risk, as shown in the current study.

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Appendix A

TABLES

Table 1: Participant Characteristics (n=436)

	Mean ± SD
Age, years	44.1 ± 14.0
	N (%)
BMI	
Obese (BMI ≥ 30)	150 (34.4)
Body Fat Percentage	
Obese (males: ≥ 25%; females ≥ 30%)	278 (63.8)
Gender	
Female	310 (71.1)
Male	126 (28.9)
Ethnicity	
Hispanic	26 (6.0)
Non-Hispanic	410 (94.0)
Race	
Non-minority	281 (64.4)
Minority	155 (35.6)
Education	
Less than High School	19 (4.4)
High School Diploma or GED	90 (20.6)
Some College or Trade School	145 (33.3)
College	182 (41.7)
Household Income	
Less than $15,001	43 (9.9)
$15,001 - $30,000	77 (17.7)
$30,001 - $60,000	136 (31.2)
$60,001 - $100,000	112 (25.7)
$100,001 - $200,000	54 (12.4)
Greater than $200,000	14 (3.2)

Abbreviations: BMI, body mass index; GED, General Education Development test; SD, standard deviation.

Table 2: Participant Characteristics by BMI-Defined Obesity Status

	Obese (n=150)	**Non-obese (n=286)**	**P-value**
	Mean ± SD		
Age, years	45.3 ± 14.2	43.5 ± 13.8	0.189
Retail Food Environment Index	2.0 ± 1.6	2.1 ± 2.1	0.419
Modified Retail Food Environment Index	0.46 ± .28	0.48 ± 0.30	0.543
Gender			0.193
Female	113 (36.5)	197 (63.5)	
Male	37 (29.4)	89 (70.6)	
Race			<.001*
Non-minority	80 (28.5)	201 (71.5)	
Minority	70 (45.2)	85 (54.8)	
Education			<.001*
Less than High School	11 (57.9)	8 (42.1)	
High School Diploma or GED	39 (43.3)	51 (56.7)	
Some College or Trade School	57 (39.3)	88 (60.7)	
College	43 (23.6)	139 (76.4)	
Household Income			0.062
Less than $15,001	16 (37.2)	27 (62.8)	
$15,001 - $30,000	32 (41.6)	45 (58.4)	
$30,001 - $60,000	53 (39.0)	83 (61.0)	
$60,001 - $100,000	36 (32.1)	76 (67.9)	
$100,001 - $200,000	10 (18.5)	44 (81.5)	
Greater than $200,000	3 (21.4)	11 (78.6)	

Note: Significant difference between variable means or count between obesity classification by independent t-tests or Chi-square analysis (*p<.001).

Table 3: Association Between BMI-Defined Obesity Prevalence and the Food Environment

	Odds Ratio		*Adjusted Odds Ratio*	
		95% CI		95% CI
RFEI	0.96	0.86 – 1.06	0.95	0.85 – 1.07
mRFEI	1.00	0.99 – 1.01	1.00	0.99 – 1.01

Note: Adjusted odds ratio is adjusted for sex, race, and educational level.
Abbreviations: RFEI, Retail Food Environment Index; mRFEI, modified Retail Food Environment Index; OR, odds ratio; CI, confidence interval.

Table 4: Association Between Body Fat-Defined Obesity Prevalence and the Food Environment

	Odds Ratio		*Adjusted Odds Ratio*	
		95% CI		95% CI
RFEI	0.83**	0.75 – 0.92	0.83*	0.74 – 0.92
mRFEI	1.01*	1.00 – 1.02	1.01*	1.00 – 1.02

Note: Adjusted odds ratio is adjusted for sex, race, and educational level.
Abbreviations: RFEI, Retail Food Environment Index; mRFEI, modified Retail Food Environment Index; OR, odds ratio; CI, confidence interval.
*p<0.05
**p<.001

Table 5: Univariate Odds Ratios for BMI-Defined Obesity and Body Fat-Defined Obesity Prevalence and Food Outlets

	BF Obesity OR	CI	*BMI Obesity OR*	95% CI
Grocery Store	1.13	0.91 – 1.41	0.96	0.77 – 1.19
Convenience Store	0.90*	0.81 – 1.00	1.06	0.96 – 1.18
Fast-Food Restaurant	0.81**	0.73 – 0.90	0.79**	0.70 – 0.91

Abbreviations: OR, odds ratio; CI, confidence interval; BF, body fat-defined; BMI, body mass index-defined

*$p<0.05$

**$p<0.001$

Appendix B

STUDY DOCUMENTS

B.1 De-identified Data Agreement Form

Research Protections 9-2005

Agreement for Research Involving - De-Identified and Coded Private Information

This agreement is made effective this 22 day of February 2023, by and between Walker Poston, Ph.D., M.P.H._ holder of key to decipher the code (hereafter Holder) and Catherine Davis, B.S., the investigator receiving the de-identified/coded private information (hereafter Recipient) for the currently proposed research project entitled:

The Association Between Obesity Prevalence and the Food Environment

On 10 August 2004, the Office for Human Research Protections issued "Guidance on Research Involving Coded Private Information or Biological Specimens". This agreement is based upon this guidance

The Holder and Recipient hereby certify that:

(1) The private information or specimens were not collected specifically for the currently proposed research project through an interaction or intervention with living individuals; **or** the private information or specimens were collected specifically for the currently proposed research project – however, the recipient was not involved in the interaction or intervention with living individuals; **and**

(2) The Recipient cannot readily ascertain the identity of the individual(s) to whom the coded private information or specimens pertain because the investigator(s) and the Holder of the key hereby enter into an agreement prohibiting the release of the key to the Recipient under any circumstances, until the individuals are deceased

By signing, both the Holder of the key to decipher the code and the Recipient of coded private information agree to the aforementioned conditions.

Signature of Holder	Signature of Recipient
Name: Walker S. Carlos Poston, Ph.D., M.P.H.	Name: Catherine Davis, BS
Title: Senior Principal Investigator	Title: Master's Student
Institution: NDRI-IBHR	Institution: University of Delaware
Date: 12 October 2014	Date: 22 February 2023

Only de-identified data (that is, data from which real names or other identifiable characteristics have been removed) will be provided to Dr. Poston. Failure to protect confidentiality of all research project data or human subjects will be addressed and reported to respective NDRI and U.S. Federal oversight bodies as required.

Name:
Title:
Institution:
Date: