

2017

# Exploring Spatial Patterning and the Impact of Obesogenic built Environments for Youth Obesity

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EXPLORING SPATIAL PATTERNING AND THE IMPACT OF OBESOGENIC BUILT  
ENVIRONMENTS FOR YOUTH OBESITY

by

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Submitted in Partial Fulfillment of the Requirements

For the Degree of Doctor of Philosophy in  
Health Promotion, Education, and Behavior

The Norman J. Arnold School of Public Health

University of South Carolina

2017

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## DEDICATION

This dissertation research and doctoral degree is dedicated to my family and friends.

To Mom and Dad, you have always supported me in following my dreams and passions and been there every step of the way. Thank you for teaching me that I could accomplish what I put my mind to and the value of hard work and determination. I know Granjean, Pop, and Mimi would be so proud of this accomplishment.

To Abby, I cannot thank you enough for your unwavering support, patience, and encouragement. You helped me stay grounded, keep perspective, and have balance. I would not have made it through this journey without you, and I would not have wanted to do it with anyone else. I am excited to see where our next steps lead.

To the rest of my incredible support system: thank you for your friendship, support, and laughter. This milestone is so much sweeter because I have you to share it with.

## ACKNOWLEDGEMENTS

I would like to acknowledge my supportive dissertation committee members, Dr. Andrew Kaczynski, Dr. Brie Turner-McGrievy, Dr. Dwayne Porter, Dr. Jihong Liu, and James Hibbert who challenged me to think critically and with a multidisciplinary lens. Your time, efforts, and enthusiasm are greatly appreciated.

I would also like to thank Drs. Julian Reed and Alicia Powers from Furman University and for your continued mentorship and support of this dissertation project. In addition, I thank my colleagues at LiveWell Greenville and all community partners in Greenville, SC for your continued support, encouragement, and collaboration on this research. Your perspective continually improved my work and helped me stay grounded, always asking ‘how can this improve my community?’.

Additionally, this work would not have been possible without generous funding from the Piedmont Health Foundation, University of South Carolina Office for the Vice President of Research (SPARC), and University of South Carolina Provost.

## ABSTRACT

Youth obesity is a major public health concern due to an array of physical, social, and psychological health consequences. Residential location, often referred to as ‘place’, has continued to emerge as a key health determinant with studies showing that where a child lives impacts their health. Environments where it is easy for individuals to have low levels of physical activity – either by discouraging active behavior or promoting sedentary behavior – and easy for individuals to consume unhealthful foods – either by the limited availability of healthful foods or increased availability of unhealthy foods – have been coined ‘obesogenic’. Additional research is needed to improve measurement of obesogenic built environments and test associations with childhood obesity.

This study occurred in a southeastern US county (population:474,266) in 2013 and combined four unique datasets: 1) demographic, weight status, and addresses from all 3<sup>rd</sup> through 5<sup>th</sup> grade youth enrolled in a large southeastern school district (n=13,469), 2) detailed audit data on all public park facilities, 3) location of all food stores and restaurants, and 4) sociodemographic Census data. Global Moran’s Index and Anselin’s Local Moran’s I (LISA) were used to detect global and local spatial clustering of youth obesity, while residuals from a series of linear regression models were subsequently spatially analyzed and mapped to examine correlates of spatial clustering. Significant, positive global clustering (Index=0.04,  $p<0.001$ ) was detected. In addition, LISA results showed that about 4.7% (n=635) and 7.9% (n=1,058) of the sample were identified as high and low obesity localized spatial clusters ( $p<0.01$ ). Individual and neighborhood

sociodemographic characteristics accounted for the majority of spatial clustering and differential patterns emerged by level of urbanization (e.g., urban, suburban, rural).

The second part of this study developed and tested an obesogenic built environment measure. Public parks (n=103) were identified and then scored using detailed audit data, while two commercial databases of food stores (n=395) and restaurants (n=717) were collected, categorized, and geocoded. Grocery stores that offered access to fresh produce were classified as 'healthy' while convenience stores, discount/drug stores, fast food restaurants, and fast casual restaurants with less access to fresh produce were classified as 'less healthy'. Using GIS techniques, kernel density estimation procedures were used to create, normalize, and summarize separate raster (pixel) surfaces representing the nutrition and park environments. Using multilevel linear analyses, results showed that health promoting built environments, as indicated by availability of parks, presence of healthy food stores, and lack of unhealthy food outlets, were related to lower BMI z-score among youth ( $b=-0.25$ ,  $p<0.05$ ).

Identifying geographic areas that contain spatial clusters is a powerful tool for understanding the location of and contributing factors to patterns of childhood obesity. Environments that were classified as health promoting by providing greater access to public spaces to be active and places to consume healthier food options were related to lower youth obesity. This dissertation study integrated innovative methodology to analyze spatial patterns of youth obesity and develop and test a unique characterization of obesogenic built environments.

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## LIST OF ABBREVIATIONS

BEACH.....	Built Environment and Community Health
BG.....	Block Group
BMI.....	Body Mass Index
CPAT .....	Community Park Audit Tool
DHEC.....	Department of Health and Environmental Control
GIS .....	Geographic Information Systems
LISA.....	Anselin's Local Moran's I
HE .....	Healthy Eating
PA .....	Physical Activity
SES.....	Socioeconomic Status
US .....	United States

# CHAPTER I

## INTRODUCTION

The prevalence of childhood obesity in the United States (US) remains high, disproportionately impacts low-income and racial/ethnic minority youth, and is often accompanied by an array of physical, social, and emotional health consequences.<sup>1-4</sup> Physical inactivity and unhealthy dietary patterns are key health behaviors contributing to the youth obesity epidemic.<sup>5</sup> To address this widespread health condition, public health efforts have largely shifted from targeting only individual-level factors to studying how the environments where people live influence health behaviors and outcomes.<sup>6-8</sup> Indeed, the role of place has emerged as a health determinant with ample research demonstrating relationships between residential characteristics and health behaviors and diseases.<sup>9</sup>

Spatial epidemiology focuses on the distribution of health outcomes with an emphasis on how diseases vary by geographic contexts.<sup>10,11</sup> Although the broad public health literature has seen an increase in spatial epidemiological approaches, much obesity-related research still lacks an explicit focus on the use of spatial tools and analyses when examining patterns and determinants.<sup>11</sup> Specifically, few studies have examined whether health conditions, like obesity, are spatially clustered.<sup>12</sup> Exploring spatial clustering of youth obesity is critical to better understand geographic locations and patterns of obesity and examine what individual and community-level factors are correlated with those clusters.<sup>12</sup> Furthermore, mapping spatial patterns results in powerful

visualizations, which can be used to identify and further study communities most impacted by obesity, and highlight priority areas for public health intervention.<sup>12,13</sup>

Communities are comprised of complex systems with many important components including built, or person-made, environment features.<sup>14-16</sup> Several elements of the built environment have demonstrated relationships with youth health behaviors and outcomes, including parks and recreation facilities, food stores, and restaurants.<sup>17-19</sup> The availability of parks and specific park features, like playgrounds, have consistently demonstrated positive relationships with youth physical activity (PA)<sup>20-25</sup> and some longitudinal studies have shown that healthier child weight status is associated with the availability of green space over time.<sup>26-28</sup> Furthermore, the types of food outlets available are considered fundamental for promoting healthy eating (HE) behaviors.<sup>29-32</sup> Similarly, the availability of healthier food outlets, like grocery stores, have been related to lower child weight status,<sup>33,34</sup> while availability of less healthful food options, like fast food restaurants, have been associated with increased levels of child obesity.<sup>35</sup>

Despite the importance of both PA and HE environments for child obesity, several gaps need to be addressed. First, most studies examining environmental influences on obesity have primarily focused on adults, and among the research targeting children, the literature has presented largely mixed findings.<sup>18,19</sup> In addition, studies have predominately measured only park availability, though the characteristics and quality of parks have been documented as essential elements for promoting park visitation and PA.<sup>36,37</sup> Research examining the relationship between the food environment and childhood obesity has primarily focused on one type of food outlet, so studies lack inclusion of both health-promoting (e.g., grocery stores) and health-detracting (e.g., fast

food restaurants) outlets.<sup>38</sup> Finally and importantly, very few studies have simultaneously accounted for environmental factors on both sides of the energy-balance equation.<sup>39,40</sup>

Comprehensive lists and detailed audit data of publicly available park facilities as well as two commercial databases of food stores and restaurants were used to create a measure of the obesogenic built environment. Using a large database of elementary-aged youth (n=13,469) complete with objectively measured height and weight, address, and several demographic characteristics, this study employed innovative spatial analysis techniques to 1) explore the spatial clustering of youth obesity, 2) develop a multicomponent measure of the obesogenic built environment, and 3) examine the relationship between obesogenic built environments and youth obesity.

The proposed research built upon two recently-published studies from the Built Environment and Community Health (BEACH) Laboratory ([beachlab.sc.edu](http://beachlab.sc.edu)). First, a previous study examined whether park availability and park quality were equitably distributed according to socioeconomic indicators and race/ethnicity in the same southeastern US county.<sup>41</sup> A neighborhood disadvantage index, comprised of four socioeconomic indicators, was created for all block groups (BGs, n=255) in the study area. Detailed audits of all publicly available parks (n=103) were conducted using the Community Park Audit Tool (CPAT).<sup>42</sup> Results showed that the availability of parks was equitably distributed according to neighborhood socioeconomic disadvantage; however, high disadvantaged neighborhoods were more likely to have greater park incivilities compared to low disadvantaged neighborhoods.<sup>41</sup> Park quality indicators have the potential to play a large role in promoting park visitation and park-based PA, so lower

park quality in high minority and high socioeconomically disadvantaged neighborhoods could limit the health benefits that parks can have for youth in these areas.

Second, a recent study led by the BEACH Lab developed a standardized metric (ParkIndex) for measuring park exposure using empirically-derived and spatially-representative methods.<sup>43</sup> Results from a survey of 891 adults in Kansas City, Missouri showed that two park summary variables were significantly associated with park use – number of parks and average park quality index.<sup>43</sup> These results were used to create a mapped surface representing the probability of park use. This study highlights the importance of availability and quality of parks and provided a foundation for a multicomponent park measure.<sup>43</sup> This dissertation research utilized similar procedures from these studies to determine overall park quality score and built upon these studies by adding nutrition components to the obesogenic environment measure and examining how these features were associated with an important health outcome – youth obesity.

This dissertation project is a key component of an interdisciplinary research agenda to 1) better understand the complexity of community-level determinants for youth obesity, 2) utilize innovative spatial tools to improve built environment measurement, and 3) explore whether obesogenic places contribute to racial/ethnic and socioeconomic disparities in obesity. This research uses a multilevel framework to approach childhood obesity and works to integrate and maximize methodological approaches from disciplines outside of public health, including geography and environmental health sciences.<sup>8</sup> Moreover, the methodology used and results discovered in this dissertation project can serve to advance childhood obesity research and practice and are geographically transferrable.



## 1.1. SPECIFIC AIMS AND HYPOTHESES

**Aim 1a:** Explore global and local spatial clustering of youth obesity in a large southeastern US county.

**Hypothesis 1a:** Statistically significant global spatial clustering of youth obesity will be identified across the study area and local spatial clusters will be identified and mapped in specific regions of the study area.

**Aim 1b:** Determine which individual and neighborhood sociodemographic characteristics are related to the spatial clustering of youth obesity.

**Hypothesis 1b:** Individual and neighborhood sociodemographic characteristics will be correlated with global and local spatial clustering of youth obesity.

**Aim 2a:** Develop a multicomponent measure of obesogenic built environments that incorporates park and nutrition elements.

**Hypothesis 2a:** Obesogenic built environment measures will be mapped in the study county.

**Aim 2b:** Examine the associations between the obesogenic built environment measure and youth obesity in the study county.

**Hypothesis 2b:** More supportive obesogenic built environments will be associated with lower youth weight status.

**Aim 2c:** Examine whether associations between obesogenic built environments and youth obesity vary by youth race/ethnicity, SES, and level of urbanization.

**Hypothesis 2c:** Obesogenic built environments will be associated with higher levels of youth obesity for racial/ethnic minority, low-SES, and urban residing youth.

## CHAPTER II

### BACKGROUND AND SIGNIFICANCE

#### 2.1. BACKGROUND

*Youth Obesity: Prevalence, Disparities, and Determinants.*

Youth obesity has been recognized as a major public health problem of the 21<sup>st</sup> century due to the wide array of physical, social, and emotional health consequences that often accompany overweight and obesity during childhood.<sup>1-3</sup> The prevalence of childhood and adolescent obesity has increased over the past three decades with a disproportionate burden on youth that are low-income, racial/ethnic minorities, and reside in the southeastern United States.<sup>4</sup> Obesity researchers have recognized the complex and multifactorial nature of this chronic condition and attribute childhood obesity to a variety of individual, interpersonal, community, and broad policy-level factors. In particular, individual-level demographic characteristics, such as race/ethnicity and socioeconomic status (SES) and health behaviors, like PA and HE, are important determinants for childhood obesity.<sup>44</sup> Likewise, community environments that influence health behaviors also significantly contribute to youth obesity.<sup>22,45</sup>

Overweight and obese youth have worse physical and psychosocial health outcomes compared to normal weight peers.<sup>1-3</sup> Specifically, overweight and obese youth are at higher risk for developing risk factors for cardiovascular disease and type 2 diabetes such as elevated blood pressure, levels of cholesterol, blood glucose as

well as increased rates of asthma, musculoskeletal problems, and sleep disruptions.<sup>3,46,47</sup> Evidence has also shown an increased risk of internalizing disorders such as depression and anxiety as well as externalizing disorders such as behavioral disruptions and attention-deficit hyperactivity disorder among overweight and obese youth.<sup>3,46,48</sup> Researchers have also documented consistent patterns of low self-esteem, particularly among females, and higher incidence of bullying among obese youth.<sup>49-51</sup> Moreover, overweight and obese youth have demonstrated an increased likelihood for being obese into adolescence and adulthood.<sup>44,52</sup> For example, a recent study demonstrated that children who were overweight when entering kindergarten at age five were nearly four times more likely to be obese in early adolescence,<sup>44</sup> while another study showed that an estimate 50% of obese children become obese adults.<sup>52</sup> Persistent adult obesity is related to decreased quality of life, increased rates of chronic disease, as well as increased morbidity and mortality.<sup>16,53</sup> Overall, there are a myriad of health concerns that accompany childhood obesity making this a major public health concern.

The prevalence of childhood and adolescent obesity has steadily increased until 2010, while recent patterns have shown promise for leveling off over the past five years.<sup>54</sup> Youth weight status is defined by body mass index (BMI) percentiles, which are categorized based on height for weight growth charts based on age and gender and are classified in the following categories: i) underweight (less than 5<sup>th</sup> percentile) ii) healthy weight (5<sup>th</sup> percentile to <85<sup>th</sup> percentile), iii) overweight (85<sup>th</sup> percentile to less than 95<sup>th</sup> percentile), or iv) obese (95<sup>th</sup> percentile or greater).<sup>55</sup> In 2009-2010, 16.9% of US children and adolescents ages 2-19 were classified as obese and 31.8% were classified as

overweight and obese.<sup>4</sup> Specifically, 18.0% of children ages 6-11 were obese and 18.4% of adolescents ages 12-19 were obese.<sup>4</sup>

Researchers have found consistent racial/ethnic and socioeconomic disparities in youth obesity levels.<sup>4,5,52</sup> Across both male and female children and adolescents, non-Hispanic Blacks and Hispanics have significantly higher prevalence of obesity compared to their non-Hispanic White counterparts. Specifically, Hispanic and non-Hispanic Black males (ages 6-11) have a 22% and 13% increased prevalence, respectively, of obesity compared to non-Hispanic White males.<sup>4,52</sup> Females display similar patterns, with the largest disparity noted between non-Hispanic Blacks and non-Hispanic Whites between the ages of 12-19 (11.5%).<sup>4,52</sup> Likewise, research has shown that lower SES children have higher risk of obesity.<sup>52,56</sup> For example, one study showed that children with less educated parents are two times more likely to be obese compared to children with parents that have college degrees,<sup>52</sup> while another study demonstrated that children in families below the poverty threshold are approximately three times more likely to be obese than those families that exceed the poverty threshold by 400%.<sup>5</sup> In addition, disparities in obesity rates by geographic areas have been well-documented such that the southeastern United States has the highest prevalence of obesity compared to the western and northern areas of the country.<sup>52</sup> The stark differences in obesity rates for racial/ethnic minorities and low SES youth have led to national public health goals specifically aimed at reducing these disparities, in addition to decreasing overall youth obesity rates.<sup>57</sup>

#### *Youth Physical Activity*

PA is one of the primary health behaviors that can help prevent and combat obesity. The 2008 PA Guidelines for Americans recommend that youth ages 5-18

accumulate 60 minutes of moderate-to-vigorous aerobic activity each day to sustain health benefits; bone and muscle strengthening activities should be completed at least 3 days per week.<sup>58</sup> Youth that meet the PA recommendations have better musculoskeletal strength, cardiorespiratory fitness, and body composition and are at less risk for chronic disease indicators such as hypertension, elevated blood glucose levels, high blood lipid profiles, and mental health conditions like depression.<sup>1,59</sup> Furthermore, children who get no PA per week are substantially more likely to be obese than children who are active at least 5 days per week.<sup>5</sup>

Despite well-documented, positive health benefits for children meeting PA recommendations, most youth do not meet the guidelines.<sup>60</sup> Objectively-measured PA data from a nationally representative surveillance study, the National Health and Nutrition Examination Survey, demonstrated that less than half (42.0%) of children ages 6-11 meet the PA recommendations.<sup>60</sup> Consistently, a steep decline in PA patterns are observed during the transition from childhood to adolescence for males and females;<sup>60,61</sup> however, meeting PA recommendations in childhood is a strong and positive predictor of adolescent and adult PA.<sup>62</sup> Given the low proportion of youth that meet PA recommendations and how important early child behavior is, further understanding PA predictors is essential for addressing childhood obesity.

### *Youth Healthy Eating*

Unhealthy dietary patterns also contribute to youth overweight and obesity.<sup>63,64</sup> The US Department of Agriculture and US Department of Health and Human Services jointly created the national dietary guidelines for Americans in 2010 and recently released updated guidelines in late 2015.<sup>65</sup> There are five overarching concepts provided

in these guidelines: 1) Follow a HE pattern across the lifespan, 2) Focus on variety, nutrient density, and amount, 3) Limit calories from added sugars and saturated fats and reduce sodium intake, 4) Shift to healthier food and beverage choices, and 5) Support HE patterns for all populations. Specifically, the national dietary guidelines continue to recommend 5 or more servings of fruits and vegetables per day for children and adults.<sup>65</sup> Evidence has shown that the majority of US children do not meet these recommendations.<sup>66,67</sup> Additionally, the fast-food industry has grown tremendously since the 1970s, with these foods demonstrating higher sodium and fat concentration while lacking key essential nutrients important for developing youth.<sup>29,68,69</sup> There have been observed trends in higher consumption of high-fat and high-sugar food products such as fast food and sugar-sweetened beverages among children.<sup>70</sup> In particular, research has shown that overweight children consumed fewer servings of fruit and higher servings of high-fat foods than normal weight peers.<sup>35,70</sup> A diet that lacks fruits and vegetables and consists of foods with a high fat and sugar content can have negative health consequences for youth.<sup>63,64</sup> Poor nutrition habits and food consumption may interfere with development during childhood and have been linked with increased overweight and obesity, blood pressure, cholesterol, and fasting blood glucose in youth.<sup>63,64</sup>

Overall, two main health behaviors that influence youth obesity are HE and PA with research documenting that a majority of youth do not meet national standards for either health behavior.<sup>70,71</sup> While a vast amount of literature has focused on individual-level determinants and interventions to improve these health behaviors, community level factors have emerged as determinants for childhood obesity and associated and associated health behaviors.<sup>72,73</sup>

## *Environment Influences on Physical Activity, Healthy Eating, and Obesity*

There are three similar, yet nuanced, ecological models that have guided this study, each of which is presented and discussed in the following paragraphs. Structural, or ecological, models of behavior change and determinants of health have expanded the conceptualization that only individual-level determinants, like knowledge, attitudes, and beliefs, influence factors for health behaviors and chronic disease.<sup>6-8</sup> Instead, social ecological models focus on multiple levels of influence, including organizational (e.g., churches, workplaces), community (e.g., neighborhood infrastructure) and policy-level (e.g., laws and regulations) approaches to addressing chronic disease.<sup>6-8</sup> In particular, ecological models have highlighted the importance of built, or person-made, environments for obesity prevention, including how environment-level changes has the potential to reach large populations by modifying the context in which individuals consistently interact.<sup>14</sup> Elements of the built environment, such as housing, transportation, and parks and green spaces, have increasingly been recognized as integral components for promoting healthy behaviors and preventing chronic disease.<sup>14-16</sup> Subsequently, the amount of research produced related to environmental influences on PA, HE, and obesity has substantially increased in the past fifteen years resulting in an improved evidence base.<sup>74,75</sup> Furthermore, ecological approaches have facilitated interdisciplinary research approaches to health behavior change and have become a well-recognized approach that public health organizations and institutions use to guide their research and practice.<sup>57,76</sup>

Although ecological models have broadened public health research, more work is necessary to understand, measure, and study associations between elements of ecological models and health outcomes.<sup>6,8</sup> One key tenet of ecological models, beyond the explicit

inclusion of organizational, environmental, and policy elements, is the reciprocal nature of all levels in the framework.<sup>7</sup> Human behavior is a function of an individual within their physical and social environments and both individuals and environments exert influence on one another.<sup>7</sup> Increased efforts are needed to integrate models that examine broad environment and policy factors as well as the reciprocal influences. To address some of the complexities, theoretical models have been adapted to focus on specific behaviors like active living and healthy eating,<sup>8</sup> while other researchers have developed frameworks outlining mechanisms and measurement approaches through which multiple built environment features simultaneously impact PA, HE, weight status, and associated chronic disease outcomes.<sup>77-80</sup> The following theoretical frameworks have been developed to highlight the multifactorial and complex influences on PA, HE, and obesity. Elements of these frameworks were used to inform the specific conceptual model for this study, which is presented in chapter three. Specific built environment elements were chosen for this study based on empirical evidence linking these factors with children's health behaviors and outcomes.

#### *Ecological Model for Active Living*

A decade ago, Sallis and other prominent researchers in the field of built environment and health adapted a social ecological model specifically for active living (Figure 2.1).<sup>8</sup> The term active living reflects how the field of PA and public health has evolved over the past several decades, with an emphasis on environmental influences and a multidisciplinary focus to guide practice and policy changes.<sup>8</sup> The ecological model for active living focuses on four major active living domains: recreation, household, occupational, and transportation.<sup>8</sup> The 'active recreation' domain of this ecological



framework demonstrates that within active recreation, multiple characteristics of the neighborhood and recreation environment (i.e., availability and quality of parks and trails) are critical for promoting PA, particularly for children.<sup>8</sup> Simultaneously, the framework also emphasizes the importance of intrapersonal (e.g., gender) and neighborhood characteristics (e.g., SES) that reflect broader social climate of communities.<sup>8</sup> While recreation is only one of four main domains of the ecological model for active living, examining the intersection of individual (e.g., gender, race/ethnicity) and neighborhood demographics (e.g., race/ethnicity, SES), parks, and youth obesity is a major tenet of active living that will be examined in this study.

#### *Ecological Model for Healthy Eating*

Like PA, dietary behavior is recognized as a complex health behavior with diverse influences.<sup>73</sup> Similar to the ecological model for active living, Story and colleagues specified an ecological model related to healthy eating (Figure 2.2).<sup>73</sup> This framework details the numerous influences on dietary behavior ranging from individual personal factors (e.g., demographics and skills) to the broadest macro-level environments (e.g., government structures and policies).<sup>73</sup> This framework explicitly highlights the importance of physical environment settings, which includes a variety of food stores and restaurants located within neighborhoods and communities and characteristics of those food outlets such as availability, accessibility, barriers, and opportunities for acquiring healthy food.<sup>73</sup> This dissertation project will incorporate multiple aspects of the physical food environment settings, including number and types of food stores and restaurants.

### *Combined Built Environment Model*

Ecological models specific to HE and PA allow researchers to conceptualize the determinants and measurement for each behavior separately.<sup>8,73</sup> However, these behaviors and environments that influence them co-occur in real world settings and are important to study simultaneously.<sup>81</sup> Environments that promote obesity by discouraging or limiting PA as well as promoting unhealthy dietary patterns or limiting access or consumption of healthy food have been coined ‘obesogenic’.<sup>81</sup> The ANGELO framework was the first conceptual model to specifically focus on obesogenic environments.<sup>81</sup> This model recognized two aspects of environments – micro and macro – and also categorized four types of environments - physical, economic, political, and sociocultural – that all exert influence on obesity and related behaviors.<sup>81</sup> In addition, a recent literature review examining the influences of built environment influences on child and adolescent weight status critically examined existing studies focused on both the PA and food environment indicators, measurement, and links to health behaviors and outcomes in youth, which is pertinent to this dissertation project.<sup>79</sup> Figure 2.3 summarizes five major components of the built environment that contribute to health behaviors and outcomes. The left side highlights how PA facilities, transportation infrastructures, and community design are the primary environment features influencing PA, while the right side of the conceptual model details the various food outlets that impact dietary patterns. **Each of these models, 15 years apart, showcase the necessity for simultaneously examining multiple environmental components related to youth obesity.**<sup>79,81</sup>

### *Spatial Clustering of Youth Obesity*

Place-focused research examining how community features influence health behaviors and health outcomes includes spatial components, whether implicitly or explicitly stated.<sup>79</sup> Spatial epidemiology focuses on the spatial distribution of health outcomes with an emphasis on how disease distributions vary by geographic contexts.<sup>82</sup> To address complex health problems, like obesity, multidisciplinary research teams have worked collaboratively to examine how built environment features contribute to population-level health.<sup>8</sup> Although such collaborations have pushed the field forward, much research still lacks an explicit focus on and use of spatial tools and analyses to measure patterns of obesity.<sup>11</sup>

Spatial epidemiology relies on computer-based geographic information systems (GIS) software and technology as the primary mechanism to visualize, measure, and conduct analyses looking at time, space, and feature.<sup>11</sup> Indeed, the use of GIS for public health research has surged in the past decade, though the primary areas of study have been related to cancer research and environmental exposures like air and water pollution.<sup>11</sup> The primary GIS tools used in the literature have been spatial proximity (e.g., measuring distance through techniques like point-to-point distances or buffers) and aggregation of spatial features to administratively-defined units (e.g., census tracts).<sup>11</sup> For example, researchers have measured the distance from an individual's home to the nearest park<sup>83</sup> and determined the number of grocery stores per census tract to define access to PA or nutrition outlets.<sup>84</sup> While these methodologies have been important for establishing and building evidence about the relationships between built environment,

HE, and PA, another important method to continue to integrate in this field is spatial clustering analysis.<sup>11</sup>

Spatial clustering is often referred to as spatial autocorrelation, or non-random spatial patterning, which can measure the nature and strength of geographical interdependence between data points.<sup>85</sup> Despite the increased use of GIS for public health applications, many studies that incorporate spatial proximity or spatial aggregation methods have not measured whether spatial autocorrelation exists.<sup>11,13</sup> Predominant general or multilevel regression models that are used to estimate associations between built environment features and obesity may violate the assumption that all observations should be independent of each other if significant spatial autocorrelation is present.<sup>82</sup> Assessing spatial autocorrelation, or clustering, is recommended as a first step in place-focused research to understand spatial patterns in the dependent variable and minimize overstating significance between exposures and outcomes.

Examining the spatial patterns of obesity outcomes and creating visualizations of these clusters is also critical for identifying neighborhoods and communities most impacted by chronic disease outcomes, like obesity.<sup>12,13</sup> Such identification can highlight priority areas for public health intervention.<sup>12,13</sup> In addition to identifying priority areas, researchers can also examine what individual and community-level factors may underlie the observed spatial clustering.<sup>12</sup> For example, one recent study that examined the geographic patterns of adult obesity also explored what sociodemographic characteristics were associated with the identified spatial clustering.<sup>12</sup> The results showed that the most important predictor was SES, measured by residential property values, such that low SES areas had the highest degree of spatial clustering of obesity.<sup>12</sup> Continued exploration can

allow researchers to better understand whether spatial clustering patterns are similar across different populations, like children and adults, and in different geographic areas (e.g., compare areas in the southeastern US vs. western US).<sup>11</sup>

### *Parks, Physical Activity, and Childhood Obesity*

Public parks and recreational resources are key components of community and neighborhood infrastructure that can promote active living, physical and mental health, and overall well-being across diverse communities.<sup>17,37,86-89</sup> Specifically, public parks offer spaces (e.g., open green space) and facilities (e.g. trails, playgrounds) for individuals to participate in PA.<sup>83,90,91</sup> Also, parks and open green spaces have demonstrated psychological and social benefits to individuals by reducing stress and mental fatigue,<sup>92</sup> creating a sense of wellness,<sup>93,94</sup> and increasing social interaction and social cohesion among neighbors.<sup>95</sup> A noteworthy conceptual model published by Bedimo-Rung highlighted the mechanisms through which parks, recreation, and green spaces influence multiple dimensions of health.<sup>37</sup> The model illustrated how park characteristics and individual and interpersonal characteristics can influence park visitation, and subsequently, facilitate participation in park-based PA.<sup>37</sup> Such behavioral patterns can impacts multiple dimensions of health for park users (e.g., physical, social, psychological). Overall, parks are low to no-cost resources for communities that offer both structured and unstructured opportunities in which residents can engage with one another and participate in PA.

Parks and open green spaces are particularly important health-promoting community features for youth.<sup>96</sup> A vast majority of built environment and health studies have focused on the adult population, though the past decade years has seen an increased

focus on environmental influences for children.<sup>97</sup> Parks and recreation spaces can provide safe places for children and adolescents to be outdoors, engage in free-play PA, and participate in organized activities and games (e.g., sports).<sup>96</sup> Some research has shown that parks and recreation spaces are the one of the most frequently used outlets to engage in free-play,<sup>98</sup> while others have also demonstrated that parks are one of the primary spaces that children and adolescents have to engage in PA outside of the school day.<sup>98</sup> In addition, parks and recreation spaces have been recognized as essential spaces for facilitating social interaction and engagement among families, friends, and neighbors.<sup>95,99</sup>

### *Park Availability*

Availability of resources has been recognized as a key element of ecological models that has the potential to influence obesity by providing infrastructure that can facilitate health-promoting behaviors.<sup>100,101</sup> Cohen and colleagues described four key factors that influenced behavior change: 1) **availability** of protective or harmful products 2) **physical structures**, 3) social structures and policies and 4) media and cultural messages.<sup>100</sup> Likewise, Blankenship and colleagues classified three types of approaches for structural or ecological level change: **availability**, acceptability, and accessibility.<sup>101</sup> As shown, these seminal publications identified availability of health-promoting resources as essential elements for population-level behavior change and impact on health outcomes. In general, the availability of parks provides individuals and communities with increased opportunities to be active; as such, research examining the impact of the availability of parks, recreation facilities, and open green space for youth has flourished.

One of the first studies to examine the association between availability of parks and youth PA found that the total percentage of park and recreation area in a child's neighborhood was related to increased objectively-measured PA in a small sample of elementary-aged children in New York.<sup>20</sup> Likewise, the vast majority of studies have demonstrated that the availability, measured as both the overall number or density of park facilities, is associated with higher levels of PA among children.<sup>20-25</sup> However, some research has shown that the association between park availability and park use patterns varies by demographic characteristics in youth. For example, multiple studies have shown that females were less likely to use parks<sup>102</sup> or be observed in parks compared to males<sup>103</sup> and research has also demonstrated that Black youth were less likely to use park facilities compared to White youth.<sup>102</sup> In addition, some studies have found null or negative associations between park availability and youth PA. For example, one study of children and adolescents in Australia showed that the number of recreational facilities was related to less moderate-to-vigorous PA for elementary-aged girls.<sup>104</sup> Overall, the majority of studies found positive associations between park availability and children's PA levels, indicating that the presence of park facilities is essential for providing places for children to engage in PA.<sup>20-22</sup>

Likewise, some literature has emerged that examines the relationship between park availability and youth obesity.<sup>97</sup> The previously-presented conceptual model from Bedimo-Rung and colleagues showed that park visitation could influence several dimensions of health, but research has argued that the strongest mechanism through which parks influence health is by facilitating increased levels of PA.<sup>37</sup> While park availability has consistently demonstrated positive associations with youth PA levels, it is

also critical to consider other related measures of physical health.<sup>19</sup> Indeed, elevated weight status is recognized as key risk factor for several health conditions. As such, preventing and decreasing childhood obesity is a major public health priority in the US.<sup>57</sup> Linking built environment and community influences that impact youth obesity is important to provide evidence and develop solutions. To date, research between park availability and youth obesity has presented mixed findings.

Gordon-Larsen and colleagues produced one of the first US nationally-representative studies to examine associations between PA facilities, such as parks and recreation environments, and youth obesity (grades 7-12).<sup>22</sup> Their findings suggested that with increasing availability of PA resources within approximately 5 miles, the odds of overweight decreased and odds of participating in health-promoting amounts of moderate-to-vigorous PA increased.<sup>22</sup> Indeed, a dose-response relationship between the number of PA facilities and youth obesity was discovered such that greater number of facilities present, the odds of being overweight decreased further.<sup>22</sup> Similarly, another nationally-representative study found perceived access to parks and recreation facilities was related to lower levels of youth obesity<sup>105</sup> and other cross-sectional studies have demonstrated similar patterns between greater availability of parks and recreation facilities and lower youth obesity rates.<sup>105-108</sup>

Furthermore, three key longitudinal studies have demonstrated slower weight gain over time for youth that had improved access to parks and green space.<sup>26-28</sup> For example, Wolch and colleagues conducted an 8-year longitudinal cohort study with data from over 3,000 youth (starting at age 9) from 12 communities in Southern California.<sup>27</sup> Weight status was objectively measured annually and the primary built environment variables



included were availability of park space and recreational programs.<sup>27</sup> Results showed that the availability of park space within 500 meters of the home location was related to lower BMI at age 18, and the positive effects on BMI were stronger for boys compared to girls.<sup>27</sup> Two additional studies from Australia have presented similar findings; boys with less green space had higher waist circumference than boys living in areas with moderate-to-high green space. Likewise, higher amounts of neighborhood green space was related to slower increase in boys' weight status.<sup>28,109</sup> In addition to gender variations in the relationship between park availability and obesity, another study found differences by race/ethnicity in a US national survey.<sup>105</sup> Having a park or recreational facility was not related to obesity among Non-Hispanic White and Hispanic, while Black children had significantly lower obesity levels if a park or recreational facility was present.<sup>105</sup> These findings advanced the literature in two major ways: 1) provided strong empirical evidence that access to park space can positively influence youth weight status after accounting for several potential confounding variables and 2) demonstrated differential impacts of parks and recreation facilities on weight status for different demographic groups. These developments highlight the importance of continual advancement in the field of built environment and health as well as the role of both individual and neighborhood characteristics in the place and health relationship.

Despite several studies that have presented strong evidence that park availability positively impacts weight status of youth, studies have also found null associations between park availability and youth obesity.<sup>110-114</sup> In 2004, Burdette and Whitaker reported no associations between obesity status and proximity to playgrounds in a sample of over 7,000 low-income youth (ages 3-5) in Ohio.<sup>111</sup> Similarly, researchers have found

no association between the distance to the closest park,<sup>110,112</sup> amount of park or open green space,<sup>110,113,114</sup> or total number of parks within defined geographic areas<sup>110,115</sup> among samples of youth of with diverse age, SES, and race/ethnicity. The research that produced these findings occurred in a variety of settings that likely have different contextual influences. As well, various methodologies were employed to define availability of park space, which could also contribute to the divergence in research findings. Given the discrepancies in positive and null findings across studies, additional research is needed to disentangle the effects for park availability and youth obesity.<sup>19</sup>

### *Park Features and Quality*

Availability has been the most studied characteristic related to parks, PA, and obesity in youth. Nevertheless, many researchers have begun to measure other park aspects for influencing park visitation, park-based PA, and overall health.<sup>36</sup> The facilities and amenities located within a park are essential for promoting park visitation and park-based PA.<sup>37,83</sup> Facilities represent activity areas where visitors can engage in activities, such as playgrounds, sports fields, and walking tracks.<sup>37</sup> Amenities are park features that often promote comfort such as restrooms, water fountains, or benches, and can influence the number of park visitors and their experience and behaviors therein.<sup>37</sup> Some research has studied how certain park facilities and amenities impact youth PA levels; however, few studies have considered specific features when examining childhood obesity and parks.<sup>104</sup>

Specific park facilities and amenities have been associated with park visitation and park-based PA. One study found that perceived park availability, quality (including measures of amenities, aesthetics, maintenance, and safety), and park use by friends was

associated with increased park use among adolescents in Baltimore, Maryland.<sup>102</sup> Other studies have shown that the number of playgrounds was significantly related to youth PA.<sup>64,90,104,117</sup> and obesity.<sup>110</sup> Some research has shown that additional park features such as walking paths and park amenities (e.g., picnic areas, restrooms, lighting, and shade) resulted in higher park visitation for youth.<sup>118</sup> Similarly, several studies have also demonstrated increased park-based PA among youth in the presence of water features,<sup>119</sup> playing fields,<sup>116</sup> basketball courts,<sup>90,103,119</sup> and walking paths.<sup>90</sup> Other studies have observed higher levels of sedentary behavior with the presence of picnic facilities.<sup>103</sup>

In addition to the specific features present in parks environments, emerging research has also started to include additional quality aspects when examining park use patterns and park-based PA.<sup>37</sup> Quality has been defined differently by various measurement tools and surveys, but some of the primary measures of park quality focus on the aesthetic characteristics or incivilities found in the park.<sup>120</sup> One of the first studies to consider multiple aspects of the park environment found that accessibility to large public open spaces with more attractive characteristics was related to higher park use and PA behavior.<sup>121</sup> Similarly, a recent study explored whether the closest, largest, or most attractive open space was more closely related to walking and found that both size and attractiveness (the latter measured by 9 key items rated by stakeholders) were more important for walking than proximity alone.<sup>122</sup> Another study discovered that higher proximity to park space was related to lower weight status in adults, while a park cleanliness measure was not related to adult weight status.<sup>123</sup> To date, parks and health literature has been dominated by research that focuses primarily on availability or accessibility only, without consideration of other essential elements that may attract park

users. Studies that have included park amenities, aesthetic qualities, or incivilities suggest that such aspects of park environments should be measured and included in future research. Despite this recommendation to move the field forward, no studies to date have examined how park quality characteristics are related to children's PA or weight status, so there is substantial work needed in this area.

### *Food Environments, Healthy Eating, and Childhood Obesity*

The previous section focused on parks and recreational resources as spaces to youth to improve health primarily through PA. On the other side of the energy balance equation, the nutrition environment has been studied in relation to child dietary behaviors and weight status. Recent research has documented increasingly poor dietary behaviors among youth with decreased consumption of fruits and vegetables and increased intake of foods with high fat and sugar content.<sup>124</sup> Food outlets are key community resources that impact the types of foods that are available for both purchase and consumption and the characteristics of local food environments are widely believed to contribute to dietary patterns and weight status for youth.<sup>73</sup> Nutrition settings have been categorized into two main components: community and consumer environments.<sup>73</sup> The community environment describes macro-level characteristics of food outlets, such as the number, types, and location of food outlets, with a focus on stores and restaurants.<sup>73</sup> Food stores include grocery stores (e.g., supermarkets, smaller localized markets) and convenience stores, whereas restaurants are establishments where meals are served to customers.<sup>73</sup> Though each of these outlets often have healthy and unhealthy options, grocery stores typically offer more choices for fresh produce, while convenience stores and fast food restaurants offer a higher proportion of high fat and high sugar items and less access to

fresh fruits and vegetables.<sup>125</sup> The second nutrition environment category, the consumer environment, captures additional micro-level characteristics of those food outlets like nutritional content of foods available and cost.<sup>73</sup> Food stores and restaurants can vary dramatically in terms of the types of foods available or served, eating experience (i.e., sit-down restaurant or fast food), and price of food. Although the community and consumer nutrition environments have both been recognized as important elements for youth to access and consume healthy foods, the community nutrition environment focuses on the macro-level characteristics, which is the main focus of this dissertation.<sup>73</sup> Further understanding how the community nutrition environment is related to youth obesity is an important to explicate how community features influence health and may provide evidence to support advocating for creating community infrastructure that promotes and facilitates healthy eating.

Similar to the parks discussion, the concept of availability applies to the food environment such that the presence of certain types of stores and restaurants can impact dietary patterns and weight status.<sup>100,101</sup> Indeed, availability of food outlets has been recognized as a fundamental determinant influencing food choice,<sup>73</sup> yet many studies have shown that low-income and minority communities have less access to grocery stores<sup>73,126,127</sup> and also have higher density of both convenience stores and fast food restaurants.<sup>73,126,128,129</sup> Such inequitable environments could contribute to socioeconomic and racial/ethnic disparities in youth obesity. To further investigate these disparities, relationships between food outlet availability, HE, and childhood obesity need to be disentangled.

Studies examining the relationships between the food environment on dietary behavior and weight status have increased in the past decade, though the majority of studies have focused on adults.<sup>18,38,79</sup> Nonetheless, research has also suggested that youth with increased exposure to healthful food outlets, like supermarkets, have increased consumption of fruits and vegetables.<sup>130</sup> On the other hand, increased availability of less healthful food outlets, like fast-food restaurants and convenience stores, has been associated with poorer dietary patterns.<sup>29-32</sup> For example, one study showed that greater availability of unhealthy food outlets, defined as takeout/fast-food restaurants or convenience stores, was associated with larger consumption of sugar-sweetened beverages among children aged 9-10,<sup>31</sup> while another showed decreased likelihood of consuming fruits with greater availability of fast food outlets and convenience stores.<sup>131</sup> A 2014 review paper examined 26 studies that had focused on youth dietary behaviors and the community or consumer nutrition environment showed that a large proportion of studies (85%) reported significant associations between a food environment measure and dietary behaviors (e.g., fruit and vegetable intake, sugar-sweetened beverage intake).<sup>132</sup> Overall, evidence linking the food environment to dietary patterns has demonstrated that availability of healthful environments is related to higher quality dietary patterns compared to availability of less healthful food environments.<sup>18,132</sup>

Recently, research has begun to demonstrate robust findings between youth obesity and grocery stores, convenience stores, and fast-food restaurants.<sup>38,79</sup> Some research has shown that the presence of supermarkets or grocery stores is related to lower proportion or lower risk of youth overweight or obesity,<sup>33,133</sup> with one study finding these patterns in a nationally-representative, longitudinal study.<sup>34</sup> For example, Powell and

colleagues published a seminal paper examining the relationship between adolescent obesity and presence of local-area food stores.<sup>33</sup> After controlling for individual, family, and neighborhood characteristics, this study demonstrated that greater availability of chain supermarkets was significantly associated with lower adolescent BMI, while higher numbers of convenience stores was significantly associated with higher adolescent BMI.<sup>33</sup> This study also found differences in effect sizes such that African American youth with supermarket availability had chain supermarket availability had lower BMI compared to White and Hispanic students. This was one of the first studies to establish a relationship between youth obesity and the availability of various food stores, paving the way for more research in this important area.

Other studies have continued to demonstrate that greater availability or proximity of less healthful food outlets, like fast food outlets and convenience stores, are significantly related to increased risk for overweight and obesity in children.<sup>31,35</sup> This has included research regarding the food environment surrounding both the home residence and school location.<sup>134,135</sup> Children that have access to higher numbers of fast-food outlets have an increased risk of overweight or obesity.<sup>35,107,134,136</sup> For example, in a sample of almost one million children attending public schools in California, researchers found that the density of fast food restaurants was significantly associated with overweight prevalence.<sup>134</sup> Importantly, this study also reported that fast food restaurant density was more strongly associated with increased overweight prevalence for Black and Hispanic children, and overall, the food environment had a slightly stronger effect on BMI for younger children (5<sup>th</sup> grade) compared to older children (7<sup>th</sup> and 9<sup>th</sup> graders).<sup>134</sup> Another key study measured the relationship between the neighborhood density of fast

food restaurants and insulin resistance for a sample of Hispanic youth (ages 8-18).<sup>107</sup>

Results showed that increased access to fast food restaurants was significantly related to insulin resistance, even after controlling for weight status, waist circumference, and demographic characteristics.<sup>107</sup>

Additional research has shown that youth obesity is positively associated with increased access to convenience stores.<sup>33,137-141</sup> For example, a nationally-representative study that examined the impact of several built environment characteristics on youth (ages 5-18, average: 11.8 years) found an increased risk of overweight for youth that had higher density of convenience stores in their neighborhood.<sup>139</sup> Similarly, another study that focused on children ages 6-8 living in East Harlem, New York, reported that those with one or more convenience stores present on their block had a significant increase in the risk for high BMI percentile compared to children with no convenience stores on the block.<sup>138</sup> Researchers in California found that the availability of convenience stores was associated with about three times the risk of overweight and obesity over time among girls (ages 6-10).<sup>140</sup> Similar to the literature presented on fast food restaurants, the majority of studies report an increased risk of youth overweight or obesity with increased availability of convenience stores.

Substantial research has demonstrated positive associations between food outlets and youth obesity, but other studies have found no relationship.<sup>135,142,143</sup> For example, Sturm and colleagues found no relationship between overall food outlet density and BMI among a large sample of elementary-aged youth in a national sample.<sup>143</sup> Furthermore, a oft-cited study that examined the association between preschool children's weight status and reported no relationship between child obesity and proximity to fast-food



restaurants.<sup>111</sup> Likewise, some studies have found significant associations between one type of food outlet, like convenience stores, but reported null associations between youth overweight/obesity and other types of food outlets, like fast food restaurants or grocery stores.<sup>34,138,141</sup> These contradictory findings raise several conceptual and methodological questions regarding the relationship between youth obesity and overall food environments.

There are at least four potential explanations and future areas of research to address the mixed literature regarding youth obesity and the nutrition environment: 1) additional studies examining these nuanced relationships, 2) consistent and improved measurement practices, 3) integration of multiple dimensions of the food environment together (i.e., grocery stores, fast food restaurants, and convenience stores), and 4) including multiple aspects of the built environment when weight status or obesity is the main outcome measure. First, a 2014 systematic literature review that focused on the community nutrition environment (i.e., number and types of food outlets) found 19 studies focused on youth less than 18 years of age and even fewer studies examining elementary-aged children.<sup>38</sup> Given the health implications of childhood obesity and the emerging ecological approach to obesity in the past 15 years, this is a relatively small number of studies. Second, multiple review papers have noted the diversity in measurement for the food environment presented in the literature for both adults and children.<sup>18,38,132</sup> To date, there is no recognized measure that serves as the ‘gold standard’, so it is difficult to compare results across studies when there are different spatial techniques – distances, buffers, and count variables – used regarding the community nutrition environment.<sup>38</sup> Third, many studies focused on only one aspect of

the food environment whereas food outlets are present in the same geographical area or neighborhood and may simultaneously influence dietary patterns and weight status.<sup>81</sup>

Lastly, exploring environmental influences on obesity that fall on both sides of the energy balance equation may be a crucial element for better understanding how the park and food environment work together to influence youth weight status.

### *Obesogenic Built Environments and Youth Obesity*

Obesogenic environments are areas where it is easy for individuals to have low levels of PA – either by discouraging active behavior or promoting sedentary behavior – and easy for individuals to consume unhealthful foods – either by the limited availability of healthful foods or increased availability of unhealthful foods.<sup>81</sup> Obesogenic built environments describe the community features that influence energy intake and energy expenditure sides of the energy balance equation, both of which contribute to weight status.<sup>81</sup> For youth, the park and food environments are recognized as critical resources to promote healthy behaviors.<sup>45</sup> Thus far, this proposal has presented a comprehensive summary of research focused on the relationships between youth overweight and obesity and *either* the park or nutrition environment.<sup>97</sup> While these relationships are important to understand separately, it is also critical to recognize that multiple elements of the built environment occur together and likely simultaneously influence youth health behaviors and outcomes.<sup>81</sup> Therefore, it is equally, if not more, important to explore how these combined environments influence youth obesity in order to understand comprehensive influences and shape future community planning and policy decisions.

Research examining environmental influences on youth obesity that includes multiple measures for both PA and nutrition environments has started to emerge.<sup>144-146</sup>

For example, a recent study in New Jersey included multiple types of food outlets (i.e., supermarkets, convenience stores, and fast food restaurants) and PA environments (i.e., private and public facilities, parks) to examine built environment influences for youth ages 3 to 18.<sup>144</sup> This study found that youth that lived within ¼ mile of a convenience store were twice as likely to be overweight or obese, while living within ½ mile of a large park resulted in being half as likely to be overweight or obese.<sup>144</sup> Similarly, a study by Carroll-Scott and colleagues examined perceived access to the nearest park, nearest grocery, fast food, and convenience store, and social environment indicators related to youth obesity in New Haven, Connecticut. Higher BMI was only related to living more than ½ mile from the nearest grocery store and increased property crimes.<sup>145</sup> Likewise, a previously-described study examined the association between Hispanic youth insulin resistance, weight status, and multiple aspects of the built environment, including fast food and convenience store availability as well as the amount of park space.<sup>107</sup> Findings showed that fast food restaurants were related to high insulin resistance, while park spaces were related to lower insulin resistance.<sup>107</sup> All of the described studies show that the relationships between the food and park environments on obesity are complicated when measured together. Though both studies measured multiple aspects of the obesogenic environment for youth, the PA and nutrition environment variables are analyzed separately<sup>144</sup> or not combined in a way that gives the neighborhood an overall value to concurrently represent both the positive and negative aspects of obesogenic environments.<sup>145</sup>

A limited number of studies have created obesogenic indices to simultaneously capture and ‘score’ the obesogenic environment based on multiple criteria.<sup>39</sup> In 2014,

Tseng and colleagues developed an obesogenicity index for adults in Australia based on three overarching environments: food resources, recreational activity resources, and walkability.<sup>39</sup> In each of these categories, they used three key resources and created cutpoints based on the number of resources present in the neighborhood. Using this methodology, the researchers calculated an obesogenic score within a 2 km buffer for all study participants to use as the exposure variable in their analyses.<sup>39</sup> In this sample, the neighborhood obesogenicity was associated with higher BMI in urban areas, while neighborhood obesogenicity was associated with lower BMI in rural areas.<sup>39</sup>

Other researchers have developed ways to characterize obesogenic environments that may be more relevant to youth using somewhat similar methodology. Researchers on the Neighborhood Impact on Kids Study, based in Seattle, Washington and San Diego, California, used GIS to develop a multicomponent PA and nutrition environment indicator based on walkability, park access and quality, and food access.<sup>146</sup> The indicator defined four total neighborhood types, using high/low categorizations of elements of the obesogenic environment. High PA environments had at least one high-quality park and were above median walkability, while high nutrition environments had a supermarket within 0.5 miles and low density of fast food restaurants (based on city-specific values). Using this measure, these researchers found that children from neighborhoods that had high PA and high nutrition environments were less likely to be overweight and obese compared to children living in low PA and low nutrition environments.<sup>40</sup> Similarly, the parents of the youth in the study were also less likely to be obese in high PA and nutrition environments.<sup>40</sup> These studies show promising, innovative ways to measure multiple obesogenic environment elements. Still, very little research has addressed this topic for

children and there are multiple ways to characterize obesogenic environments that should be considered, tested, and refined to improve this area of research.

### *Literature Review Summary*

Broadly, this literature review has described the current state of literature on the relationship between youth obesity, park availability and quality, and food environments, with a discussion about the importance of spatial patterns and methodology within this line of research. Despite the breadth of research described above, there are four gaps that have been highlighted that warrant further exploration to move the field forward and contribute to the literature on obesogenic built environments and youth obesity: 1) examining of spatial clustering patterns of youth obesity, 2) incorporating multiple characteristics of the park environment, 3) integrating multiple types of food outlets when measuring the food environment, and 4) combining the detailed park (PA) and food environment (HE) information to better depict the obesogenic built environment. In the ensuing paragraphs, the significance and innovation of this project are summarized as well as the methodology utilized to address these identified gaps in the childhood obesity literature is discussed in detail.

## **2.2 SIGNIFICANCE AND INNOVATION**

### *Significance*

Youth obesity is a major public health concern with the wide array of physical, social, and emotional health consequences that often accompany overweight and obese youth during childhood and even into adulthood.<sup>1-3</sup> The prevalence of childhood and adolescent obesity has increased over the past three decades with a disproportionate burden on youth that are low-income, racial/ethnic minorities, and reside in the

southeastern US.<sup>4</sup> Examining the determinants of childhood obesity is imperative to understand how to address and prevent the epidemic at a community level.<sup>7,9</sup> Although epidemiological patterns of youth obesity across the US have been established,<sup>4</sup> fewer studies have examined spatial patterns of youth obesity at a local level.<sup>12</sup> Investigating the geographic distribution of youth obesity at a local level is critical to 1) identify areas that have high rates and clustering of youth obesity, 2) explore whether the distribution of youth obesity is completely random or whether individual- and neighborhood-level characteristics are correlated with observed patterns, and 3) determine whether geographic spatial clustering of youth obesity is contributing to observed racial/ethnic and socioeconomic disparities.<sup>147</sup> Furthermore, the identification of geographic areas that have clustering of youth obesity may be particularly useful for pinpointing priority areas for public health intervention.<sup>13,147</sup> The development of maps via GIS software that correspond with identified clustering of youth obesity can be a powerful tool for both community leaders and residents to better understand the location of and contributing factors to childhood obesity.<sup>148-150</sup>

Approaching research focused on the determinants of childhood obesity from an community-level perspective is necessary for understanding what elements are essential to create health-promoting infrastructure.<sup>6-8</sup> Indeed, built environment characteristics of neighborhoods and communities are recognized as contributing factors for population-level health behaviors, like PA and HE, and weight status.<sup>14-16</sup> For youth, ample research has demonstrated that community features, like increased park availability and quality, promote PA.<sup>20-25</sup> In addition, better access to healthful food outlets (e.g., grocery stores) is related to positive dietary patterns, while easier access to less healthy food outlets (e.g.,

fast food restaurants and convenience stores) is related to poorer child nutrition.<sup>29-32</sup>

Though these environments have been linked to health behaviors, fewer studies have linked parks and food outlets with youth obesity. Addressing built environment characteristics at a broader community level has the ability to promote population-level health by modifying the context in which children consistently interact.<sup>97</sup> By integrating comprehensive datasets on the park and food environments, the current study substantially contributed to childhood obesity and built environment research.

Finally, examining the geographic distribution and association of built environment features on youth obesity can assist with explicating the role of contextual influences on racial/ethnic and SES health disparities.<sup>78</sup> Previous conceptual models have posited that differential access to health promoting built environment features may impact youth health behaviors and outcomes,<sup>78</sup> which has resulted in many studies examining the equitable or inequitable distribution of environmental elements that may promote or detract from PA and HE.<sup>22,151</sup> However, many of these studies have not connected the differences in community features to important health outcomes. It is possible that access to and quality of parks and food outlets contributes to current obesity disparities.<sup>22,78</sup> In addition, investigating sociodemographic characteristics as correlates of spatial clustering of youth obesity may contribute to better understanding determinants of these patterns. Furthermore, a deeper understanding of spatial patterns may help inform how equitable community infrastructure can reduce health disparities.

In summary, this research substantially contributes to the field of public health by 1) explicitly focusing on the spatial patterns of youth obesity in a county in South Carolina, 2) employing an ecological perspective to examine the relationship between

youth obesity and multiple built environment features, and 3) exploring how the geographic distribution of obesogenic environments may contribute to disparities in youth obesity.

### *Innovation*

This dissertation project is innovative for several reasons. First, this study integrated several comprehensive and unique datasets to answer the research questions related to spatial clustering of obesity and impacts of obesogenic built environments on childhood obesity (previously outlined). The study sample was comprised of over 13,000 elementary-aged youth from a large county in South Carolina from the largest school district in South Carolina and the 47<sup>th</sup> largest school district in the US. Available data for each child included height and weight, address, and numerous demographic characteristics. Data were acquired through a data sharing agreement with the County's school district and include all 3<sup>rd</sup>-5<sup>th</sup> grade youth enrolled in the school district. This large and comprehensive dataset provided adequate power to conduct spatial and statistical analyses, which has been a limitation of other studies examining relationships between obesogenic environments and child health.<sup>110,112</sup> Furthermore, because this sample also defined a large proportion of the population within that age range, it provided good representation of existing spatial patterns. In addition, the datasets for the park and food environment were comprehensive in their own respective ways. For the park environment, all six park municipalities were contacted to ensure the most updated and accurate list of public parks were included in the study. Detailed audits were also conducted for each park.<sup>42</sup> For the same time period (Fall 2013), two commercial databases that contained information on all food stores and restaurants were collected and



categorized into healthy and less healthy food outlets. Finally, acquiring and using Census data provided information on sociodemographic characteristics for the residential area where each child lived.

Second, much of the research focused on the health benefits of parks has largely relied on using availability as the primary park measure.<sup>22,24, 27,104</sup> While availability of parks is demonstrably important for promoting children's PA and healthy weight status, recent studies have highlighted the importance of park features and quality indicators for promoting park use and park-based PA.<sup>37,86,96</sup> Most of the research that has focused on specific park features has either been qualitative in nature<sup>36,98</sup> or has focused on the relationship between park characteristics and PA, rather than obesity. Indeed, a review of qualitative studies focusing on PA in urban parks found that the physical attributes, including types of activity spaces, condition of park structures, and aesthetics, impact park visitation and PA.<sup>36</sup> Establishing quantitative studies would further bolster this body of literature.<sup>19,74,79</sup> This study used park features, amenities, quality, and safety features of the park to develop a comprehensive score.

Similarly, many studies examining the impact of the nutrition environment on youth dietary patterns or weight status have only focused on one type of food outlet, such as grocery stores or restaurants.<sup>32,35,111</sup> For those studies that have measured and included multiple stores or restaurants in their analyses, most have examined different food outlets as separate variables in the analyses.<sup>33,34,133</sup> Conceptually, it is unlikely that access one type of food outlet influences child weight status alone since different types of food stores and restaurants co-exist in the same communities and likely simultaneously influence dietary behavior and weight status.<sup>18,152,153</sup> This study incorporated a

comprehensive list of food stores and restaurants located in the County to define a wide-ranging nutrition environment in this study area.

Similar to moving the measurement of the nutrition environment forward to include all types of food outlets, most research has focused on only one element of the obesogenic built environment – either the PA or HE environment, separately.<sup>75</sup> These studies have provided important foundation evidence for understanding these influences and potential mechanisms between built environments and PA, HE, and weight status. However, it is critical that research includes environmental influences for both sides of the energy balance equation to further explicate how these community features impact youth weight status.<sup>39,40,77</sup> Therefore, this project combined the park and food environment together by creating a scoring measure for the total obesogenic built environment. When creating this measure, density estimations were used to accurately represent data that changes across space.<sup>154,155</sup> These density measures have been used less frequently in the literature, though they can highlight how closer and higher ‘ranked’ features are more impactful than features further away or with a lower ‘score’.<sup>11</sup> Overall, this study incorporates four large datasets with a variety of variables for a large sample of youth, surrounding residential areas, and two key components of the community built environment – parks and nutrition outlets. Using these data, innovative GIS measures were employed to characterize obesogenic built environments and test this measure with youth obesity levels.

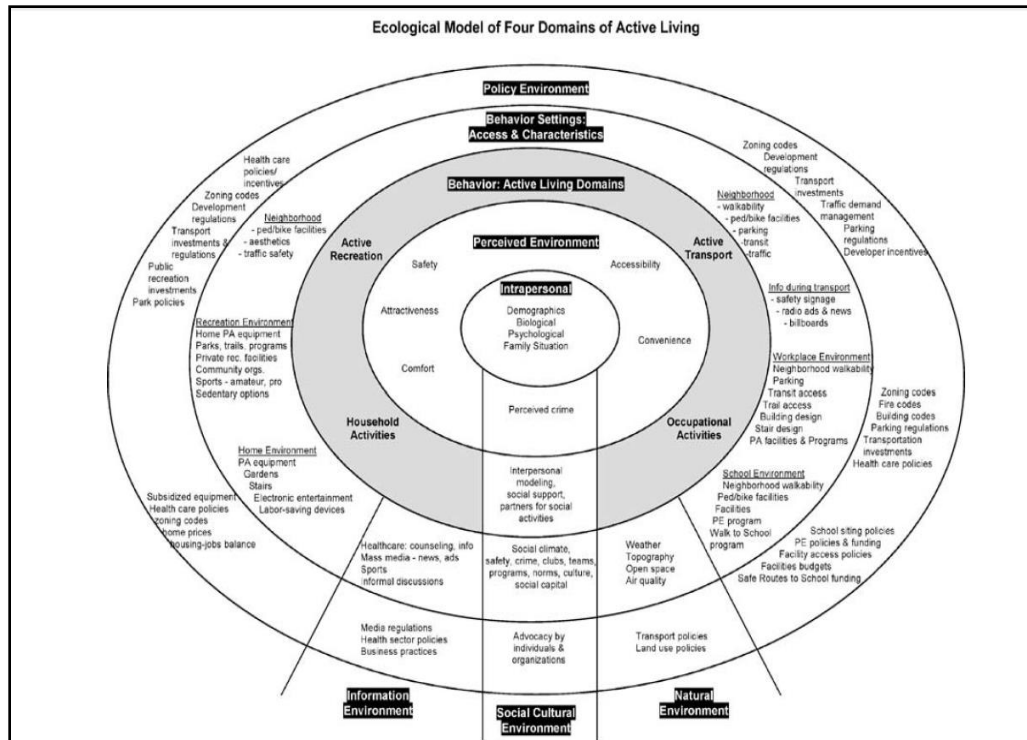


Figure 2.1 Ecological Model for Active Living developed by Sallis et al.<sup>8</sup>

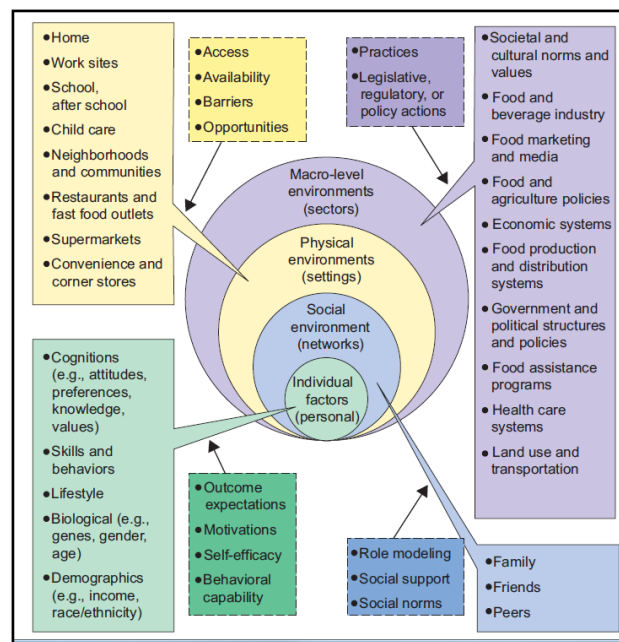


Figure 2.2 Ecological Model for Healthy Eating developed by Story et al.<sup>73</sup>

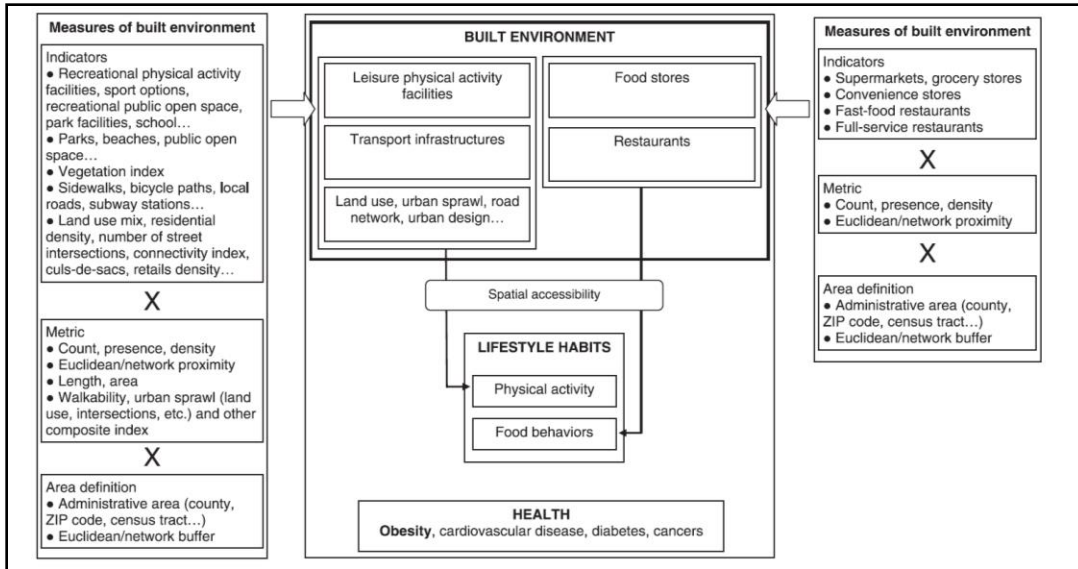


Figure 2.3 Conceptual Framework Highlighting Pathways and Measurement of Built Environment and Health developed by Casey et al.<sup>79</sup>

## CHAPTER III

### METHODOLOGY

This dissertation project is part of a broader research agenda to better understand how neighborhoods affect the health and well-being of youth, with a particular emphasis on PA, HE, and obesity. The following methods chapter describes the conceptual framework, study setting, data collection procedures, study measures, and analytical approach used for this project.

#### 3.1 CONCEPTUAL FRAMEWORKS

The conceptual model that guided this dissertation project was largely adapted from Kremers et al.'s model for energy-balance related behaviors,<sup>77</sup> and infused with theoretical concepts from the previously-described social ecological models. Kremers' original model, shown in Figure 3.1 below, highlights pathways by which individual and environment factors influence energy-balance related behaviors.<sup>77</sup> The adapted conceptual framework which guided this project, presented in Figure 3.2, illustrated how obesogenic environments impact youth overweight and obesity levels through either indirect or direct pathways.<sup>77</sup> The indirect (upper) pathway highlights behavioral mediators, PA and HE, known to influence youth obesity (unmeasured in this study). This research project focused on and tested the lower pathway in the adapted conceptual model (Figure 3.2), shown in red, by examining direct associations between built environment features and youth obesity. On the left side of the model, obesogenic built environments were categorized as the PA and HE settings, focusing on park availability,

features, and quality and availability of various types of food stores and restaurants.<sup>8,156</sup> This framework also highlighted how the impact of environmental features for youth obesity may be moderated by individual and neighborhood characteristics by examining variations by SES and race/ethnicity (specific aim 2c).<sup>77</sup> Importantly, this conceptual framework recognized the critical (albeit unmeasured) influence of broad cultural, historical, political, and economic environments that have on the development of communities that promote obesogenic behaviors; this perspective was used to frame the results and discussion of this research. Overall, the framework used for this study highlights the complex, multi-level determinants of youth obesity with an emphasis on multiple components of the obesogenic built environment.

### **3.2 STUDY SETTING**

The study setting is the largest county by population in South Carolina. It includes several small universities and a mix of rural, suburban, and urban neighborhoods. As of 2013, the County population had increased 5.1% since 2010, faster than the state average (3.2%). Population estimates, racial/ethnic composition, and the percentage of residents below the poverty line for both the broader County and the centralized urban municipality located within the County are shown in Table 3.1. The study state and county have poor rankings for obesity outcomes, like many other southeastern US areas. In 2014, South Carolina ranked as the 10<sup>th</sup> highest state for adult obesity rate, with disproportionately higher rates among African American and Latino adults.<sup>157</sup> Furthermore, in 2011, South Carolina ranked 2<sup>nd</sup> highest in obesity rates among 10-17 year old youth.<sup>157</sup> In the study county specifically, according to a recent study, 15.1% of youth ages 2-17 were overweight and 16.9% of youth ages 2-17 were obese; both ranking

higher than the state average for youth overweight and obesity.<sup>158</sup> In addition, only 27.6% of youth ages 2-17 met daily PA recommendations.<sup>158</sup> This recent epidemiological profile for obesity rates in South Carolina and the study county demonstrates the need for continued research to understand the determinants of youth obesity.

### **3.3 DATA COLLECTION**

The following section describes the data collection procedures for each of the datasets utilized in this study: youth sample, public parks, food stores and restaurants, and U.S. Census data. The next section (3.4) details the specific measures used for each of these datasets.

#### *Sample*

The study sample included all 3<sup>rd</sup>, 4<sup>th</sup>, and 5<sup>th</sup> grade youth enrolled in the public school district in the study county, representing a total of 14,232 children. Data were obtained through a contractual agreement with the county school district and in partnership with a local health-focused coalition. The dataset consisted of the following variables for each child: age, gender, SES measured by free or reduced lunch status, race/ethnicity, address, and height and weight.

Trained physical education teachers objectively measured and recorded each child's height and weight using standardized stadiometers in 2013. Demographic characteristics and location of residence (address) were recorded in an electronic system called PowerSchools throughout all schools in the district. As part of the contractual agreement with the school district, the data for all 3<sup>rd</sup>-5<sup>th</sup> grade children for all 51 elementary schools were combined into one dataset by school district staff and shared

with the research team following confidentiality protocols (See Human Protections and IRB, section 3.6).

### *Block Groups*

Data for census BGs in the study County were downloaded from the US Census Bureau for this study. BGs are the next to smallest geographical unit recognized by the Census Bureau.<sup>29</sup> They are small, generally permanent subdivisions of a county that usually contain from 600-3,000 people and are fairly homogenous in terms of population characteristics, economic status, and living conditions.<sup>29</sup> The BG shape file for the study County was downloaded from the Census Bureau website and data representing each BG (described in the Measures section) were joined to each area. A total of 255 BGs comprised the study area in 2013.

### *Enumeration and Characterization of Public Parks*

Parks were identified for enumeration and location through both digital and print resources provided by all six parks and recreation departments across the study County. Updated parks lists were confirmed through website resources and through iterative discussion with parks and recreation representatives from each agency. Gathering updated and accurate parks information is important as other studies have discovered substantial discrepancies in large, online park databases and updated lists of active, maintained parks by local recreation departments.<sup>159</sup> The iterative process used in this study ensured the most up-to-date, precise list of public parks in the study area. Ultimately, 103 parks (0.12 to 293.24 acres) were included in a finalized park database after an in-person audit determined that they were parkland useable for recreation, were publicly accessible, free of cost, and were located within the County boundaries (state



parks were excluded). The final compilation of parks represented approximately 2,523.9 total acres of public parkland.

The characteristics of all parks in the study were assessed using the Community Park Audit Tool (CPAT).<sup>42</sup> The CPAT was developed in 2011 to capture key attributes of park environments for PA, including a total of 28 questions (some with multiple components) within four main sections: park information, park access and surrounding neighborhood, park activity areas, and park quality and safety. The CPAT can be found in Appendix A.<sup>42</sup> Overall, the audit tool questions facilitated the collection of detailed information about the presence/absence, usability, and condition of park facilities and amenities in and surrounding the park.<sup>42</sup> In a recent study, the CPAT displayed good content validity and inter-rater reliability with percent agreement for most items  $\geq 70\%$ .<sup>42</sup> Audits of all parks (n=103) were conducted by trained research assistants in Fall 2013, concurrent with the collection of youth data and food outlet data. All research assistants were trained on the CPAT by one of the original tool developers. The training included detailed sessions on all questions, terminology, and examples, and classroom training was followed by multiple on-site practice park audits and review of the practice audits.

#### *Enumeration and Characterization of Food Outlets*

Food outlet data were obtained, enumerated, and classified from two secondary sources that have been used frequently in nutrition environment studies.<sup>160-162</sup> First, a complete list of stores and restaurants that held a retail food license in Fall of 2013 was obtained from the Department of Health and Environmental Control (DHEC).<sup>162</sup> While this dataset performed well in a validation study, particularly for restaurants, researchers recommended using multiple databases to improve the accuracy of the number and types

of outlets identified.<sup>162</sup> Therefore, a commercial database of food stores and restaurants, based on North American Industry Classification System (NAICS) codes, was obtained from InfoUSA.<sup>162</sup> Food outlets from the following NAICS codes were included: 4451 (grocery stores), 4452 (specialty food stores), 4461 (health and personal care stores), 4471 (gasoline stations), 4521 (department stores), 4529 (other general merchandise store), 7225 (restaurants and other eating places). The two databases were reviewed separately, with duplicate entries and ineligible outlet types removed. A complete food outlet dataset was created by merging both the DHEC and InfoUSA datasets using the described data cleaning process. The final list of food outlets was geocoded at the point address level.

All food outlets were classified using a combination of the NAICS codes and robust research tools for measuring the nutrition environment (e.g., Nutrition Environment Measures Survey in Stores (NEMS-S), Nutrition Environment Measures Survey in Restaurants (NEMS-R)).<sup>160,161</sup> Each outlet was first classified as a food store or restaurant. For food stores, the three sub-categories were grocery stores/supermarkets (e.g., Publix; n=80), convenience stores (e.g., Quiktrip; n=248), discount or drug stores (e.g., Dollar Tree, CVS; n=67). The two restaurant categories used for this study were classified as fast food (e.g., McDonald's, n=368) or fast casual (e.g., Panera Bread, n=349). All locations were classified according to the definitions provided in Table 3.2 below.

### **3.4 MEASURES**

The following section first describes the specific variables that were used for youth and BGs in this study. Then, the spatial measures that were utilized to examine

clustering patterns of youth obesity are detailed. Finally, the measures created for parks, food stores, food restaurants, and the combined obesogenic built environment measure are explained in the last part of this section.

### *Youth Measures*

The dependent variable for both specific aims in this study was youth weight status. Height, weight, date of birth, and date of testing were used to calculate BMI percentiles and BMI z-scores (number of standard deviation units away from the mean of the reference population for the same age and gender) using standardized protocols for youth from the Centers for Disease Control and Prevention.<sup>55</sup> BMI z-scores are the recommended continuous variable for statistical analyses with child weight status because BMI percentiles are less precise at the extremes and can skew the distribution of the data if high proportions of the extremes exist.<sup>163,164</sup> Standard categories (underweight, healthy weight, overweight, obese) of youth weight status using BMI percentiles were also created to provide descriptive information on the weight status of the study sample.

Several youth characteristics that were provided by the school district were used as covariates in this study, all of which are provided in Table 3.3. First, each child's address was provided by the school district. Youth addresses were geocoded using by transforming each study participant's address to the accurate geographic location. First, using StreetMap data file, 83.1% (n=11,828) were geocoded at the point address, the most accurate means of geocoding closest to address. The remaining 2,404 observations were attempted using ArcGIS Online street network and a total of 2,007 and 269 data points were again matched to point and street address level, respectively, for a total of 14,104 (98.5%) of the youth. Once mapped, a total of 632 data points fell outside of the

study county boundary, resulting in a sample of 13,472. Then, three data points were flagged for implausible BMI values and were removed from the sample. Therefore, the final sample included 13,469 youth.

Youth age was included as a continuous variable with a range between 7 and 13 and an average age of 9.7 years. Gender was classified as male or female. Like much research using data collected in schools, eligibility for free or reduced lunch status was used as a proxy for SES and was dichotomized as full pay or free/reduced.<sup>165</sup> Last, the following race/ethnicity categories for each child were provided by the school district: African American (n=2,544), Asian (n=387), Hispanic (n=1,545), Native American (n=20), Mixed (n=569), Pacific Islander (n=21), and White (n=8,383). Based on the relatively small sample sizes for Asian, Native American, Mixed, and Pacific Islander, these racial/ethnic categories were collapsed into one category called ‘Other’. Consequently, the final racial/ethnic categories for the study were African American, Hispanic, Other, and White; dummy codes were created for each category for use in the analyses.

#### *Block Group Measures*

The following BG variables were included in this study. First, BG racial/ethnic composition was measured by calculating the total percentage of racial and ethnic minorities (i.e., all persons other than those identifying as non-Hispanic White).<sup>41</sup> Second, a multivariable indicator of area-level SES, neighborhood socioeconomic disadvantage, was included.<sup>41,166</sup> Four BG level socioeconomic variables were standardized and summarized to create the disadvantage index: percent unemployed, percent of the population under 125% of the federal poverty threshold, percent less than

high school education, and percent of renter occupied housing.<sup>41,166</sup> This index was empirically tested and confirmed with principal component factor analysis.<sup>41</sup> The third BG variable was population density per square mile, which was calculated by dividing the total population of each BG by the land area (sq. miles) of the BG.<sup>167</sup>

The final BG variable included in this study was a variable that indicated the level of urbanization. The Census Bureau identifies two types of urban areas – urbanized areas (50,000 people or more) and urban clusters (at least 2,500 and less than 50,000 people); rural areas are classified as those not defined as urban.<sup>167,168</sup> Urbanized areas and urban clusters are represented with TIGER/Line Topological Faces (polygons with geocodes); this file was spatially overlaid with the BGs (the unit of analysis used to calculate all other area-level variables). If the BG contained only urban areas, it was classified as ‘urban’, whereas areas with both urban and rural areas were classified as ‘mixed’; rural areas were defined as BGs that had no urban topological faces present.<sup>167,168</sup> BG shapefiles with the aforementioned variables were joined to all individual data points using ArcMap 10.2.2 to assign these area-level characteristics to each youth participant.

#### *Spatial Cluster Detection Measures*

Many spatial analytic techniques have been developed to assess spatial patterns of variables (e.g., disease outcomes) across geographic locations.<sup>11,169</sup> Two of the overarching categories are global and local clustering; global clustering measures overall patterns in a specified area without pinpointing the exact locations, whereas local clustering measures test for small-scale patterns across the study area.<sup>11,169</sup> Both levels of clustering have different substantive meaning and interpretations and were used in distinct, yet complimentary ways.

One of the most robust analyses and commonly used approaches to detect global spatial clustering across multiple fields is Global Moran's Index (I), where the pattern of a set of features (i.e., youth location) and an associated attribute (i.e., youth weight status) are evaluated for clustering, dispersion, or random distribution.<sup>85,170-172</sup> The Moran's I values range from -1.0 representing perfectly dispersed patterns, similar to a checkerboard pattern, to +1.0 representing perfectly clustered.<sup>85,172</sup> A statistically significant Moran's I test may indicate that subsequent statistical analyses should incorporate a spatial component to adjust for the influence of clustering.<sup>11</sup> Global Moran's I was chosen for this dataset because this measure is intended for data where high and low value clusters are assumed to exist.<sup>172</sup> In summary, Global Moran's I was used to determine whether there is statistically significant spatial autocorrelation (clustering) of youth obesity across the study county.

Despite the ability to detect broad clustering in the study area, the Global Moran's I test does not indicate or provide the location of clustering.<sup>11,169</sup> Therefore, a local cluster detection measure was also used to assess more fine-grained patterns within the study County.<sup>173,174</sup> First, local spatial clustering using Anselin's Local Moran's I (LISA), often referred to as a hot-spot analysis, provided an indication of the degree of significant spatial clustering for areas that represent unexpectedly high or low BMI z-score values compared to the overall, or global, BMI z-score average across the sample.<sup>173</sup> By comparing the values to the overall BMI z-score of the sample, this test limits some potential bias that extreme BMI values could otherwise have on the clustering calculation.<sup>172,173</sup> Furthermore, this test identifies five categories for various spatial patterns that may be present in the data, shown in Table 3.4.<sup>175</sup> The mapping techniques

and analytical model specifications are further described in the following analytical approach section.

### *Obesogenic Built Environment Measurement*

Measures used to assess proximity and exposure to built environment features have varied drastically in the literature,<sup>80,176</sup> and to date, there is no recognized gold standard for characterizing obesity-related elements of the built environment.<sup>146,152</sup> A review of spatial measurement and public health literature from 2000-2010 found that two of the most common spatial measures that have dominated this body of research are distance between two points and aggregating data to predefined administrative units or buffers (chosen by researchers).<sup>11</sup> These measures have provided substantial, albeit complex and mixed, evidence regarding associations between built environment features and health behaviors and outcomes.<sup>11,74</sup> However, additional and more nuanced conceptualizations and spatial measurement of the built environment have been recommended to broaden this field.<sup>11</sup>

In recent years, several researchers have begun to employ density measures to characterize and measure the intensity of exposure to certain built environment features.<sup>11,12, 43,154,177-179</sup> Specifically, kernel density methodology transforms data points to a continuous surface map where the density can be estimated for any location.<sup>154</sup> When this method is used, the entire study area is broken into small grid cells, or pixels, known as raster surfaces which represent environment elements as a spatially continuous surface. In addition, the kernel density methodology tool can weight geographical features based on distance such that features in closer proximity receive a higher weight compared to features further away.<sup>154</sup> This unique characteristic corresponds to ample

built environment theory and research that indicates proximal features have a greater degree of influence compared to those further away.<sup>19,180</sup>

Such smoothing methods have been used less in the literature,<sup>11</sup> though they offer unique ways to characterize exposure to environmental features. Indeed, raster surfaces are the most commonly-used surface models in GIS across many disciplines, and there are many GIS tools that can be used to transform (e.g., normalize, standardize) or manipulate (e.g., add or multiply) these files. This study will develop a series of raster surfaces based on the various park and food environment features<sup>177-179</sup> and combine them to create an overall obesogenic built environment measure.

### *Park Scoring*

The first component of the obesogenic built environment will represent park availability and overall quality based on a score assigned to all parks using the detailed audit data collected. Similar to a recently published protocol creating an overall score using the CPAT,<sup>43</sup> a score for each park was calculated by summing 7 sub-components from the audit tool: six park access amenities, total number of park facilities and activity areas, total park facilities quality, six key park amenities, seven park aesthetic features, eight park quality concerns, and ten neighborhood quality concerns.<sup>43</sup> The last two groups of items were reverse-coded. All items are shown in Table 3.5. An overall score was created by summing standardized sub-scores for each of the seven categories.<sup>43</sup> The overall score for each park determined by this procedure was joined to the respective final park polygon file in ArcGIS.

After scoring each park, we transformed each park into a smoothed kernel (100x100 meter cells)<sup>43</sup> based on the park score value for each location.<sup>43,181</sup> A 1-mile



window size was applied to the park kernel where each park extended 1-mile across the study area, with the park score value decreased according to a normal, Gaussian function until it reached the boundary of the window size.<sup>181,182</sup>

Following similar procedures, five separate kernel density surfaces were created in order to represent the food stores (i.e., grocery, convenience, and discount/drug) and restaurants (i.e., fast food and fast casual). Grocery stores were assigned a value of 1, while convenience stores, discount/drug stores, fast food, and fast casual restaurants were assigned a value of -1. Positive one was chosen to represent the grocery stores, which provide access to fresh produce and have demonstrated positive relationships with healthy eating behavior and weight status in children.<sup>18,31,33,130,133</sup> Negative one was assigned to those food outlets that offer less access to fresh produce and tend to offer caloric-dense food options; these food outlets have shown negative relationships with dietary patterns and weight status.<sup>29-32,134, 135,139,183</sup> For grocery stores, a 3-mile window size was used since these food outlets have demonstrated greater population reach and in a recent study across South Carolina, the average distance to a grocery store for youth was 2.9 miles.<sup>184</sup> For convenience stores, discount/drug stores, fast food restaurants, and fast casual restaurants, a standard 1-mile window size was used.<sup>38,184</sup> The food outlets were then broadly classified and combined as two categories – healthy (i.e., grocery stores) and unhealthy (i.e., convenience and discount/drug stores, fast food and fast casual restaurants). Therefore, the three main components and raster surfaces were parks, healthy food outlets, and unhealthy food outlets.

Given the different scales for parks and food outlets, each component was normalized where the values ranged between 0 and 1. Values closer to 0 represented

high/worse obesogenic scores (i.e., no or low park values, high values for unhealthy food options, and low grocery store values), whereas values closer to 1 represented less/better obesogenic built environments (i.e., high park values, low unhealthy food values, high grocery store values). After each variable was on the same scale, the PA and HE environments were weighted equally with each receiving 50% of the total score (for the nutrition environment, the ‘unhealthy’ and ‘healthy’ elements assigned an equal weight of 25% each). The PA and HE environment were summed together to generate the final obesogenic built environment measure and a score was assigned to each child based on the value of the cell where the child lived.

Two additional obesogenic environment variables were created in order to test the sensitivity of this new measure during analyses. First, using the continuous measure just described, a two-category measure was created by first splitting the obesogenic index values from across all raster cells in the study area into four quartiles. Based on sample sizes, the three lowest quartiles were collapsed to represent ‘low’ while the highest quartile represented ‘high’. Second, following procedures used in a previously-developed obesogenic environment measure for youth, four quadrants were classified based on ‘high’ and ‘low’ values of both the park and food environment measures.<sup>146</sup> As shown in Table 3.6, high was classified as greater than or equal to the median park or food environment score across the study area, respectively, while low was less than the median park or food environment score across the study area, respectively.

### 3.5 ANALYTIC APPROACH

*Aim1a: Explore spatial clustering patterns of youth obesity in the study area.*

The spatial measures described previously – Global Moran’s I and Local Anselin’s Moran’s I – used the following analytical procedures to test for statistical significance. First, the primary continuous dependent variable, BMI z-score, was tested with the Moran’s I global spatial measure under the null hypothesis that there is no spatial clustering across the study area. The statistical output provided a measured index, expected index, variance, z-score and corresponding p-value to indicate whether the null hypothesis can be rejected or accepted.<sup>169,170,172</sup> A p-value less than 0.05 indicated a non-random spatial pattern, or spatial autocorrelation/clustering, and the z-score value specified the strength of interdependence between the data points for the main outcome (i.e., BMI z-score).<sup>170</sup> A z-score value greater than 0 would illustrate positive spatial autocorrelation where similar values tend to be located near each other, whereas a z-score value less than 0 would illustrate negative spatial autocorrelation where adjacent areas tend to have different values (i.e., high next to low).<sup>10</sup>

The second spatial analysis conducted was LISA with BMI z-score as the dependent variable. This spatial tool provided four outputs associated with the LISA test for each observation: Local Moran’s I index, z-score, p-value, and cluster/outlier type. Like Global Moran’s I, the z-score and corresponding p-value measure statistical significance indicating whether to accept or reject the null hypothesis that all spatial patterns across the study area are random.<sup>173</sup> A high positive z-score indicated surrounding features have similar values whereas a low negative z-score indicated dissonant values. The cluster/outlier type field indicated statistically significant clusters

and outliers for a 99 percent confidence level, showing the four significant types of clustering options described previously in Table 3.4.<sup>173</sup> Both global and local spatial clustering analyses were conducted in GeoDA 1.8.14, an interactive program for spatial clustering statistics and developed by the researcher who created the LISA measure.<sup>185</sup>

For both of these analyses, the distance value to conduct the test had to be defined. Generally, exploring spatial patterns is an iterative process where multiple processes and values are often used to determine the best distance value.<sup>176</sup> Therefore, the first distance tested was empirically determined using the Optimized Hot Spot Analysis tool which compared spatial autocorrelation values at a series of distances to determine the highest, or peak, spatial clustering value in the study for the outcome variable.<sup>186</sup> Evidence-based distances (i.e., 500 meters, ½ mile, 1-mile) that have shown importance for the variable or population were also examined given their conceptual importance.<sup>176</sup> The peak spatial clustering distance for the entire sample was 826.5 meters, or 0.51 miles. A half-mile distance, or approximate 10-minute walk, is recognized as a critical threshold for measuring access to and use of health-promoting community features for youth (e.g., schools, parks, food outlets).<sup>112,145,187,188</sup> Given the close approximation of the peak spatial clustering distance and the empirical foundation, a half-mile, non-weighted distance band was used for Global Moran's I and LISA analyses.

In addition, the GeoDA software provides researchers several options for conducting permutations and examining clusters at various levels of significance. Permutations are a numerical approach that uses data-driven processes to determine statistical significance.<sup>189</sup> For these analyses, permutations determined how likely it would be to observe the Moran's I value of an actual distribution under conditions of

spatial randomness. For each analysis, 999 permutations were used to examine the test statistic and a more conservative p-value of 0.01 (compared to 0.05) to adjust for multiple comparisons of testing all potential clusters.<sup>189</sup>

*Aim1b: Determine which individual and neighborhood socioeconomic and demographic characteristics are related to the spatial clustering of youth obesity*

After establishing whether global and local patterns existed, the next analytical step examined whether individual and area-level sociodemographic characteristics were related to spatial clustering of youth obesity. In order to include these covariates in spatial clustering analyses, residuals from a series of multivariate linear regression models were used as the dependent variables in both spatial analyses. Researchers have used residuals as dependent variables when adjusting for covariates in spatial clustering analyses because the value (i.e., distance from predicted value) and direction (i.e., positive or negative) of the residual can be used to indicate high and low clusters.<sup>10,12,172,190</sup> In this study, high positive residuals indicate higher than expected BMI z-scores whereas large negative residuals indicate lower than expected BMI z-scores.<sup>12</sup> In total, four linear regression models were estimated consecutively. The first model was an unconditional model that did not include any covariates. Then, model 2 included all youth characteristics (i.e., age, gender, race/ethnicity, SES), while model 3 included all BG characteristics (i.e., percent racial/ethnic minority, neighborhood socioeconomic disadvantage, population density, level of urbanization). Youth and BG characteristics were both included in model 4. Statistical output as well as the number and location of localized clusters were compared and mapped as the covariates were added to each model (estimates and maps described further in results section).

Lastly, to explore the differential patterns of spatial clustering of youth obesity by level of urbanization, the geocoded file of youth addresses was separated by the three types of areas identified: urban (n=6,788), mixed urban-rural (n=6,040), and rural (n=641). Then, the same series of spatial analyses were conducted on these three sets of data points (excluding the urban/rural classification variable as a covariate). Different distances were used based on the results from the Optimized Hot Spot Analysis for each area type given the differences in average distances between participants' residence: 500 meters for participants in urban areas, 730 meters for participants in mixed urban-rural areas, and 3,186 meters for participants in rural areas.

*Aim 2b. Examine the associations between the obesogenic built environment measure and youth obesity in the study county.*

*Aim 2c: Examine whether associations between obesogenic built environments and youth obesity vary by youth race/ethnicity, SES, and level of urbanization.*

BMI z-scores were used as the continuous, dependent variable in the following analyses.<sup>163,164</sup> First, a spatial diagnostic test was conducted in GeoDA to determine whether spatial dependency in the data required a specific spatial model for the analyses. After testing a model with the main independent variable and covariates, this test showed that a spatial lag or spatial error was not needed.<sup>189</sup> Therefore, a model building process using multilevel linear regression modeling was used to examine the associations between the obesogenic built environment measure and youth obesity. First, an unconditional model with no covariates was analyzed in order to calculate the intra-class correlation, or between neighborhood variance. Second, all youth and block group covariates were added to the next model. Then, all three obesogenic environment

measures were added in separate, consecutive analyses. Then, three separate interaction terms were tested in subsequent models. First, interaction terms with the continuous obesogenic environment measure and racial/ethnic categories were examined. Then, an interaction term between the continuous obesogenic environment measure and youth SES and youth urbanization were examined, respectively. Interpretation of results was based on significant statistical tests ( $p>0.05$ ). All multilevel models were conducted in SAS 9.2.

### **3.6 PROTECTION OF HUMAN SUBJECTS**

#### *Risks to subjects/participants*

Anticipated risks of participation in this research study were minimal and included collection of some personal information regarding height and weight and address. All participants were identified by a study ID number and not identified by participant name. After locations are geocoded, addresses were removed from the working dataset.

#### *Adequacy of protection against risks*

In an effort to minimize risks of participation, confidentiality of participants was maintained at all times. Participants were referred to by a study ID and only one secure document linked identifying information with study ID. All electronic documents were stored on secured university network servers and on password protected computers.

#### *Potential benefits to the subjects and others*

This research is designed to benefit society by gaining new knowledge about youth obesity and community-level determinants. The benefits to individuals may be learning new information about the prevalence and specific location of youth obesity and potential solutions to help address this important public health problem.

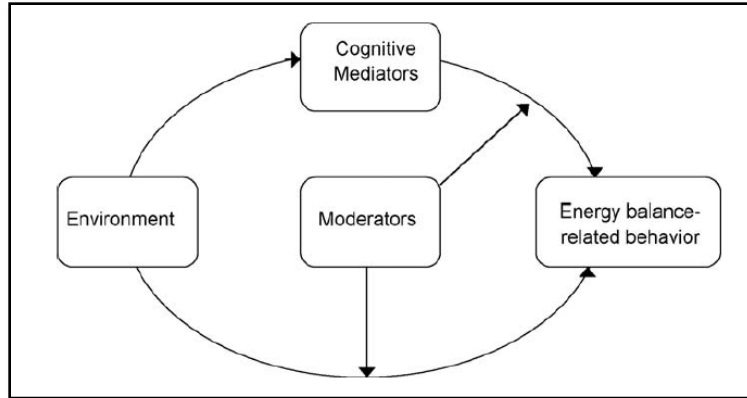
### *Data and safety monitoring*

Identifiable information present in the dataset included date of birth and address, which were necessary to measure childhood obesity and determine the location of residence to answer the study research questions. After childhood obesity status was measured and address is used to geocode the data, identifiable information was removed from the working dataset used for all statistical analyses. At that point, the analysis of secondary data (collected by the school district) was conducted with files stripped of all identifiers. In accordance with the school district recommendations, data was not stored on any mobile device. Data was stored on a secured network drive at the University of South Carolina that was only accessible by approved study team members. No persons other than the principal investigator (Kaczynski) and approved student research assistants were permitted access to the contents of the data files. The data was encrypted and password protected with the following minimum requirements: AES, 256 bit, strong password (min 8 characters, no dictionary word. Needs to be a mixture of upper/lower case, numbers, special characters). Further, the password was not communicated in email.

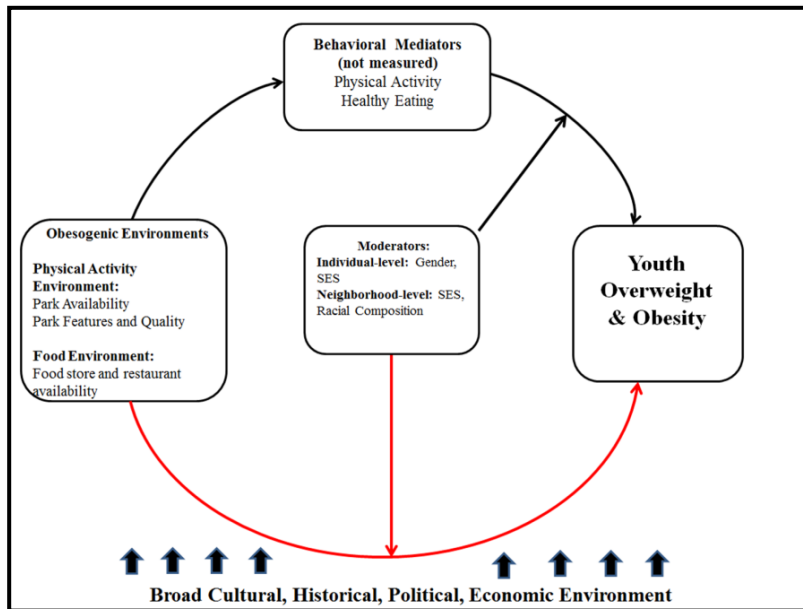
*Documentation of IRB approval and CITI training.* This study received official IRB approval through a letter from the Institutional Review Board approval from the University of South Carolina. Below is an image showing the successful completion of CITI training for the researcher (dissertation author) working with the data.







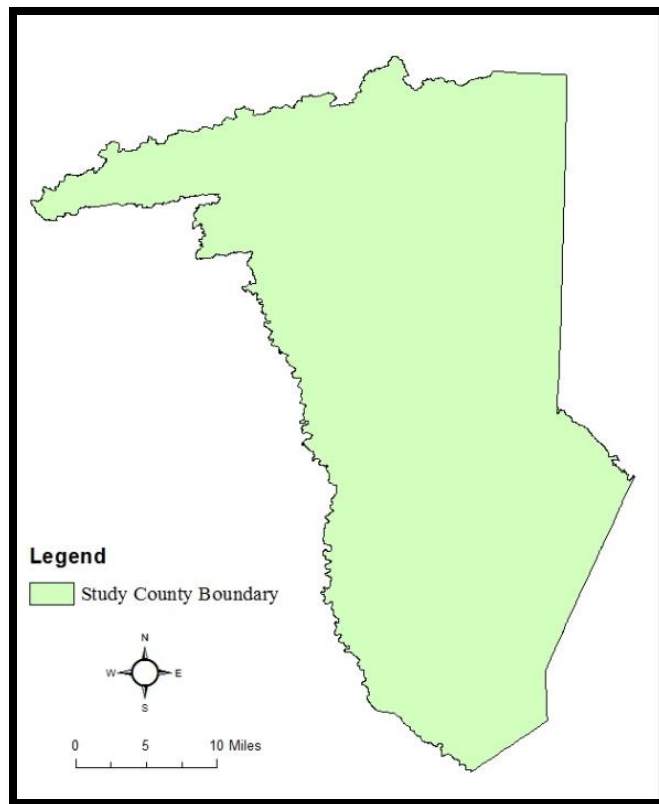
**Figure 3.1 Kremers et al.'s Framework for Energy Balance-related Behaviors**



**Figure 3.2 Adapted Conceptual Framework Highlighting the Direct Pathway Between Obesogenic Environments and Youth Weight Status**

**Table 3.1 Study Setting Demographic Characteristics in 2013**

	Overall County	Central Urban Municipality
Population	474,266	60,709
White alone (%)	77.1	64.0
Non-Hispanic White (%)	69.5	61.3
African American (%)	18.5	30.0
Hispanic or Latino (%)	8.7	5.9
Below Poverty Line (%)	15.2	18.6



**Figure 3.3 Boundary of Study County in South Carolina**

**Table 3.2 Food Environment Categories and Definitions**

<b>Food Outlet Types</b>	<b>Definitions</b>
<b>Food stores</b> <sup>160</sup>	
Grocery	Retail food store that primarily sells food (e.g., Bi-Lo, Publix)
Convenience	Retail food store with extended opening hours and convenience location, stocked with a limited range of household goods and food products (e.g., QuikTrip).
Discount and Drug Stores	Establishments that sell a limited variety of food products (e.g., Dollar Tree, CVS)
<b>Restaurants</b> <sup>161,183</sup>	
Fast food	Restaurants that are characterized by minimal service and by food that is supplied quickly after ordering where food is commonly cooked in bulk in advance and kept hot, or reheated to order (e.g., Arby's, Taco Bell)
Fast casual	Restaurant that is similar to fast-food in that it does not offer table service, but promises somewhat higher quality of food and atmosphere where customers often order and pay at a counter and food is brought to the table (e.g., Atlanta Bread Company, Moe's Southwest Grill)

**Table 3.3 Sample Characteristics (n=13,469)**

	Mean (SD) or %
Age (years)	9.7 (1.0)
Gender	
Male	50.8%
Female	49.2%
Student Lunch Status	
Full Priced	54.7%
Free or Reduced Price	45.3%
Race/Ethnicity	
White	62.2%
African American	18.9%
Hispanic	11.5%
Other	7.4%
BMI Z-score	0.5 (1.1)
BMI Percentile	64.0 (1.0)
BMI weight status categories	
Underweight	3.1%
Normal weight	62.3%
Overweight	15.7%
Obese	18.8%

**Table 3.4 Spatial Patterns Identified by the Anselin's Local Moran's I Test**

Category	Definition
Not Significant	No spatial autocorrelation (clustering) is detected.
High-High	Clustering of high values of BMI z-score; positive spatial autocorrelation
High-Low	Clustering of high values adjacent to low values of BMI z-score; negative spatial autocorrelation
Low-High	Clustering of low values adjacent to high values of BMI z-score; negative spatial autocorrelation
Low-Low	Clustering of low values adjacent to low values of BMI z-score; positive spatial autocorrelation

**Table 3.5 Categories and Items Used to Develop the Overall Park Score**

	<b>Park Category</b>	<b>Items</b>	<b>Range</b>
1	Park Access	Signage, public transit stop, parking, sidewalks, trail or path, bike routes, traffic signals	0-7
2	Park Facilities	Number of: Baseball fields, basketball courts, dog parks, fitness stations, green spaces, lakes, playgrounds, skate parks, splash pads, sports fields, swimming pools, tennis courts, trails, volleyball courts, and other (write-in additional facilities)	0-15
3	Park Facilities Quality	Usability(0.5 point), and condition (0.5point) of: Baseball fields, basketball courts, dog parks, fitness stations, green spaces, lakes, playgrounds, skate parks, splash pads, sports fields, swimming pools, tennis courts, trails, volleyball courts, and other (write-in additional facilities)	0-15
4	Park Amenities	Restrooms, lights, drinking fountains, benches, picnic tables, trash cans	0-6
5	Park Aesthetic Features	Artistic feature, historical or educational feature, landscaping, meadow, trees throughout park, wooded area, water feature	0-7
6	Park Quality Concerns	Dangerous spots, excessive animal waste, excessive litter, excessive noise, graffiti, poor maintenance, threatening behaviors, vandalism	0-8 (reverse coded)
7	Neighborhood Quality Concerns	Evidence of threatening persons/behavior, excessive litter, excessive noise, graffiti, heavy traffic, inadequate lighting, lack of eyes on the street, poorly maintained properties, vacant or unfavorable buildings, vandalism	0-10 (reverse coded)

**Table 3.6 Description of the Quadrant Measure Representing Obesogenic Built Environments**

Quadrant Description	Category definition
High Park, High Nutrition Environment	$\geq$ Median for park and nutrition environment standardized scores
High Park, Low Nutrition Environment	$\geq$ Median for park environment standardized scores < Median for nutrition environment standardized scores
Low Park, High Nutrition Environment	< Median for park environment standardized scores $\geq$ Median for nutrition environment standardized scores
Low Park, Low Nutrition Environment	< Median for park and nutrition environment standardized scores

## CHAPTER IV

### RESULTS

This chapter is comprised of two independent manuscripts that detail the findings of this study and partially fulfill the requirements of this dissertation. The first manuscript, “Patterns and Sociodemographic Correlates of Spatial Clustering of Childhood Obesity in a Southeastern US County” will be submitted for publication consideration in the *Health and Place*. The second manuscript, “Associations between a Multicomponent Obesogenic Built Environment Measure and Youth Obesity” will be submitted for publication consideration in *Obesity*.

## CHAPTER IV: MANUSCRIPT 1

### PATTERNS AND SOCIODEMOGRAPHIC CORRELATES OF SPATIAL CLUSTERING OF CHILDHOOD OBESITY IN A SOUTHEASTERN US COUNTY.<sup>1</sup>

<sup>1</sup>Hughey SM, Kaczynski AT, Hibbert J, Porter DE, Turner-McGrievy G, and Liu, J. To be submitted to *Health and Place*.



## Abstract

Youth obesity is a major public health concern due to the physical, social, and psychological health consequences. While rates and disparities of youth obesity levels are known, less research has explored fine-grained spatial clustering patterns and associated correlates. Therefore, this study 1) examined spatial clustering of youth obesity, and 2) investigated what individual- and neighborhood-level sociodemographic characteristics are correlated with spatial patterns. This study occurred in a southeastern US county (pop:474,266) in 2013. Trained physical education teachers collected height and weight for all 3<sup>rd</sup>-5<sup>th</sup> grade youth (n=13,469) and schools provided youth demographic attributes. BMI z-scores were calculated using standard procedures. Youth addresses were geocoded and block group (BG) data obtained from the US Census Bureau. Global Moran's Index and Anselin's Local Moran's I (LISA) were used to detect global and local spatial clustering, respectively. To examine correlates of spatial clustering, BMI z-score residuals from a series of four linear regression models were spatially analyzed, mapped, and compared. SAS 9.4 and GeoDA were used for analyses; ArcGIS was used for mapping. Significant, positive global clustering (Index=0.04, p<0.001) was detected. LISA results showed that about 4.7% (n=635) and 7.9% (n=1,058) of the sample were identified as high and low obesity localized spatial clusters (p<0.01), respectively. Individual and neighborhood sociodemographic characteristics accounted for the majority of spatial clustering and differential patterns were observed by level of urbanization. Identifying geographic areas that contain significant spatial clusters is a powerful tool for understanding the location of and exploring contributing factors to youth obesity.

## Introduction

Childhood obesity has been recognized as a major public health problem of the 21st century due to the wide array of physical, social, and emotional health consequences that often accompany overweight and obesity in youth.<sup>1-3</sup> Studies have also documented that overweight and obese youth have a higher risk of increased weight status into adolescence and adulthood<sup>4,5</sup> and persistent adult obesity is related to decreased quality of life, increased rates of chronic disease, as well as increased morbidity and mortality.<sup>6,7</sup> Disparities in childhood obesity rates also persist, with a disproportionate burden on youth who are low-income, racial/ethnic minorities, and live in the southeastern US.<sup>8,9</sup>

Researchers and practitioners have recognized the complex causes of youth obesity, with many individual, interpersonal, community, environmental, and societal factors contributing to weight status.<sup>10</sup> As a result, multilevel social ecological frameworks are widespread in public health research and practice, and continuing to examine determinants of childhood obesity from a multidisciplinary lens is imperative to address this problem at a population level.<sup>7,11-13</sup> Moreover, integrating advanced spatial tools and analyses can pinpoint the location of youth obesity clusters and help determine what factors are related to such clustering patterns.

Place-focused research examining how community and environment-level factors influence various health behaviors and outcomes includes spatial components, whether implicitly or explicitly stated.<sup>14,15</sup> Spatial epidemiology focuses on the distribution of health outcomes with an emphasis on how diseases vary by geographic contexts.<sup>15,16</sup> Research in this field relies on computer-based geographic information systems (GIS) software and technology as the primary mechanism to visualize, measure, and conduct

analyses investigating health trends in time and space.<sup>15,16</sup> Although broad public health literature has seen an increase in the use of GIS applications traditionally employed by geographers and environmental health scientists, much obesity-related research still lacks an explicit focus on and use of spatial tools and analyses when examining patterns and determinants.<sup>16</sup> Many studies documenting the prevalence of obesity distribution in various geographic areas have aggregated data at administratively-defined units (e.g., census tracts, ZIP codes) to analyze and describe these rates..<sup>4,9,16-18</sup> While these methodologies have served as a foundation for understanding obesity rates by regions, additional spatial clustering tools and analyses can be used to examine fine-grained geographic patterns and correlates of obesity.<sup>19-22</sup>

Spatial clustering, or non-random spatial patterning, measures the nature and strength of geographical interdependence between data.<sup>23</sup> Despite the increased use of GIS for public health applications, many studies that incorporate spatial proximity or aggregation methods have not measured spatial autocorrelation, or clustering.<sup>16,22</sup> If significant spatial autocorrelation is present, the statistical assumption of independent observations may be violated.<sup>24</sup> Consequently, assessing spatial autocorrelation is recommended as a first step in place-focused research to minimize overstating significance between exposures and outcomes.<sup>24</sup> Furthermore, mapping spatial patterns results in powerful visualizations, which can be used to identify and further study communities most impacted by chronic disease outcomes, like obesity, and highlight priority areas for public health intervention.<sup>19,22</sup> Understanding determinants of particular spatial patterns is a critical step towards understanding the causes of and potential types of intervention needed to combat the obesity epidemic and promote community health.

To date, some researchers have employed spatial clustering analyses to examine unique geographic patterns of obesity; however, there are several topics that warrant further attention in this area.<sup>25</sup> First, among studies that have examined obesity clustering, the vast majority have focused on adults;<sup>19-21,26-29</sup> to our knowledge, only a few studies have investigated spatial clustering of child or adolescent obesity.<sup>22,30</sup> Exploring these patterns for children will provide unique insight for this population and the ability to provide initial comparisons between studies focusing on different age groups. Second, many studies that have explored spatial clustering of obesity conducted analyses of administrative units, such as census tracts, zip codes, or states.<sup>20,26-30</sup> Conducting spatial clustering analyses at an individual level (i.e., point data) can provide additional detailed information on fine-grained patterns in the study area that are not constrained by administratively-defined units.<sup>19,21</sup> Finally, some studies have also examined whether demographic (e.g., socioeconomic status) and community-level factors (e.g., physical activity and nutrition environments) are related to the geographic patterning of obesity. Among those studies, sociodemographic characteristics have emerged as some of the main explanatory variables of observed spatial patterns.<sup>19,21</sup> Exploring spatial clustering models that account for key indicator variables is essential to better understand geographic patterns of childhood obesity.

In addition to the four aforementioned gaps, few studies have explored patterns of obesity by level of urbanization. Indeed, in large cities, all sub-units may be categorized as urban and may not warrant further analysis. However, other geographic areas contain more diversity in terms of urbanicity, including suburban and rural areas proximal to urban city centers. The contextual differences between urban, suburban, and rural may

substantially influence youth health behaviors and weight status, and subsequently, spatial clustering analyses on youth obesity.<sup>31-33</sup> Furthermore, rural areas have been acknowledged as another focus of youth obesity disparities because children in these areas demonstrate higher rates of overweight and obesity.<sup>34</sup> Exploring spatial clustering patterns by urban, suburban, and rural areas will allow comparison between these varying types of neighborhoods.

To address these gaps in the literature and contribute to the fields of childhood obesity and spatial epidemiology, the objectives of this study were to 1) analyze spatial clustering patterns of childhood obesity in a large, southeastern US County, 2) examine whether individual and area-level sociodemographic characteristics were associated with spatial clustering of youth obesity, and 3) explore differential spatial clustering patterns of obesity by levels of urbanization.

## **Methods**

### **Study Setting**

This study occurred in 2013 in a large county in the southeastern United States, which had a total population of 474,266, of which 77.1% was Non-Hispanic White, 18.5% was African American, and 8.5% was Hispanic or Latino.<sup>35</sup> In 2013, the median household income of the county was \$48,886 and approximately 15.0% of residents lived below the federal poverty line.<sup>35</sup> The county encompassed approximately 750 square miles of land area.

## Measures and Data Collection

### *Youth Obesity and Demographic Characteristics*

Trained physical education teachers from 51 elementary schools collected and recorded the height and weight for all children in 3<sup>rd</sup> through 5<sup>th</sup> grade (n=14,232) enrolled in the county school district as a part of regular district protocol. Height, weight, date of birth, and date of testing were used to calculate body mass index (BMI) percentiles and BMI z-scores using standardized protocols for youth from the Centers for Disease Control and Prevention.<sup>36</sup> Demographic information and address were also obtained for each individual. Three demographic variables were categorized for all youth: gender (male/female), socioeconomic status (SES) measured by school lunch status (free/reduced or full pay), and race/ethnicity (African American, Hispanic, White, or Other).

### *Block Group Characteristics*

Several variables were collected for all census block groups (BGs, n=255) in the study county. BGs are the next to smallest geographical unit recognized by the U.S. Census Bureau and have been used as rough approximations of neighborhoods in previous studies.<sup>37</sup> Neighborhood, or area-level, indicators have shown significant associations with childhood obesity and may be particularly important to spatial patterns of childhood obesity.<sup>9,38,39</sup> Thus, the following key BG variables were included in this study. First, racial/ethnic composition was measured by calculating the total percentage of racial and ethnic minorities (i.e., all persons other than those identifying as non-Hispanic White).<sup>40</sup> Second, a multivariable indicator of area-level SES (i.e., percent unemployed, percent of the population under 125% of the federal poverty threshold,

percent less than high school education, and percent of renter occupied housing) was included.<sup>40,41</sup> All variables were standardized and summarized together to create the SES index.<sup>40</sup> The third BG variable was population density per square mile, which was calculated by dividing the total population of each BG by the land area (sq. miles) of the BG.<sup>42</sup>

The final BG variable included in this study indicated the level of urbanization. The Census Bureau identifies two types of urban areas – urbanized areas (50,000 people or more) and urban clusters (at least 2,500 and less than 50,000 people); rural areas are classified as those not defined as urban.<sup>42,43</sup> Urbanized areas and urban clusters are represented with TIGER/Line Topological Faces (polygons with geocodes); this file was spatially overlaid with the BGs (the unit of analysis used to calculate all other area-level variables). If the BG contained only urban areas, it was classified as ‘urban’, whereas BGs with both urban and rural areas were classified as ‘mixed’; rural areas were defined as BGs that had no urban topological faces present.<sup>42,43</sup> BG shapefiles with the aforementioned variables were joined to all individual data points using ArcMap 10.2.2 to assign these area-level characteristics to each participant.

### Geospatial Approach

#### *Geocoding*

Youth addresses (n=14,232) were geocoded at the point address level in ArcGIS 10.2.2 using ESRI’s 2013 StreetMap data file, concurrent with youth obesity data collection. A total of 98.5% of the addresses were geocoded at either the street address (n=269) or point address levels (n=13,835), the two most accurate means of geocoding; 128 observations were removed from the dataset because they were geocoded at less

precise levels (e.g., postal codes, municipality). Additional observations were removed due to the address residing outside of the study County boundary (n=632) and extreme BMI values (n=3) for a final sample of 13,469 youth.

### *Spatial Clustering*

Two of the overarching spatial analytic techniques used to assess spatial clustering patterns are global and local; global clustering measures overall patterns in a specified area without pinpointing the exact locations, whereas local clustering measures test for small-scale patterns across the study area.<sup>16,44</sup> Both levels of clustering have different substantive meaning and interpretations and were used in this study in distinct, yet complimentary ways.

One of the most robust and commonly-used approaches to detect global spatial clustering across multiple fields is Global Moran's Index (I), where the pattern of a set of features (i.e., study participants) and an associated attribute (i.e., youth weight status) are evaluated for clustering, dispersion (i.e., checkerboard), or random distribution.<sup>21,23,45, 46</sup> Global Moran's I was also chosen for this dataset because it is intended for data where high and low value clusters are assumed to exist, which has been supported in previous studies.<sup>21</sup>

Despite the ability to detect broad clustering in the study area, the Global Moran's I test does not indicate or provide the location of clustering.<sup>16,44</sup> Therefore, a local cluster detection measure, Anselin's Local Moran's I (LISA), was used to assess more fine-grained patterns within the study County.<sup>47,48</sup> Often referred to as a hot-spot analysis, this clustering test provided an indication of the degree that localized areas represent unexpectedly high or low BMI z-score values compared to the overall, or global BMI z-



score average across the sample.<sup>47</sup> Furthermore, this test can identify five categories of various spatial patterns that may be present in the data: Not Significant, High-High, High-Low, Low-High, and Low-Low.<sup>20</sup> This study was particularly interested in the High-High and Low-Low patterns of clustering that represent areas where youth with high and low BMI values, respectively, are surrounded by youth with similar values, indicating areas of geographic concentrations of high or low youth obesity. Results from the LISA analysis were mapped to show the location of identified clusters.

### *Geospatial Analyses*

BMI z-score was used as the continuous, dependent variable for the following spatial analytical procedures.<sup>49,50</sup> For the Moran's I global spatial measure, the null hypothesis tested was that there is no spatial clustering across the study area.<sup>21,44,45</sup> Similarly, the null hypothesis for the LISA measure was that all spatial patterns across the study were random. When conducting Global Moran's I and LISA (GeoDA 1.8.14), several specifications were selected, including distance options, number of permutations, and significance values. First, the distance selected to conduct the spatial clustering analyses has varied across studies and context, yet it is critical to the test and results.<sup>51</sup> Both conceptual and empirical rationale determined the distance for analyses in this study. The Optimized Hot Spot Analysis tool in ArcGIS 10.2.2 was first employed to compare spatial autocorrelation values at a series of distances to determine the highest, or peak, spatial clustering value in the study area.<sup>52</sup> The peak spatial clustering distance for the entire sample was 826.5 meters, or 0.51 miles. A half-mile distance has been recognized as a critical threshold for measuring access to and use of health-promoting community features for youth (e.g., schools, parks, food outlets).<sup>53-56</sup> Given the close

approximation of the peak spatial clustering distance and the empirical foundation, a half-mile, non-weighted distance band was used for Global Moran's I and LISA analyses.

In addition, the GeoDA software provides researchers several options for conducting permutations and examining clusters at various levels of significance. Permutations are a numerical approach that uses data-driven processes to determine statistical significance.<sup>57</sup> For these analyses, permutations determined how likely it would be to observe the Moran's I value of an actual distribution under conditions of spatial randomness. For each analysis, we used 999 permutations to examine the test statistic and a more conservative p-value of 0.01 (compared to 0.05) to adjust for multiple comparisons of testing all potential clusters.

After establishing whether global and local patterns existed, the next analytical step examined individual and area-level sociodemographic characteristics related to spatial clustering of youth obesity. In order to include these covariates in spatial clustering analyses, residuals from a series of multivariate linear regression models were used as the dependent variables in both spatial analyses. Researchers have used residuals as dependent variables when adjusting for covariates in spatial clustering analyses because the value (i.e., distance from predicted value) and direction (i.e., positive or negative) of the residual can be used to indicate high and low clusters.<sup>15,19,21,58</sup> In this study, high positive residuals indicated higher than expected BMI z-scores whereas large negative residuals indicated lower than expected BMI z-scores.<sup>19</sup> In total, four linear regression models were estimated consecutively. The first model was an unconditional model with no covariates. Then, model 2 included all youth characteristics (i.e., age, gender, race/ethnicity, SES), while model 3 included all BG characteristics (i.e., percent

racial/ethnic minority, neighborhood socioeconomic disadvantage, population density, level of urbanization). Youth and BG characteristics were both included in model 4. Statistical output as well as the number and location of localized clusters were compared and mapped as the covariates were added to each model (maps described further in results section).

Lastly, to explore the differential patterns of spatial clustering of youth obesity by level of urbanization, we first separated the geocoded file of youth addresses by three types of areas identified: urban (n=6,788), mixed urban-rural (n=6,040), and rural (n=641). Then, we conducted the same series of spatial analyses on these three sets of data points, with the exception of the urban/rural classification variable. However, different distances were used based on the results from the Optimized Hot Spot Analysis for each area type given the differences in average distances between participants: 500 meters for participants in urban areas, 730 meters for participants in mixed urban-rural areas, and 3,186 meters for participants in rural areas.

## **Results**

### *Sample Characteristics*

All youth and block group sample characteristics are presented in Table 4.1. The majority of the sample was white (62%) while 45% were eligible for free or reduced lunch. The average BMI z-score was 0.5 (SD=1.1), with 15.7% and 18.8% classified as overweight and obese, respectively. On average, youth were about 10 years old and had an average of 28% racial/ethnic minorities (SD=20.4) living in their BG. Approximately half of youth lived in urban BGs, while 44.8% lived in urban-rural mixed BGs and 4.8% lived in rural BGs. The average number of children per block group was 52.8 (SD=41.3).

### *Global Spatial Clustering*

As shown in Table 4.2, Moran's I tests showed that there was a small, but significant, positive global spatial autocorrelation for BMI z-score across the study area (Index=0.04, Z-value=14.3,  $p < 0.001$ ), indicating a general tendency for BMI z-score values to be located near other similar BMI z-score values (Model 1). The subsequent models that included different sets of covariates resulted in changes in the Index values, z-values, and significance values. In Model 2, which adjusted for youth characteristics, the Index value was substantially reduced but still statistically significant (Index= 0.007, Z-value= 2.6,  $p=0.005$ ). Model 3 included several BG characteristics and no youth variables; the results showed a slight decrease in the Index value from the unconditional model (Model 1) but adjusting for these variables still resulted in significant, positive global spatial autocorrelation (Index=0.014, Z-value=5.1,  $p < 0.001$ ). In the final model that included both youth and BG variables, global spatial clustering was no longer significant (Index=0.003, Z-value=0.9,  $p < 0.169$ ).

### *Local Spatial Clustering*

Results from the Local Anselin Moran's I tests showed significant local clustering patterns; the number of high-high and low-low cluster observations for Models 1 through 4 are presented in the latter half of Table 4.2. High-high cluster observations represent youth that have elevated BMI z-scores compared to the overall population and are also surrounded by other youth that have similarly high BMI z-scores and vice-versa for low-low clusters. In Model 1 with no covariates, there were a total of 635 high-high and 1,058 low-low spatial cluster observations, representing 4.7% and 7.9% of the sample, respectively. Similar patterns were observed in the LISA results as Global Moran's I

throughout the model building process. Specifically, after adjusting for youth characteristics (Model 2), the number of high-high and low-low cluster observations were reduced by over half, with only 1.9% and 2.5% of participants now located in high and low statistically significant local clusters, respectively. In Model 3 that adjusted for BG characteristics, fewer significant clustered observations were noted compared to Model 1 but more than were identified in Model 2 (Table 4.2). Finally, Model 4 showed the lowest proportion of local spatial cluster observations.

A series of maps were developed to visually represent the changes in the local clustering patterns throughout the model building process. Maps representing the concentrations of each type of spatial cluster were developed using the point density function.<sup>21</sup> Each statistically significant point was smoothed a half-mile, concurrent with the distance used to conduct the clustering analyses. One map was created for each of the four models with shades of red areas showing the concentration of high-high clusters while shades of blue representing the concentration of low-low obesity clusters.<sup>21</sup> As shown in Figure 4.1, Model 1, the western areas of the study county had substantial areas of high-high obesity clusters, whereas the eastern of the county showed high concentrations of low-low obesity clusters. Interestingly, several high-high and low-low clusters are observed adjacent to one another, particularly near the center and smaller areas surrounding the center of the study county. The images for Models 2, 3, and 4 show the changes in the concentration of local clusters as correlate variables were examined.

#### *Spatial Clustering by Level of Urbanization*

Using the same model building described for the overall sample, global and local spatial clustering was also explored by level of urbanization by running each set of

analyses separately for youth living in urban, urban-rural mixed, and rural areas (Table 4.3). For Global Moran's I, significant global clustering was observed in the urban (Index=0.030, Z-score=6.6,  $p<0.01$ ), urban-rural mixed (Index=0.027, Z-score=5.4,  $p<0.01$ ), and rural areas (Model 1; Index=0.029, Z-score=2.7,  $p=0.001$ ). Differential patterns were observed based on level of urbanization as correlate variables were included. For youth that lived in urban areas, global spatial clustering was attenuated in Models 2 and 4 after including individual socio-demographic characteristics and both individual and neighborhood socio-demographic characteristics, respectively (Table 4.3). However, in urban-rural mixed areas, global clustering was only attenuated by including the combination of individual and BG characteristics (Model 4), whereas global clustering was present in all models for youth that lived in rural areas. The local clustering results showed similar patterns across all four models as the global patterns described (lower half of Table 4.3). However, in Model 1, urban areas had a higher proportion of high-high cluster observations (5.6%) compared to urban-rural mixed (2.9%) and rural (2.3%) areas.

## Discussion

Exploring and visually representing spatial clustering patterns of BMI values provides unique insight into locations that have varying concentrations of high or low childhood obesity.<sup>15,23,47,59</sup> Despite an increased use of GIS in public health and, specifically, obesity-related research, fewer studies have examined spatial clustering of obesity in youth,<sup>30</sup> at the individual data point level,<sup>19,21</sup> and correlates of spatial patterns.<sup>16,19,21</sup> Results showed that there was statistically significant global clustering across the study area and local spatial clustering in specific regions of the county. Global

clustering was attenuated and the number of individual local clusters was greatly reduced after adjusting for both youth and neighborhood socio-demographic characteristics, though variations were discovered by level of urbanization.

Low, but significant, positive spatial global autocorrelation was found, indicating that BMI z-scores were not randomly distributed within the study boundaries and that high values were more proximal to other high values.<sup>47</sup> Some researchers have found similar global spatial clustering patterns,<sup>21</sup> while other studies have reported no global autocorrelation of obesity.<sup>22,26</sup> The unit of analysis (e.g., individual points, census tracts) has varied in studies examining spatial clustering of obesity and may be contributing to differential observed patterns.<sup>60</sup> Inconsistencies in global clustering results could also be attributable to broader contextual differences between study cities. In addition to global autocorrelation, localized spatial patterns of obesity were detected using Local Anselin Moran's I (LISA).<sup>47</sup> Overall, about 13% of the sample was located in either high or low local spatial clusters. A large concentration of low weight status clusters was found in eastern areas of the county, whereas high weight status clusters were more prominent in the western region. Researchers using the same Local Moran's I analysis for BMI among adults in Seattle, WA reported similar low and high patterns in distinct regions (i.e., northern and southern) of their study area.<sup>19</sup>

Visually representing areas of unusually high or low youth obesity levels can highlight places where obesity prevention strategies and intervention are needed most.<sup>19,59</sup> Furthermore, identifying these patterns informs new lines of research seeking to understand the similarities and differences between the youth (e.g., demographics, health behaviors) and communities (e.g., demographics, built environment, health-related

policies) located in opposite (i.e., low or high) spatial clusters. More importantly, studying the processes and determinants contributing to spatial clustering patterns will be critical for determining the most effective strategies to combat and prevent youth obesity.

The second main analysis of this study examined the correlates of spatial clustering of youth obesity by including individual and area-level socioeconomic and demographic indicators in subsequent analytical models. Overall, individual-level and neighborhood-level variables accounted for a portion of global clustering, separately, but the combination of these variables attenuated global autocorrelation and substantially reduced the concentration of significant local cluster points. Similarly, one study in northern California showed that combined individual and neighborhood-level characteristics accounted for the majority of global and local spatial clustering of adult obesity,<sup>21</sup> while the previously described study in Seattle reported that property values, an area-level SES indicator, was the primary variable accounting for the local spatial clustering of adult obesity.<sup>19</sup>

The combination of individual and block group characteristics explaining the observed global and local spatial clustering closely resonates with the multifaceted social ecological model of health.<sup>11,61</sup> This theoretical framework posits that health outcomes are impacted by multiple levels of influence (e.g., intrapersonal, interpersonal, institutional, community, broad policy). This study highlights how both individual and neighborhood-level socio-demographic factors contribute to manifestations of varying spatial patterns of youth weight status at a local level. While this study shows important correlates of spatial clustering, the socio-demographic variables included in the analytical models are likely reflective of complex processes that contribute to these spatial



patterns.<sup>62</sup> For example, BG socioeconomic disadvantage was included as a neighborhood correlate variable and was comprised of multiple elements of SES, including education, employment, housing, and poverty.<sup>40</sup> These economic indicators are reciprocally related to important social and public policies and conditions (e.g., education) and health-promoting built environments (e.g., access to food outlets).<sup>62</sup> While recognizing the high degree of relatedness, or correlation, between economic indicators and larger contextual policies and environments, future research should seek innovative ways to incorporate more of these variables in spatial clustering studies.

Importantly, this study found nuanced clustering patterns and correlates of spatial clustering based on the level of urbanization where youth lived. Previous research has detected high and low local spatial clusters in areas with different population densities.<sup>19,21</sup> For example, two studies found that low obesity clustering was found in more urban areas for adults, whereas high obesity clustering was more prominent in less densely populated areas.<sup>19,21</sup> In this study, the overall prevalence of overweight and obese youth was highest among youth living in rural areas (42.5%) compared to urban (33.4%) and suburban (35.2%) areas. However, the spatial clustering analyses revealed specific spatial patterns that somewhat differed from the overall prevalence, highlighting the differences between a general statistical model and spatial model. Spatial clustering results showed that a higher proportion of the high-high youth obesity clusters were identified in urban areas whereas a higher proportion of local clustering for youth with lower weight status was found in one particular suburban area. While this phenomenon was not observed in all urban and suburban areas, this pattern may partially be explained by urban sprawl.<sup>63</sup> Urban sprawl reflects patterns of expansion outside of centralized

urban areas, often marked by more affluent residents shifting residence, leaving high concentrations of low-income residents in urban areas.<sup>63</sup> Additional research could explore whether local spatial patterns of high and low obesity are found in historically disadvantaged or advantaged areas, respectively, and whether these patterns persist over time. Several studies have documented differences in the prevalence of youth overweight and obesity by urban and rural areas, but to our knowledge, this is one of the first studies to conduct localized spatial analyses by level of urbanization

### *Limitations*

Several study limitations should be noted. First, this study is focused on one county in the southeastern US, which limits the generalizability of the findings.<sup>64</sup> However, to our knowledge, this is the first study to examine spatial clustering of childhood obesity in the southeastern US area, a region with notably high rates of obesity. Similarly, though this study included a large sample of elementary-aged youth (all 3<sup>rd</sup>-5<sup>th</sup> grade students in public schools), this limited the scope of ages analyzed. Comparing spatial patterns for populations across the lifespan could help researchers and practitioners understand what geographic factors influence health outcomes such that interventions, including policy and environment changes, can best meet the needs of a diversity of populations.

Additionally, this study was cross-sectional and no causality can be attributed to the findings.<sup>64</sup> This has been a limitation for many spatial clustering studies focused on health, particularly as this field is rapidly growing;<sup>16</sup> however, while recognizing there are often difficulties in accessing specific location variables (i.e., address) in datasets, there is a need for longitudinal studies analyzing obesity patterns in terms of space and

time to better understand whether spatial patterns of obesity persist over time.<sup>59</sup> For example, with multiple years of data, we could observe whether the high-high and low-low spatial clusters persists, are exacerbated, or dissipate as the same children age. The capabilities of multiple spatial software programs are advancing in ways that can handle innovative spatiotemporal analyses.<sup>59,65</sup> Furthermore, like other statistical analyses, spatial clustering results are sensitive to the specifications chosen, such as bandwidth distance and number of permutations. The decisions made in this study were theoretically and empirically based, and included an iterative process to test the sensitivity of results over multiple models.<sup>65</sup> These decisions should be clearly reported so that other researchers can compare the results across studies. Finally, obesity is a complex health condition that is influenced by many factors, many of which were not measured in this specific population. For example, data on behavioral patterns regarding nutrition and physical activity were not available for this large sample, but likely play a substantial role in impacting obesity and the spatial patterns observed.

### *Conclusions*

In summary, the results of this study showed global and local spatial patterning of youth obesity in a southeastern U.S. county, which reinforces the importance of spatial relationships among health conditions, including obesity. Individual-level socio-demographic characteristics were identified as a primary correlate of the spatial patterns identified, though more work is needed to explicate the mechanisms driving these associations. Overall, identifying geographic areas that contain significant spatial clusters is a powerful tool for understanding the location of and exploring contributing factors to childhood obesity.

**Table 4.1. Sample Characteristics (n=13,469)**

<b>Youth Characteristics</b>	Mean or %	SD	Range
Body Mass Index (BMI) z-score	0.5	1.1	(-8.1, 3.0)
BMI percentile	64.0	1.0	(0, 99.9)
BMI categories			
Underweight	3.1%		
Normal weight	62.3%		
Overweight	15.7%		
Obese	18.8%		
Age (years)	9.7	1.0	(7, 13)
Gender			
Male	50.8%		
Female	49.2%		
Student lunch status			
Full priced	54.7%		
Free or reduced price	45.3%		
Race/ethnicity			
White	62.2%		
African American	18.9%		
Hispanic	11.5%		
Other	7.4%		
<b>Block Group Characteristics</b>			
BG Percent racial/ethnic minority (%)	28.0	20.4	(0, 98.6)
BG Neighborhood socioeconomic disadvantage	-0.8	2.7	(-5.5, 9.9)
BG Population density (persons per sq. mile)	1554.64	1073.94	(15.3, 11555.5)
BG Level of urbanization			
Urban	50.4%		
Urban-Rural Mixed	44.8%		
Rural	4.8%		

**Table 4.2. Global Moran's I and Local Moran's I Results**

Model #	Global Moran's I			Local Moran's I	
	Index value	Z-score	p-value	High-High Cluster Observations (#, %)*	Low-Low Cluster Observations (#, %)*
Model 1 <sup>a</sup>	0.039	14.3	0.001	635 (4.7%)	1058 (7.9%)
Model 2 <sup>b</sup>	0.007	2.6	0.005	260 (1.9%)	339 (2.5%)
Model 3 <sup>c</sup>	0.014	5.1	0.001	335 (2.5%)	411 (3.1%)
Model 4 <sup>b &amp; c</sup>	0.003	0.9	0.169	205 (1.5%)	185 (1.4%)

*p*<0.001, Distance tested: 0.5 mile

<sup>a</sup>No covariates included, unconditional model

<sup>b</sup>Adjusted for youth characteristics (age, gender, SES, race/ethnicity)

<sup>c</sup>Adjusted for block group characteristics (percent racial/ethnic minority, neighborhood socioeconomic disadvantage, population density,

**Table 4.3. Global Moran's I and Local Moran's I Results by Level of Urbanization**

Model #	Global Moran's I					
	Urban (n=6,788)		Urban-Rural Mixed (n=6,040)		Rural (n=641)	
	Index value	Z-score	Index value	Z-score	Index value	Z-score
Model 1 <sup>a</sup>	0.052	11.6***	0.031	6.4***	0.029	2.7*
Model 2 <sup>b</sup>	0.005	1.0	0.007	1.6*	0.021	1.9*
Model 3 <sup>c</sup>	0.019	4.5***	0.015	3.2*	0.033	2.9**
Model 4 <sup>b,c</sup>	0.002	0.4	0.006	1.3	0.024	2.1*

Model #	Local Moran's I					
	Urban (n=6,788)		Urban-Rural Mixed (n=6,040)		Rural (n=641)	
	High-High Cluster Observations (#, %)*	Low-Low Cluster Observations (#, %)*	High-High Cluster Observations (#, %)*	Low-Low Cluster Observations (#, %)*	High-High Cluster Observations (#, %)*	Low-Low Cluster Observations (#, %)*
Model 1 <sup>a</sup>	381 (5.6%)	381 (5.6%)	174 (2.9%)	377 (6.2%)	15 (2.3%)	15 (2.3%)
Model 2 <sup>b</sup>	184 (2.7%)	100 (1.5%)	100 (1.7%)	146 (2.4%)	11 (1.7%)	9 (1.4%)
Model 3 <sup>c</sup>	195 (2.9%)	155 (2.3%)	123 (2.0%)	175 (2.9%)	14 (2.2%)	17 (2.7%)
Model 4 <sup>b &amp; c</sup>	151 (2.2%)	85 (1.3%)	97 (1.6%)	100 (1.7%)	15 (2.3%)	12 (1.9%)

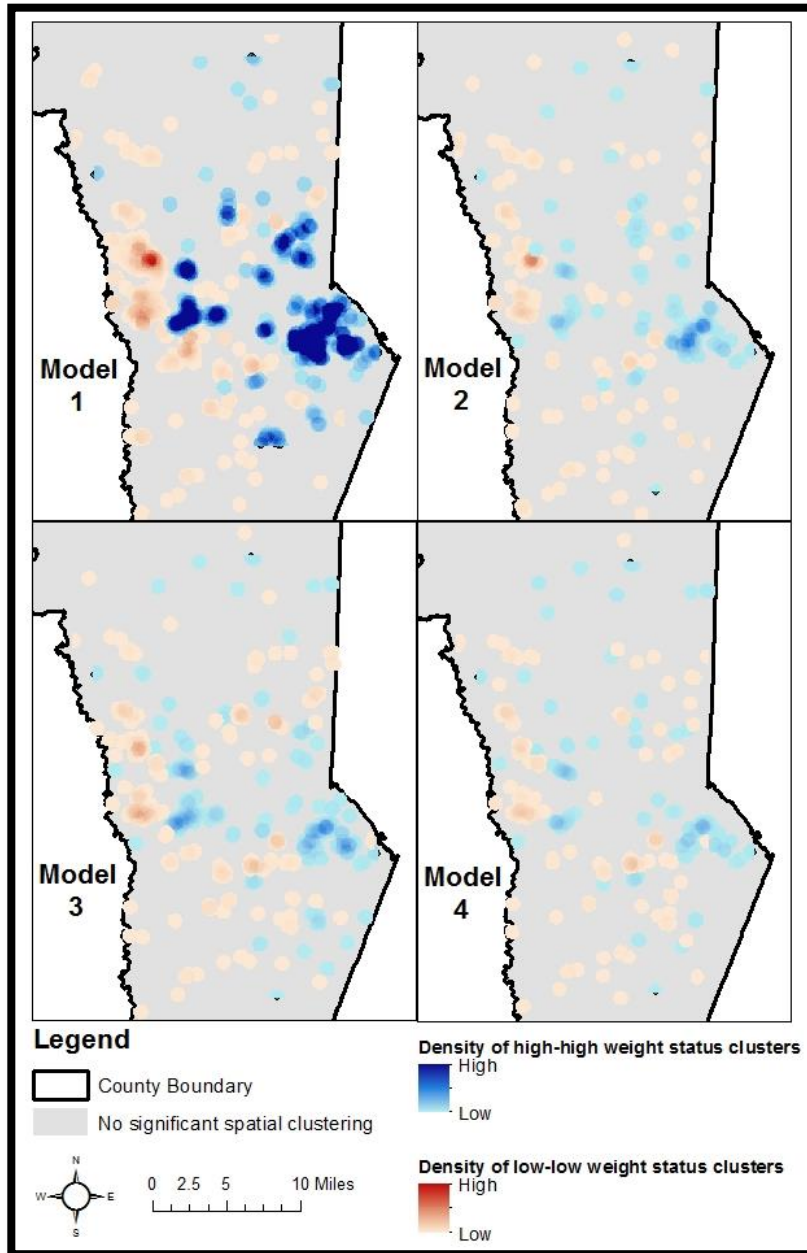
\**p*<0.05, \*\**p*<0.01, \*\*\**p*<0.001

Distances tested: Urban (500 meters), Urban-Rural Mixed (730 meters), Rural (3000 meters)

<sup>a</sup>No covariates included, unconditional model

<sup>b</sup>Adjusted for youth characteristics (age, gender, SES, race/ethnicity)

<sup>c</sup>Adjusted for block group characteristics (percent racial/ethnic minority, neighborhood socioeconomic disadvantage, and population density)



**Figure 4.1. Density of Significant High-high and Low-low Local Spatial Clusters of Youth Weight Status in a Southeastern US County**

Notes: Model 1 includes no covariates, Model 2 adjusts for youth socio-demographics, Model 3 adjusts for block group socio-demographics, and Model 4 adjusts for both youth and block group characteristics.

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## CHAPTER IV: MANUSCRIPT 2

### ASSOCIATIONS BETWEEN A MULTICOMPONENT OBESOGENIC BUILT ENVIRONMENT MEASURE AND YOUTH OBESITY<sup>1</sup>

<sup>1</sup>Hughey SM, Kaczynski AT, Porter DE, Hibbert J, Turner-McGrievy G, and Liu, J. To be submitted to *Obesity*.

## Abstract

Obesogenic built environments are places where it is easy for individuals to have low levels of physical activity and consume unhealthful foods. The purposes of this study were to 1) develop a unique indicator of obesogenic built environments for children, 2) examine associations between obesogenic built environments and youth obesity, and 3) explore variations in these associations by socioeconomic status, race/ethnicity, and level of urbanization. In a southeastern US county, public parks were scored using detailed audit data while two databases of food stores and restaurants were compiled. Grocery stores that offered access to fresh produce were classified as ‘healthy’, while convenience stores, discount/drug stores, fast food restaurants, and fast casual restaurants with less access to fresh produce were classified as ‘unhealthy’. Using kernel density estimations, separate raster (pixel) surfaces were created for each built environment component. Each surface was then normalized to the same scale and summed to create the obesogenic environment measure. Multilevel linear models were used to examine associations between the composite obesogenic built environment measure and body mass index (BMI) z-score for 13,469 elementary-aged youth in the county. Overall, health-promoting built environments were related to lower weight status in youth ( $\beta = -0.25$ ,  $p < 0.05$ ), with variations for youth living in urban and non-urban areas. This study demonstrated a unique way to quantify obesogenic built environments and the results provide evidence for the importance of continuing to advance research and practice for creating healthier community environments as one solution to preventing and combatting childhood obesity.

## Introduction

The prevalence of childhood obesity in the United States remains high, disproportionately impacts low-income and racial/ethnic minority youth, and is often accompanied by an array of physical, social, and emotional health consequences.<sup>1-4</sup> The role of place has emerged as a critical consideration as a plethora of research has demonstrated that where one lives is an important health determinant.<sup>5,6</sup> Although communities are complex systems with many components, built, or person-made, features are recognized as vital aspects of community infrastructure that can promote or impede health.<sup>7-9</sup> Furthermore, environmental approaches can promote population-level health and facilitate sustainable change for communities by modifying the context in which people live and interact.<sup>10-12</sup> Environments where it is easy for individuals to have low levels of physical activity (PA) – either by discouraging active behavior or promoting sedentary behavior – and easy for individuals to consume unhealthful foods – either by the limited availability of healthful foods or increased availability of unhealthy foods – have been coined ‘obesogenic’.<sup>13</sup> Obesogenic built environments describe community structures that influence PA and nutrition behaviors, representing both elements of the energy balance equation that contribute to weight status.<sup>14</sup> For youth, parks and food outlets are recognized as critical features of obesogenic built environments because of their demonstrated ability to impact health behaviors and weight status.<sup>10,15,16</sup>

Public parks and recreational resources are key components of community infrastructure that can promote active living, positive psychological and social health, and overall well-being across diverse communities.<sup>17-22</sup> For youth, parks can provide places to

be outdoors, engage in free-play PA, and participate in organized activities.<sup>22</sup> Researchers have shown that parks are one of the most frequently-used facilities to engage in free-play,<sup>23</sup> and primary spaces that children engage in PA outside of the school day.<sup>23</sup> Many studies have demonstrated that park availability, measured as both the overall number or density of parks, is associated with higher levels of youth PA.<sup>24-28</sup> Likewise, three longitudinal studies reported slower weight gain for youth that had improved access to parks and green space,<sup>29-31</sup> while at the same time, other researchers have found no associations between park availability and youth obesity or varying associations based on socio-demographic characteristics.<sup>32-36</sup>

On the other side of the energy balance equation, the community nutrition environment describes macro-level characteristics of food outlets, such as the number, types, and location of food stores and restaurants.<sup>16</sup> Each of these aspects of the nutrition environment have demonstrated an association with youth dietary patterns and weight status.<sup>11,12</sup> For example, youth with greater exposure to food outlets that offer fresh produce, like grocery stores, have increased consumption of fruits and vegetables and lower risk of overweight and obesity.<sup>37-40</sup> Conversely, increased availability of less healthful food outlets, like fast-food restaurants and convenience stores, has been associated with poorer dietary patterns and increased risk for child overweight and obesity.<sup>41-44</sup> Importantly, mixed findings have also been presented regarding the community nutrition environment and childhood obesity.<sup>43-48</sup>

Research on obesogenic environments has grown as evidence has shown the importance of health-promoting community structures.<sup>49,50</sup> However, there are at least three advancements that could improve this area of research, including 1) improvement



and inclusion of detailed measurement of park features, amenities, and quality indicators, 2) integration of multiple elements of the food environment simultaneously (i.e., stores and restaurants), and 3) development and analysis of a multicomponent obesogenic environment measure.

First, increased availability and proximity promote park visitation, use, and PA.<sup>17-</sup><sup>19</sup> Additional park elements, such as size,<sup>51</sup> facilities,<sup>52,53</sup> amenities,<sup>54</sup> and aesthetics<sup>55</sup> also influence park use and PA, with qualitative and quantitative studies supporting measurement and inclusion of multiple components of the park environment.<sup>51,56</sup> For example, one study explored whether the closest, largest, or most attractive (measured by nine key features rated by stakeholders) open space was more closely related to walking; results showed that both size and attractiveness were more important for walking than proximity alone.<sup>57</sup> Similarly, a review of qualitative studies on this topic showed that park features, condition and maintenance, aesthetics, safety, and social environments are critical for promoting park use.<sup>56</sup> To date, park availability has been the primary measure assessed in relation to childhood obesity;<sup>30,58</sup> therefore, including additional park characteristics has the potential to improve this body of research.

Likewise, bolstering the number and types of food outlets that are included in obesogenic built environment measures could advance how researchers quantify exposure to the food environment. For example, many studies have focused on only one type of food outlet, like grocery stores *or* fast food restaurants;<sup>33,44, 45</sup> however, these various food outlets are all present within communities and likely simultaneously influence dietary behaviors and weight status.<sup>59-61</sup> Indeed, one study found that the availability of all types of food retail, including stores and restaurants, was related to

lower youth obesity.<sup>62</sup> However, other researchers have found no associations between youth obesity and different measures of food environments, including counts and density of food stores and restaurants.<sup>63</sup> Incorporating multiple types of food stores and restaurants in a composite measure of obesogenic environments may provide additional insight into this nuanced area of research.<sup>64,65</sup>

Similarly, most research in this area has focused on the PA or healthy eating (HE) environments separately.<sup>66</sup> Yet, environments co-occur and simultaneously work together to impact obesity through PA and HE behaviors, suggesting the importance of combining multiple built environment elements into one measure.<sup>10,49</sup> Consequently, researchers have started to quantify obesogenic built environments for youth.<sup>67,68</sup> For example, Frank and colleagues developed a multicomponent obesogenic built environment indicator that had four quadrants based on high/low categorizations of the PA and nutrition environment elements; high PA environments had at least one high-quality park and were above median walkability, while high nutrition environments had a supermarket within 0.5 miles and low density of fast food restaurants (based on city-specific averages).<sup>67</sup> Results showed that children living in 'high' PA and nutrition neighborhoods were less likely to be overweight and obese compared to those living in 'low' PA and nutrition neighborhoods.<sup>69</sup> Continuing to refine, improve, and test obesogenic built environment measures can further explicate the relationship between community built environment features and youth weight status.<sup>68-70</sup> This body of work can help inform both research and practice across multiple disciplines, including public health, community planning and development, transportation, and parks and recreation.

In summary, research on obesogenic built environments is complex, with a plethora of conceptual and methodological approaches used to quantify and explain observed associations and relationships. Acknowledging this complexity, the two purposes of this study were to 1) develop a unique indicator of obesogenic built environments for children using detailed measurement of parks and multiple types of food stores and restaurants, and 2) examine the associations between obesogenic built environments and youth obesity, exploring variations by race/ethnicity, socioeconomic status (SES), and level of urbanization.

## **Methods**

### Study Setting

This study occurred in a large county in the southeastern United States, with a 2013 total population of 474,266, of which 77.1% was Non-Hispanic White, 18.5% was African American, and 8.5% was Hispanic or Latino.<sup>71</sup> In 2013, the median household income of the county was \$48,886 and approximately 15.0% of residents lived below the federal poverty line.<sup>71</sup>

### Data Collection

#### *Youth Obesity*

In 2013, trained physical education teachers from 51 elementary schools collected and recorded the height and weight for all children in 3<sup>rd</sup>-5<sup>th</sup> grade (n=14,232) enrolled in the county school district as part of a regular district protocol. Height, weight, date of birth, and date of testing were used to calculate body mass index (BMI) percentiles and BMI z-scores using standardized protocols.<sup>72</sup> Three demographic variables were also obtained and categorized for each child – gender (male/female), SES measured by school

lunch status (free/reduced or full pay), and race/ethnicity (African American, Hispanic, White, or Other). As well, youth addresses were also obtained and 98.5% (n=14,104) were geocoded at the point (98.1%) or street (1.9%) address level; those that fell outside of the county boundary (n=632) or were flagged for implausible BMI values (n=3) were removed from the data set for a final sample of 13,469 youth.

### *Block Group Characteristics*

Several variables were collected for all census block groups (BGs, n=255) in the study county to include as covariates. First, racial/ethnic composition was measured by calculating the total percentage of racial and ethnic minorities (i.e., all persons other than those identifying as non-Hispanic White).<sup>73</sup> Second, a multivariable indicator of area-level SES (i.e., percent unemployed, percent of the population under 125% of the federal poverty threshold, percent less than high school education, and percent of renter occupied housing) was included.<sup>40,41</sup> All variables were standardized and summarized together to create the SES index.<sup>73,74</sup> Finally, BGs were also classified as urban, rural, or mixed based on definitions and files provided by the U.S. Census Bureau.<sup>75,76</sup>

### *Park Enumeration, Audits, and Scoring*

Parks were enumerated through both digital and print resources and confirmed by representatives from all six parks and recreation departments in the study county to ensure validity.<sup>77</sup> Ultimately, 103 parks (0.12 to 293.24 acres; total: 2,523.9 total acres) were included in a finalized park database after an in-person audit determined that each park was useable for recreation, publicly accessible, and free of cost. All parks were then assessed using the Community Park Audit Tool (CPAT).<sup>78</sup> The CPAT was developed to capture detailed attributes of park environments for PA, including four main sections:

park information, access and surrounding neighborhood, activity areas, and quality and safety.<sup>78</sup> This tool has displayed good content validity and inter-rater reliability.<sup>78</sup> Audit data for each park were transformed into a total park score by summing seven standardized sub-components from the audit tool as shown in Table 4.4.<sup>79</sup> The last two groups of items were reverse-coded.

#### *Nutrition Environment Enumeration and Categorization*

Food outlet data were obtained, enumerated, and classified from two secondary sources that have been used frequently in nutrition environment studies.<sup>80-82</sup> First, a complete list of stores and restaurants that held a retail food license was obtained from the state Department of Health and Environmental Control.<sup>82</sup> Researchers have recommended using multiple databases to improve the accuracy of the number and type of outlets identified.<sup>82</sup> Therefore, a commercial database of food stores and restaurants, based on North American Industry Classification System (NAICS) codes, was also obtained from InfoUSA.<sup>82</sup> A complete nutrition environment profile was created by combining both datasets after duplicates were removed, and all nutrition outlets were geocoded at the point address level.

All food outlets were then classified using a combination of the NAICS codes and robust research tools for measuring the nutrition environment (e.g., Nutrition Environment Measures Survey in Stores, Nutrition Environment Measures Survey in Restaurants).<sup>80,81</sup> Each outlet was first classified as a food store or restaurant. For food stores, the three sub-categories were grocery stores/supermarkets (e.g., Publix; n=80), convenience stores (e.g., Quiktrip; n=248), and discount or drug stores (e.g., Dollar Tree, CVS; n=67). The two restaurant categories used for this study were classified as fast food

(e.g., McDonald's, n=368) or fast casual (e.g., Panera Bread, n=349).<sup>83</sup> All categories and definitions are provided in Table 4.5.

#### *Obesogenic Built Environment Measure*

To date, there is no recognized gold standard on methodology to use when characterizing obesity-related elements of the built environment.<sup>60,67,84,85</sup> Two of the most common spatial measures used are distance between two points and aggregating data to administrative units or buffers.<sup>86</sup> However, more nuanced conceptualizations and spatial measurement of the built environment have been recommended to broaden this field.<sup>86</sup> Spatial density tools can characterize and measure the intensity of exposure to built environment features.<sup>79,86-91</sup> Kernel density analyses transform data points to a surface map broken down into small grid cells, or pixels (i.e., raster surface). This technique allows features to be weighted based on distance such that closer proximity receives a higher value compared to features further away.<sup>49,88,92,93</sup> Raster surfaces are the most commonly-used surface models in GIS across many disciplines, and there are many GIS tools that can be used to transform (e.g., normalize, standardize) or manipulate (e.g., sum, multiply) multiple raster surfaces.

In order to create a comprehensive obesogenic built environment measure, a kernel density surface was created for each built environment element included in this study. The first component represented the scores for each park, which accounted for availability, features, and quality aspects of all parks. Specifically, each park was transformed into a smoothed kernel (100x100 meter cells)<sup>79</sup> based on the park score value for each location.<sup>79,94</sup> A 1-mile window size was applied to the park kernel where each park extended 1-mile across the study area, with the park score value decreasing

according to a normal, Gaussian function until it reached the boundary of the window size.<sup>94,95</sup>

Following similar procedures, five separate kernel density surfaces were created in order to represent the food stores (i.e., grocery, convenience, and discount/drug) and restaurants (i.e., fast food and fast casual). Grocery stores were assigned a value of 1, while convenience stores, discount/drug stores, fast food, and fast casual restaurants were assigned a value of -1. Positive one was chosen to represent the grocery stores, which provide access to fresh produce and have demonstrated positive relationships with healthy eating behavior and weight status in children.<sup>37-39,43,59</sup> Negative one was assigned to those food outlets that provide less access to fresh produce and tend to offer caloric-dense food options; these food outlets have shown negative relationships with dietary patterns and weight status.<sup>41-44,47, 83,96,97</sup> For grocery stores, a 3-mile window size was used since these food outlets have demonstrated greater population reach and in a recent study across South Carolina, the average distance to a grocery store for youth was 2.9 miles.<sup>98</sup> For convenience stores, discount/drug stores, fast food restaurants, and fast casual restaurants, a standard 1-mile window was used.<sup>98,99</sup> The food outlets were then broadly classified and combined as two categories – healthy (i.e., grocery stores) and unhealthy (i.e., convenience and discount/drug stores, fast food and fast casual restaurants). Therefore, the three main components and raster surfaces were parks, healthy food outlets, and unhealthy food outlets.

Given the different scales for the park and food outlet components, each component was normalized where the values ranged between 0 and 1. Values closer to 0 represented high obesogenic scores (i.e., no or low park values, high values for unhealthy

food options, and low grocery store values), whereas values closer to 1 represented less obesogenic built environments (i.e., high park values, low unhealthy food values, high grocery store values). After each variable was on the same scale, each of the three components was weighted such that both the PA and nutrition component each received 50% of the total score. For the nutrition environment, the healthy and unhealthy elements were each assigned an equal weight of 25%. Then, the three components were summed together to generate the obesogenic built environment measure and a value was assigned to each child based on the cell where the child lived.

Two additional obesogenic environment variables were created in order to test the sensitivity of this measure during analyses. In addition to the continuous measure just described, a two-category measure was created by first splitting the obesogenic index values from across all raster cells in the study area into four quartiles. Based on sample sizes, the three lowest quartiles were collapsed to represent 'low' while the highest quartile represented 'high'. Lastly, following procedures used in a previously-developed obesogenic environment measure for youth,<sup>67</sup> four quadrants were classified based on 'high' and 'low' values of both the park and food environment measures. High was classified as greater than or equal to the median park or food environment score across the study area, respectively, while low was less than the median park or food environment score across the study area, respectively.

### Statistical Analyses

BMI z-scores were used as the continuous, dependent variable in all analyses.<sup>100,101</sup> First, a spatial diagnostic test was conducted in GeoDA to determine whether spatial dependency in the data required a specific spatial model for the analyses.



After testing a model with the main independent variable and covariates, this analysis showed that a spatial lag or spatial error was not needed.<sup>102</sup> Therefore, multilevel linear regression modeling was used to examine the associations between the obesogenic built environment measure and youth obesity. Several models were examined consecutively and are presented in Table 4.7. First, an unconditional model with no covariates was conducted in order to calculate the intra-class correlation, or between neighborhood variance (not shown). Second, all youth and block group covariates were added in Model 1. Then, all three obesogenic environment measures (e.g., continuous, two-category, and quadrant variables) were added in separate, consecutive analyses (Models 2, 3, and 4). Model 5 presents the interaction between level of urbanization and the continuous obesogenic built environment variable where youth from the urban-rural mixed and rural block groups were collapsed into one category due to the small sample size of youth from rural areas. Interactions with youth race/ethnicity and SES were tested but not included because no significant interactions were detected. All multilevel models used a significance value at  $p < 0.05$  and were conducted in SAS 9.2.

## **Results**

### *Sample Characteristics*

All youth and BG sample characteristics are presented in Table 4.6. The majority of the sample was white (62%) and 45% were eligible for free or reduced lunch. The average age of the sample was about 10 years old, and the average BMI z-score was 0.5 (SD=1.1), with 15.7% and 18.8% classified as overweight or obese, respectively. Approximately half of the youth lived in urban BGs (50.4%), while 44.8% lived in urban-rural mixed BGs and 4.8% lived in rural BGs. The average number of children per block

group was 52.8 (SD=41.3). Overall, the average obesogenic built environment score was 0.34 on a scale between 0 and 1.

### *Obesogenic Built Environment*

In an unconditional model with no covariates included, the intra-class correlation was 0.04, indicating approximately 4.0% of the variance in the dependent variable, BMI z-score, was between block groups (i.e., level-2 units), supporting the use of multilevel modeling.<sup>103</sup> Throughout all models, youth that were lower SES, racial/ethnic minority (Black, Hispanic any race, Other), and lived in BGs with greater socioeconomic disadvantage had significantly higher BMI z-score values (Table 4.7, Model 1). Furthermore, female youth had significantly lower BMI z-scores compared to boys.

In Model 2, the continuous measure of the obesogenic built environment demonstrated a negative association with BMI z-score ( $b = -0.25$ ,  $p < 0.05$ ), indicating that, across all youth in this setting, more health-promoting built environments (values closer to 1) were related to lower BMI z-score. Additionally in Model 3 using the two-category variable, youth living in 'high' (better) obesogenic areas had lower BMI z-score compared to youth living in the 'low' obesogenic areas ( $b = -0.05$ ,  $p < 0.05$ ). However,, Model 4 shows that none of the quadrant categories were associated with BMI z-score. No significant interactions were detected between youth race/ethnicity and SES and the continuous obesogenic built environment variable, but, as shown in Model 5, a significant interaction was found for the indicator of urbanization.

Given the significant interaction detected, a series of analyses were conducted separately for youth living in urban and non-urban environments (Table 4.8). After adjusting for youth age, gender, race/ethnicity, SES, BG socioeconomic disadvantage and

BG racial/ethnic composition, no associations were found between any of the three obesogenic environment variables and BMI z-score for youth living in urban areas. However, a significant association was detected between the continuous obesogenic built environment indicator and BMI z-score for youth living in non-urban areas ( $b=-0.38$ ,  $p<0.01$ ), indicating that more health-promoting environments were related to lower weight status. No significant associations were detected between BMI z-score and the two category or quadrant obesogenic built environment indicators.

A series of four maps were created representing each element of obesogenic built environment (i.e., parks, healthy food outlets, less healthy food outlets) and the combined obesogenic built environment measure (Figure 4.2, ArcGIS 10.2.2). As described, values closer to 0 (white/light green) indicated less supportive built environments while values closer to 1 (dark green) indicated more supportive built environments.

### **Discussion**

The built environment is comprised of many community components that are important for promoting PA, HE, and positive weight status for youth.<sup>49,93</sup> Obesogenic built environments are places where the community infrastructure impedes active living or access to healthy foods.<sup>13</sup> While this area of research has grown substantially, few studies have examined built environment elements representing both sides of the energy balance equation simultaneously. Using detailed park audits and multiple food stores and restaurants, this study developed a unique, raster-based obesogenic built environment measure using GIS. Results showed that more supportive built environments were associated with lower weight status in a sample of over 13,000 youth in a southeastern U.S. county, with variations for youth living in urban and non-urban areas. Overall, this

study demonstrated an innovative method to quantify exposure to obesogenic built environments and tested this measure in a large sample of youth. Several areas warrant further attention to advance this field.

In this study, the obesogenic built environment measure was comprised of three components – park environment, healthful food outlets (i.e., grocery stores/supermarkets), and less healthful food outlets (i.e., convenience stores, discount stores, fast food restaurants, and fast casual restaurants). Representing all three components on the same scale (0=most unhealthy environment, 1=most healthy environment), results showed that more supportive built environments were related to lower weight status in youth. This finding complements a large body of research linking residential built environment characteristics and obesity.<sup>10,49,66</sup> Indeed, a seminal study on obesogenic environments in Seattle and San Diego showed that children living in neighborhoods with more positive environments for PA and HE had 37% lower odds of being overweight than children living in neighborhoods ranked the least supportive.<sup>67,69</sup> In addition, researchers in the northeastern US examined the impact of obesogenic built environment features on youth in a similar age range as this study.<sup>104</sup> Their results showed that lesser access to grocery stores was related to higher BMI, greater access to fast food outlets was related to unhealthy eating, and perceived access to parks was related to higher PA levels.<sup>104</sup> Like these studies and ecological frameworks for health, our results empirically demonstrate that individual (e.g. race/ethnicity, SES) and environment-level characteristics (e.g., parks, food outlets) are related to childhood obesity.<sup>67,69,104-106</sup> Such evidence supports multifaceted strategies and approaches to addressing youth obesity at a population level.

Although studies have shown similar connections between built environments and obesity, less research has explored variations by urban and non-urban areas. Built environment and obesity research has largely been studied in urban areas, but the current study county was comprised of urban, suburban, and rural communities. A separate series of analyses showed that when the sample was split by urban and non-urban areas, the associations between the obesogenic built environment measure and youth obesity were only present in non-urban areas. Another study that developed an obesogenic index (i.e., food resources, recreational activity resources, and walkability) for adults in Australia found an interaction between urban and rural areas, but in different directions than observed in this study; specifically, less supportive built environments were related to higher BMI for adults in urban areas but lower BMI for adults in rural areas.<sup>68</sup> The researchers partially attributed this finding to the lack of green grocers in rural areas,<sup>68</sup> and the food outlets included in this study comprised more ‘unhealthy’ options, which may be influencing the observed associations. Additionally, major differences in the sample (adults v. children) and context (Australia v. southeastern US) may be contributing to the observed differences across studies. However, one potential explanation for no significant associations between obesogenic environments and obesity for urban youth in this study relates to social environment variables that may influence how children in this setting interact with park and food environments.<sup>104</sup> For example, the previously described study in the northeastern US included measures of crime and social capital in their analyses on neighborhood influences for youth obesity. Increased levels of property crime were related to higher BMI, while higher levels of neighborhood social ties were related to increased youth PA.<sup>104</sup> These indicators could be influencing the

degree to which children and families in urban areas visit and utilize public parks and food outlets in their neighborhoods.

While conceptually-sound attempts can be made to ascertain the mechanisms explaining variations by urban and non-urban areas and between built environment elements and obesity generally, more research is needed to empirically test the pathways between built environments and health behaviors and outcomes. For example, studies have combined global positioning system (GPS) with health behavior tracking (i.e., accelerometers) to understand location-based behavioral patterns (e.g., ‘activity spaces’).<sup>28,107</sup> It is particularly important to collect information for individuals with diverse socio-demographic backgrounds and who live in communities with varied built environments infrastructure. There are inherent challenges to collecting such complex information, including participant recruitment and data collection and processing burdens.<sup>108,109</sup> However, better understanding the impacts of exposure to and interaction with built environment features on health has the potential to improve research frameworks and policy and practice decision-making.<sup>108,109</sup>

Despite the data challenges faced in measuring and quantifying exposure to and interaction with obesogenic built environments, this study demonstrated an innovative way to create a GIS-based measure using raster-based surfaces. The surfaces produced using kernel density techniques employed a distance decay function where the built environment feature had a higher value at its location and decreased over a specified distance. This distance decay procedure corresponds with Tobler’s frequently-cited first law of geography that “everything is related to everything else, but near things are more related than distant things”.<sup>110</sup> In addition to this measurement technique, there are many

GIS tools for manipulating (e.g., normalizing, standardizing) and combining (e.g., adding, multiplying) multiple raster datasets. For example, additional layers of built or social environment data (e.g., commercial physical activity facilities, crime) could be processed and scaled on the same range and added to an obesogenic built environment measure. Furthermore, raster surfaces in this study were used as one alternate technique versus aggregating data to administrative units. While administrative units, such as census tracts or city neighborhoods, are a source of important socio-demographic data, researchers should continue to build on methodology and measurement to improve understanding of individual exposure to and interaction with built environments.<sup>108,111</sup> Researchers must continue to test the applicability and translation of GIS measurement across different contexts to determine the gold standard methodology. For example, built environments vary drastically across dense, urban areas compared to suburban and rural areas; therefore, studies should examine whether the same measurement applies to these different contexts.

### *Limitations*

Several limitations of this study should be noted. First, the study design was cross-sectional, so no causality can be attributed to study findings.<sup>112</sup> Second, while this study included a large sample of youth from the southeastern United States, a geographic area less examined in research on the built environment and health, this potentially limits the generalizability of study findings to youth living in other geographic regions, such as large metropolitan areas.<sup>112</sup> In addition, the built environment components selected and used in this study reflect major aspects of the PA and nutrition environments for youth.<sup>67,104</sup> However, an exhaustive list of built environment elements was not included

(e.g., commercial PA outlets, walkability, mobile food markets), so these should potentially be included in future studies, including examining the differences in PA and HE environments by urban, suburban, and rural areas. Furthermore, while detailed park audit data were collected and used, additional elements of the food stores and restaurants, such as price and availability of specific items, were not included since this project did not have the capacity to collect audit data for over 1,100 identified food outlets.<sup>16</sup> In this study, we broadly classified grocery stores as ‘healthy’ food outlets and convenience stores, discount/drug stores, fast-food restaurants and fast casual restaurants as ‘unhealthy’ food outlets. Despite these challenges, the large and comprehensive dataset of youth and multiple components of the built environment allowed us to demonstrate the utility of spatial density measures and raster surfaces for quantifying and analyzing exposure to varying levels of the obesogenic built environment.

### *Conclusions*

The communities and neighborhoods where children live have been identified as key health determinants and the built environment infrastructure therein can influence multiple health behaviors and outcomes. This study demonstrated a unique way to quantify obesogenic built environments and tested this measure with a sizeable sample of youth in a large southeastern US county. Overall, more supportive built environments were related to lower youth weight status, providing additional evidence for the importance of continuing to advance research and practice related to ameliorating obesogenic community environments as one solution to preventing and combatting childhood obesity.



**Table 4.4. Categories and Items Used to Develop Overall Park Score**

	<b>Park Category</b>	<b>Items</b>	<b>Range</b>
1	Park Access	Signage, public transit stop, parking, sidewalks, trail or path, bike routes, traffic signals	0-7
2	Park Facilities	Number of: Baseball fields, basketball courts, dog parks, fitness stations, green spaces, lakes, playgrounds, skate parks, splash pads, sports fields, swimming pools, tennis courts, trails, volleyball courts, and other (write-in additional facilities)	0-15
3	Park Facilities Quality	Usability(0.5 point), and condition (0.5point) of: Baseball fields, basketball courts, dog parks, fitness stations, green spaces, lakes, playgrounds, skate parks, splash pads, sports fields, swimming pools, tennis courts, trails, volleyball courts, and other (write-in additional facilities)	0-15
4	Park Amenities	Restrooms, lights, drinking fountains, benches, picnic tables, trash cans	0-6
5	Park Aesthetic Features	Artistic feature, historical or educational feature, landscaping, meadow, trees throughout park, wooded area, water feature	0-7
6	Park Quality Concerns	Dangerous spots, excessive animal waste, excessive litter, excessive noise, graffiti, poor maintenance, threatening behaviors, vandalism	0-8 (reverse coded)
7	Neighborhood Quality Concerns	Evidence of threatening persons/behavior, excessive litter, excessive noise, graffiti, heavy traffic, inadequate lighting, lack of eyes on the street, poorly maintained properties, vacant or unfavorable buildings, vandalism	0-10 (reverse coded)

**Table 4.5. Food Environment Categories and Definitions**

<b>Food Outlet Types</b>	<b>Definitions</b>
<b>Food stores</b> <sup>161</sup>	
Grocery	Retail food store that primarily sells food (e.g., Bi-Lo, Publix)
Convenience	Retail food store with extended opening hours and convenience location, stocked with a limited range of household goods and food products (e.g., QuikTrip).
Discount and Drug Stores	Establishments that sell a limited variety of food products (e.g., Dollar Tree, CVS)
<b>Restaurants</b> <sup>162</sup>	
Fast food	Restaurants that are characterized by minimal service and by food that is supplied quickly after ordering where food is commonly cooked in bulk in advance and kept hot, or reheated to order (e.g., Arby's, Taco Bell)
Fast casual	Restaurant that is similar to fast-food in that it does not offer table service, but promises somewhat higher quality of food and atmosphere where customers often order and pay at a counter and food is brought to the table (e.g., Atlanta Bread Company, Moe's Southwest Grill)

**Table 4.6. Sample Characteristics (n=13,469)**

<b>Youth Characteristics</b>	<b>Mean or %</b>	<b>SD</b>	<b>Range</b>
Body Mass Index (BMI) z-score	0.5	1.1	(-8.1, 3.0)
BMI percentile	64.0	1.0	(0, 99.9)
BMI categories			
Underweight	3.1%		
Normal Weight	62.3%		
Overweight	15.7%		
Obese	18.8%		
Age (years)	9.7	1.0	(7, 13)
Gender			
Male	50.8%		
Female	49.2%		
Student lunch status			
Full priced	54.7%		
Free or reduced price	45.3%		
Race/ethnicity			
White	62.2%		
African American	18.9%		
Hispanic	11.5%		
Other	7.4%		
Obesogenic Built Environment (continuous)	0.34	0.11	(0.18, 0.89)
Obesogenic Built Environment (two category)			
Low (worse)	39.6		
High (better)	60.4%		
Obeosgenic Built Environment – (quadrants)			
Low parks, low nutrition	29.3%		
Low parks, high nutrition	39.9%		
High parks, low nutrition	9.9%		
High parks, high nutrition	21.0%		
BG Percent racial/ethnic minority (%)	28.0	20.4	(0, 98.6)
BG Neighborhood socioeconomic disadvantage	-0.8	2.7	(-5.5, 9.9)
BG Level of urbanization			
Urban	50.4%		
Non-Urban	49.6%		

**Table 4.7. BMI z-score Associations with Youth Characteristics, Block Group Characteristics, and Obesogenic Built Environment Variables (n=13,469)**

	Model 1 <i>b</i> (SE)	Model 2 <i>b</i> (SE)	Model 3 <i>b</i> (SE)	Model 4 <i>b</i> (SE)	Model 5 <i>b</i> (SE)
<i>Fixed Effects</i>					
Intercept	0.24 (0.10)*	0.33 (0.11)*	0.27 (0.10)*	0.25 (0.10)*	0.19 (0.12)
Age	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)
Low SES	0.24 (0.02)***	0.26 (0.02)***	0.25 (0.03)***	0.24 (0.02)***	0.24 (0.02)***
Female	-0.08 (0.02)***	-0.08 (0.02)***	-0.08 (0.02)***	-0.08 (0.02)***	-0.08 (0.02)***
Race (White=ref)					
Black	0.25 (0.03)***	0.25 (0.03)***	0.25 (0.03)***	0.25 (0.03)***	0.25 (0.03)***
Hispanic	0.36 (0.03)***	0.36 (0.03)***	0.36 (0.03)***	0.36 (0.03)***	0.36 (0.03)***
Other	0.12 (0.04)**	0.12 (0.04)**	0.12 (0.04)**	0.12 (0.04)**	0.13 (0.04)**
BG Socioeconomic disadvantage	0.03 (0.01)***	0.03 (0.01)***	0.03 (0.01)***	0.03 (0.01)***	0.03 (0.01)***
BG Racial composition	-0.0 (0.0)	-0.0 (0.0)	-0.0 (0.0)	-0.0 (0.0)	-0.0 (0.0)
BG Urbanicity (urban=ref)					
Not Urban	0.07 (0.03)*	0.07 (0.03)*	0.06 (0.03)*	0.07 (0.03)*	0.03 (0.08)***
Obesogenic built environment (continuous)		-0.25 (0.11)*			0.12 (0.18)
Obesogenic built environment (two category, low=ref)					
High			-0.05 (0.02)*		
Obesogenic built environment (quadrant) (Low low=ref)					
Low park, High nutrition				-0.03 (0.03)	
High park, Low nutrition				-0.04 (0.04)	
High park, High nutrition				-0.05 (0.03)	
Obesogenic Built Environment*Urbanicity					-0.57 (0.2)*

\*p<0.05, \*\*p<0.01, \*\*\*p<0.001

Model 1=all youth and block group covariates; Models 2,3,4= Continuous, categorical, and quadrant obesogenic built environment variables added, respectively; Model 5=interaction between continuous obesogenic environment and urban/non-urban variable added

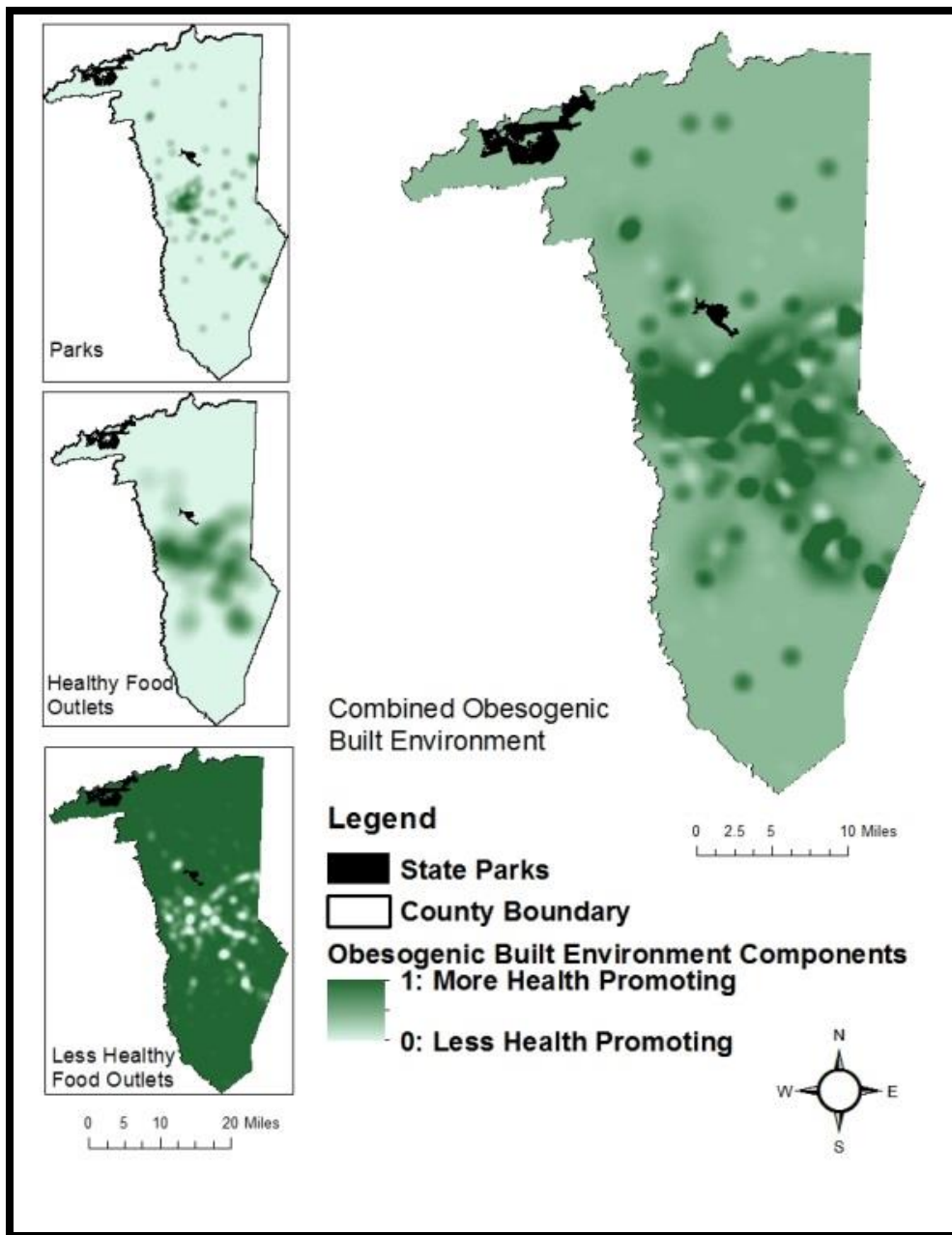
**Table 4.8. BMI z-score Associations Between Youth Obesity and Obesogenic Built Environment Variables by Urban and Non-urban Areas**

<i>Fixed Effects</i>	Urban (n=6,788)	Non-Urban <sup>a</sup> (n=6,681)
<i>Fixed Effects</i>	<i>b</i> (SE)	<i>b</i> (SE)
Obesogenic built environment (continuous)	0.04 (0.01)	-0.38 (0.13)**
Obesogenic Built Environment (two category, low=ref)		
High	-0.01 (0.03)	-0.06 (0.03)
Obesogenic built environment (quadrant, low low=ref)		
Low park, High nutrition	-0.08 (0.05)	0.02 (0.04)
High park, Low nutrition	0.10 (0.06)	0.00 (0.06)
High park, High nutrition	-0.06 (0.05)	-0.07 (0.05)

\*p<0.05, \*\*p<0.01, \*\*\*p<0.001

<sup>a</sup>=combination of youth living in suburban and rural areas

All models adjusted for youth age, gender, race/ethnicity, SES, and BG socioeconomic disadvantage and racial/ethnic composition.



**Figure 4.2. Kernel Density Surfaces used to Represent Obesogenic Built Environment Components in a Southeastern US County**

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## CHAPTER V

### DISCUSSION

#### *Summary of Major Findings*

Obesity has emerged as one of the greatest public health challenges of this century.<sup>191</sup> Childhood obesity is particularly concerning because of the physical, social, and psychological challenges faced at an early age, in addition to the increased likelihood of remaining overweight and obese into adulthood.<sup>1-3</sup> Addressing childhood obesity at a population-level requires a broad and multifaceted perspective and approach.<sup>74,75</sup>

Continually mounting evidence shows that built environment infrastructure impacts key health behaviors and outcomes, including active living, nutrition, and obesity. Despite a surge in research in this area, the utilization of advanced spatial methodological techniques and analyses can describe more localized patterns of youth obesity and improve the characterization of exposure to obesogenic environments.<sup>11</sup> This study 1) explored global and local spatial clustering of youth obesity and determined which individual and neighborhood characteristics were correlated with youth obesity, 2) developed a raster-based GIS measure of obesogenic built environments that incorporated density measures of both the park and food environment, and 3) examined associations between obesogenic built environments and youth obesity, including variations by race/ethnicity, socioeconomic status, and level of urbanization. This final conclusions chapter highlights the results from the two specific aims of the study, with discussion of how this work relates to previously published research. Finally, this chapter concludes



with a discussion of the implications of this work for public health research and practice, study limitations, and future areas of research to advance this field.

The first specific aim of this study focused on examining global and local spatial clustering and sociodemographic correlates of these patterns of childhood obesity among a large sample from the southeastern US. Low, but significant, positive spatial global autocorrelation was found, indicating that BMI z-scores were not randomly distributed within the study boundaries and that high and low values were more proximal to other high and low values, respectively.<sup>173</sup> Some researchers have found similar global spatial clustering patterns,<sup>172</sup> while other studies have reported no global autocorrelation of obesity.<sup>13,192</sup>

Furthermore, significant local clustering of youth obesity was also detected in the present study. Overall, about 13% of the sample was located in either high or low local spatial clusters. A large concentration of low weight status clusters were found in eastern areas of the county, whereas high weight status clusters was more prominent in the western region. Researchers using the same Local Moran's I analysis for BMI among adults in Seattle, WA reported similar low and high patterns in distinct regions (i.e., northern and southern) of their study area.<sup>12</sup> Visually representing areas of unusually high or low youth obesity levels can highlight places where obesity prevention strategies and intervention are needed most.<sup>12,193</sup> One potential explanation that warrants additional research is whether social and cultural diffusion processes result in similar geographic patterns in health behaviors and outcomes for youth. Perhaps similarities, or adapted, social and cultural norms and behaviors in proximal neighborhoods manifest in these localized patterns of health outcomes.<sup>194</sup>

The second analysis of specific aim 1 examined individual and area-level socioeconomic and demographic correlates of spatial clustering of youth obesity. Overall, individual-level and neighborhood-level variables accounted for a portion of global clustering, separately, but the combination of these variables attenuated global autocorrelation and substantially reduced the concentration of significant local cluster points. Similarly, one study in northern California showed that combined individual and neighborhood-level characteristics accounted for the majority of global and local spatial clustering of adult obesity,<sup>172</sup> while the previously described study in Seattle reported that property values, an area-level SES indicator, was the primary variable accounting for the local spatial clustering of adult obesity.<sup>12</sup>

The combination of individual and block group characteristics explaining the observed global and local spatial clustering closely resonates with the multilevel ecological models of health.<sup>6,7</sup> This theoretical framework posits that health outcomes are impacted by multiple levels of influence (e.g., intrapersonal, interpersonal, institutional, community, broad policy). This study highlights how both individual and neighborhood-level socio-demographic factors contribute to manifestations of varying spatial patterns of youth weight status at a local level. While this study showed important correlates of spatial clustering, the socio-demographic variables included in the analytical models are likely reflective of complex social and economic processes that may contribute to these spatial patterns.<sup>78</sup> For example, BG socioeconomic disadvantage was included as a neighborhood correlate and was comprised of multiple elements of SES, including education, employment, housing, and poverty.<sup>41</sup> These economic indicators are reciprocally related with important social and public policies and conditions (e.g.,

education) and health-promoting built environments (e.g., access to food outlets), making it difficult to explain or disentangle factors related to spatial clustering.<sup>78</sup> While recognizing the high degree of relatedness, or correlation, between economic indicators and larger contextual policies and environments, future research should seek innovative ways to incorporate more of these variables in spatial clustering studies.

Finally, the last analysis of specific aim 1 discovered nuanced spatial patterns of youth obesity by urban, suburban, and rural areas. Likewise, previous research has detected high and low significant local spatial clusters of obesity in areas characterized by varying levels of urbanization.<sup>12,172</sup> For example, two studies found that low obesity clustering was found in more urban areas, whereas high obesity clustering was more prominent in less densely populated areas.<sup>12,172</sup> Our results showed contrary findings in that a higher proportion of the high-high youth obesity clusters were identified in urban areas, whereas a higher proportion of local clustering for youth with lower weight status was observed in one particular suburban area. While these patterns were not prominent across all urban and suburban areas of the County, this pattern may partially be explained by urban sprawl.<sup>195</sup> Urban sprawl reflects patterns of expansion outside of centralized urban areas, often marked by more affluent residents shifting residence, leaving high concentrations of low-income residents in urban areas.<sup>195</sup> Additional research could explore whether local spatial patterns of high and low obesity are found in historically disadvantaged or advantaged areas, respectively, and whether these patterns persist over time.

The second aim of this dissertation project focused on developing an innovative method to quantify exposure to obesogenic built environments and testing this measure in

a large sample of youth in the southeastern US. In this study, the obesogenic built environment measure was comprised of three components – park environment, healthful food outlets (i.e., grocery stores/supermarkets), and less healthful food outlets (i.e., convenience stores, discount stores, fast food restaurants, and fast casual restaurants). Representing all three components on the same scale (0=most unhealthy environment, 1=most healthy environment), the results showed that more supportive built environments were related to lower weight status in youth. This finding is consistent with some research linking residential built environment characteristics and obesity,<sup>75,79,97</sup> but differs from studies that have found null associations.<sup>110,135,142</sup> For example, a seminal study on obesogenic environments in Seattle, Washington and San Diego, California showed that children living in neighborhoods with more positive environments for PA and HE had 37% lower odds of being overweight than children living in neighborhoods ranked the least supportive.<sup>40,146</sup> In addition, researchers in the northeastern US examined the impact of obesogenic built environment features on youth in a similar age range to this study.<sup>145</sup> Their results showed that lesser access to grocery stores was related to higher BMI, greater access to fast food outlets was related to unhealthy eating, and perceived access to parks was related to higher PA levels.<sup>145</sup> Like these studies and ecological frameworks for health, our results empirically demonstrated that environment-level characteristics (e.g., parks, food outlets) were related to childhood obesity.<sup>7,40,145,146,196</sup> Such evidence supports multifaceted strategies and approaches to addressing youth obesity.

Although studies have shown similar connections between built environments and obesity, less research has explored variations by urban and non-urban areas. Obesogenic

environment and obesity research has largely occurred in urban areas, but this study county comprised a variety of neighborhoods and communities categorized as urban, suburban, and rural. A separate series of analyses showed that when the sample was split by urban and non-urban areas, the associations between the obesogenic built environment measures and youth obesity were only present in non-urban areas. Another study that developed an obesogenic index for adults in Australia (comprised of food resources, recreational PA facilities, and walkability) found an interaction between urban and rural areas and the obesogenic index, but in different directions than observed in this study; specifically, less supportive built environments were related to higher BMI for adults in urban areas but lower BMI for adults in rural areas.<sup>39</sup> The researchers partially attributed this finding to the lack of green grocers in rural areas;<sup>39</sup> major differences in the sample (adults v. children) and context (Australia v. southeastern US) likely contribute to the observed differences across studies.

However, one potential explanation for no significant associations between obesogenic environments and obesity for urban youth relates to social environment variables that may influence how children in this setting interact with park and food environments.<sup>145</sup> For example, the previously described study in the northeastern US included measures of crime and social capital in their analyses on neighborhood influences for youth obesity.<sup>145</sup> Increased levels of property crime were related to higher BMI, while higher levels of neighborhood social ties were related to increased youth PA.<sup>145</sup> These indicators could be influencing the degree to which children in urban areas visit and utilize public parks and food stores in their neighborhoods, but additional research would be needed to test these hypothesized mechanisms.

This study demonstrated an innovative way to create a GIS-based measure using raster-based surfaces that has the potential to be geographically transferrable to other study areas and additional built environment measures. The surfaces produced using kernel density techniques employed a distance decay function where each built environment feature had a higher value at its location and decreased over a specified distance. This distance decay procedure corresponds with Tobler's frequently-cited first law of geography that "everything is related to everything else, but near things are more related than distant things".<sup>10</sup> In addition to this measurement technique, GIS programs have many tools that allow for manipulation of multiple raster surfaces (e.g., adding or multiplying together, standardizing values). For example, additional layers of built or social environment data (e.g., commercial PA facilities, walkability, crime) could be processed and scaled on the same range and added to an obesogenic built environment measure. Furthermore, raster surfaces in this study were used as one alternate technique versus aggregating data to administrative units. While administrative units, such as census tracts or BGs, are a source of important socio-demographic data, researchers should continue to build on methodology and measurement to improve understanding of individual exposure to and interaction with built environments.<sup>197,198</sup> Researchers must continue to test the applicability and translation of GIS measurement across different contexts to determine the gold standard methodology. For example, built environments vary drastically across dense, urban areas compared to suburban and rural areas; therefore, studies should examine whether the same measurement applies to these different contexts.

Some important themes were observed across both project aims. First, this work integrates a multidisciplinary framework. This project was guided by both health behavior and spatial epidemiological frameworks and literature and bolstered by methodologies rooted in geography and environmental health sciences. Research and practice aimed at preventing and treating the complex issue of childhood obesity and other chronic conditions will need to continue to employ such interdisciplinary approaches in order to identify innovative and effective solutions. Specifically, this research team included experts in geography and GIS tools and analyses as well as nutrition and PA researchers in health behavior and epidemiology; collaboration between these disciplines facilitated the development of this unique obesogenic environment measure that would have otherwise gone unseen.

In addition, this dissertation project demonstrated specific geographical patterns and correlates of childhood obesity, highlighting existing spatial health disparities. For example, distinct areas of high and low clustering were identified in two communities in this setting; the clustering of high obesity was located along the western edge of the urbanized area, which has historically been considered a socioeconomically disadvantaged area, while the clustering of low youth obesity levels was located in a wealthy suburban area. Furthermore, the second specific aim demonstrated that racial/ethnic minority youth, low SES youth, and youth that live in disadvantaged neighborhoods had higher BMI z-scores across all analytical models. These spatial and socioeconomic disparities cannot be ignored and more work is needed to fully understand the causes of and determine appropriate solutions for these stark health inequities.

Lastly, one of the main premises of the conceptual framework driving this dissertation project is that where someone lives and the characteristics of that residential environment are important influences for health. The results from both specific aims of this study showed the importance of place in different ways. As described, the first study reported that spatial clustering patterns of youth obesity varied in different neighborhoods or communities within a local county. This measurement occurred at a relatively small scale compared to other national studies, further supporting the notion that residence is an important factor for obesity. Furthermore, the secondary analyses of this study demonstrated that more health-promoting built environments were related to lower youth obesity. In this southeastern US county, place was a determinant for childhood obesity.

#### *Implications for Public Health Research and Practice*

Multiple aspects of this dissertation project, including the methodology and results, have implications for public health research and practice. First, spatial clustering tools were used to identify communities that had unusually high patterns of youth with elevated weight status. Most health departments and government agencies employ GIS experts for planning purposes, so this could be another tool utilized to inform local officials or leaders about the areas of concern for obesity. This data could be communicated with schools, community centers, churches, and other key centerpieces of communities that serve children and have a vested interest in childhood obesity prevention. Although this could be an excellent tool, increased collaboration and data sharing agreements between government agencies and entities that collect this data, like school districts, would be required.<sup>199</sup> Often, there are political, ethical, or logistical hurdles to collecting, using, and disseminating data sources; however, there is vast



potential for these collaborations to advance public health efforts in local communities.<sup>199</sup>

As mentioned, this study demonstrates the importance of applying unique analytical tools from other academic disciplines to a well-known public health problem. Overall, the current study exhibits multiple successful collaborations and new lenses on childhood obesity research.

Local government agencies, like DHEC, and coalitions, like Eat Smart Move More South Carolina, are dedicated to prevention efforts that utilize empirically-driven evidence to determine both the locations and strategies that should be implemented for obesity prevention. This study used data from a county in the southeastern US and shows that both individual and built environment influences were related to childhood obesity. This type of data can provide empirical support for ongoing and future efforts and serve as preliminary data for local, regional, or national grant proposals or private funding mechanisms so that these organizations can continue evidence-based practices. Despite valiant attempts at integrating prevention efforts in the national U.S. healthcare system, DHEC and local coalitions are often the main organizations working on prevention efforts in community-based settings and can benefit from the types of spatial and statistical data generated here.

When data show that PA and HE environments are important for childhood obesity, localized efforts to improve the availability or quality of infrastructure may be prioritized. For example, while it may be difficult to substantially increase the overall amount of park space available in a municipality in a short period of time, additional efforts like shared-use agreements with schools or faith-based organizations may be pertinent to providing additional spaces for youth to be active.<sup>200</sup> Likewise, small-scale

improvements to park or nutrition environments (e.g., adding lighting or landscaping to improve park safety or improving labeling for healthy options in convenience stores) can enhance existing spaces. Solid empirical data is necessary to begin to make the case for these types of collaborations for local leaders and officials (e.g., parks and recreation and food vendors). Furthermore, if local agencies were able to use the data from the spatial clustering analyses, those identified spaces could show a leverage point for where interventions (e.g., shared-use agreements, small-scale infrastructure improvements) have the potential for the most impact for childhood obesity. Likewise, identifying high need areas may help prioritize spaces for long-term park and recreation capital investment, or in the short term, identify neighborhoods where increased community engagement or programming efforts may best help residents.<sup>201</sup>

For the nutrition environment, broad-scale policy regulation of the location of stores and restaurants has been a difficult and sometimes controversial undertaking.<sup>202-204</sup> However, this study, along with additional empirical evidence, could provide support for zoning policies that limit proximity of less healthful food outlets to key environments that children are exposed to, like neighborhoods and schools. In reality, such policies have had substantial political pushback and may have potential unintended consequences.<sup>205</sup> For example, limiting the proximity of specific stores or restaurants may provide less access to unhealthy options, but this may also provide less access to food overall, which may be concerning for areas considered food deserts or food insecure. While changing broad policies, like zoning, is complex, communities may be able to focus efforts on increasing access to fresh fruits and vegetables overall through innovative solutions, like mobile produce markets. Researchers have also suggested that other policies, like menu

calorie labeling, may have an impact on obesity-related behaviors.<sup>203,206</sup> These examples regarding policy and environment changes for the park and nutrition environment show the complexity and difficulty of making change at such a broad level; however, successful efforts could have the potential to impact a large proportion of the population.

Research on obesogenic environments has grown tremendously in the past decade,<sup>79</sup> but the methodology employed in this study has the potential to have a significant impact on the conceptualization and measurement of the built environment.<sup>207</sup> One other research group has described raster-based GIS techniques to advance measurement of health behaviors in a spatial context, but this team was also focused on capturing a variety of health behaviors through GIS and app-based technology (e.g. mobile travel and dietary diary).<sup>177</sup> This dissertation project uniquely used a weighting function in quantifying the obesogenic environments and combined multiple raster data sources into one measurement. Many studies have examined elements of the built environment separately, which has provided data to link behaviors and built environment elements.<sup>27,84</sup> However, people experience exposure to various components of community infrastructure in their daily lives, so combining these measures together can contribute to a different conceptualization of exposure to the built environment. The methods used in this study could propel built environment and health researchers to test raster-based surfaces in future work, potentially comparing the typical vector (e.g., point, polygon data) with the raster-based data to determine more of a gold-standard measurement to use.

### *Limitations*

This study was subject to several limitations. First, both aims employed a cross-sectional study design so no causality can be attributed to the presented results,<sup>208</sup> an often cited criticism of built environment research.<sup>207</sup> Second, this study was focused on one large county in the southeastern United States. While this allowed us to look in-depth at localized areas, including only one county limits the generalizability of study findings compared to different geographic contexts.<sup>208</sup> Similarly, though this study included a large sample of elementary-aged youth (all 3<sup>rd</sup>-5<sup>th</sup> grade students in public schools), this limited the scope of the ages analyzed and limits the generalizability to other populations across the lifespan.<sup>208</sup> Importantly, childhood obesity is a complex health condition that is influenced by many factors. While this study included some individual and built environment characteristics to illustrate spatial clustering patterns and the associations between youth obesity and built environment characteristics, there are many other factors that contribute to youth obesity. For example, data on behavioral patterns regarding nutrition and PA were not available for this large sample but likely play a substantial role in impacting obesity and should be tested in future work.

This study introduced a unique measure to characterize built environment features across different communities. The language and measurement regarding ‘place’ and ‘community’ in built environment research often remains vague, without specific definition or varying interpretations of definitions. ‘Place’ broadly refers to a portion of space or a geographic area, yet people often experience and interact within many places throughout daily activities. This broad definition of place has led to a wide array of GIS measurement used in built environment research, from Euclidean and network buffers to

administrative units to the raster surfaces used in this study.<sup>176</sup> This is often described as the modifiable area unit problem (MAUP), how research conclusions can vary based on how data are aggregated.<sup>209</sup> Using specific geocoded data, like in this study, helps ameliorate this issue by knowing the exact residential location of study subjects. Three future steps can be taken to help provide clarity in the language and definitions of ‘place’ and ‘community’. First, explicitly defining what a particular study or group of researchers means by ‘place’ will help provide more transparency in exactly what geographic areas are being studied and provide a way for researchers to compare the meaning of place across studies. Second, researchers should work to better understand how people perceive and define both ‘place’ and ‘community’ to inform the geographic tools and measures that are used to examine relationships between built environments and health.<sup>211,212</sup> Last, research aimed at understanding how exposures to different places – including residential, work, and recreational – influence health could also help researchers know which places are most influential and inform the best measurement techniques to use in research.<sup>211,212</sup>

In addition to the broad limitations across the entire study, each aim was also subject to particular limitations. Like other statistical analyses, spatial clustering results are sensitive to the specifications chosen, such as bandwidth distance and number of permutations. The decisions made in this study were theoretically and empirically based, and included an iterative process to test the sensitivity of results over multiple models.<sup>185</sup> However, researchers have used different specifications in different cities or regions, and these decisions and rationale should be clearly reported in published manuscripts so that other researchers can compare the results across studies.

For the second specific aim, the built environment components that were selected and used in this study reflect major aspects of the PA and HE environments for youth.<sup>145,146</sup> Nonetheless, an exhaustive list of built environment elements was not included (e.g., commercial PA outlets, mobile food markets), so this remains an option for future expansion of the current measure and methodology. Furthermore, while detailed park audit data were collected and used, additional elements of the food stores and restaurants, such as price and availability of fresh produce, were not included and are important characteristics that can influence dietary patterns.<sup>73</sup> The burden to collect audit data for over 1,100 identified food outlets was beyond the scope of the resources for this project. Despite these challenges, the large and comprehensive dataset of youth and multiple components of the built environment allowed us to demonstrate the utility of spatial density measures and raster surfaces for quantifying and analyzing exposure to varying levels of the obesogenic built environment.

#### *Future Directions*

The literature examining spatial clustering patterns and relationships between built environment elements and youth obesity is dominated by cross-sectional study designs.<sup>207</sup> Each area of research (i.e., spatial clustering and built environment) would benefit tremendously by incorporating more rigorous study designs, such as longitudinal assessments and long-term natural experiments. This has been a limitation for many spatial clustering studies focused on health, particularly as this field is rapidly growing;<sup>11</sup> however, while recognizing there are often difficulties in accessing specific location variables (i.e., address) in datasets, there is a need for longitudinal studies analyzing obesity and other chronic disease patterns over time to understand how exposure to

certain obesogenic environments impacts trajectories of health behaviors and outcomes.<sup>193</sup> The capabilities of multiple spatial software programs are advancing in ways that can handle innovative spatiotemporal analyses.<sup>185,193</sup> In addition to incorporating longitudinal study designs, identifying spatial clustering patterns informs new lines of research seeking to understand the similarities and differences between the youth (e.g., demographics, health behaviors) and communities (e.g., demographics, built environment, health-related policies) located in opposite (i.e., low or high) spatial clusters. Importantly, studying the processes and determinants contributing to spatial clustering patterns will be critical for determining the most effective strategies to combat and prevent youth obesity.

More research is needed to empirically test the pathways between built environments and health behaviors and outcomes.<sup>210</sup> Data are needed on the geospatial patterns of youth health behaviors and interactions with multiple built environment features. For example, one research group has combined global positioning systems with health behavior tracking (i.e., accelerometers) to understand location-based behavioral patterns (e.g., ‘activity spaces’).<sup>25,211</sup> It is particularly important to collect information for individuals with different socio-demographic backgrounds and who live in communities with varying built environment infrastructure in order to understand differences in exposure to and interaction with obesogenic environments. There are inherent challenges to collecting such complex information, including participant recruitment and data collection and processing burdens.<sup>197,212</sup> However, better understanding the impacts of exposure to and interaction with built environment features on health has the potential to improve research frameworks and policy and practice decision-making.<sup>197,212</sup>

Lastly, this study used objective measurement to characterize exposure to built environment elements, but other researchers have shown the importance of considering subjective perceptions of obesogenic environment features.<sup>80,213-215</sup> Indeed, a major section of the previously presented ecological model for active living encompasses the perceived environment as a key factor for PA behaviors.<sup>8</sup> For example, this study collected audit data to score the parks and assigned distances to each built environment component, whereas residents' perceptions of quality and proximity of parks may be different. While objective measurement is used and presented more widely in the literature, the perceptions of availability and acceptability of built environment components have also shown robust associations.<sup>214-217</sup> Ideally, future research efforts could determine ways to incorporate objective and perceived reality measures regarding the built environment.<sup>215</sup>

### *Conclusion*

The communities and neighborhoods where children live have been identified as key health determinants and the built environment infrastructure therein can influence multiple health behaviors and outcomes. This study showed spatial clustering patterns of youth obesity and demonstrated a unique way to quantify obesogenic built environments with a sizeable sample of youth in a large southeastern US county. Overall, more supportive built environments were related to lower youth weight status, providing additional evidence for the importance of continuing to advance research and practice for creating healthier community environments as one solution to preventing and combatting childhood obesity.



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## APPENDIX A – COMMUNITY PARK AUDIT TOOL

## COMMUNITY PARK AUDIT TOOL

### Instructions

Before you begin, try to locate a map of the park. Next, review the CPAT training guide and audit tool. It is important to make sure each question and response is clear when you are marking your answer. Then, go to the park and fill out this audit tool. The tool (6 pages) is divided into four sections that focus on different parts of the park. Further instructions are at the top of each section.

### **Tips for Using the Community Park Audit Tool (CPAT)**

- Drive, bike, or walk around the park to get a feel for what's in the park and the neighborhood around the park.
- Questions on the CPAT are grouped in sections in the order that you might come across them in a park. However, you may need to switch between sections or pages as you complete the park audit. Therefore, it is important to look through the tool before you begin.
- When you are finished, go back and make sure you have completed all the sections and questions.
- There is space at the end of each section where you can write down comments as you complete your audit. The margins or back of the page can be used to take notes, but make sure to transfer your comments into the answer spaces.
- If you see anything that requires immediate attention, contact the local parks department.

### Section 1: Park Information

Park Name: \_\_\_\_\_ Observer Name or ID: \_\_\_\_\_

Park Address/Location: \_\_\_\_\_

Were you able to locate a map for this park?  No  Yes

Was the park easy to find onsite?  No  Somewhat  Yes

Date (m/d/yr): \_\_\_/\_\_\_/\_\_\_\_\_

Temperature: \_\_\_ °F Weather:  Clear  Partly Cloudy  Rain/Snow

Start Time: \_\_\_\_\_ am or pm (circle) End Time: \_\_\_\_\_ am or pm (circle) Length of visit: \_\_\_\_\_ min

Comments on Park Information:

## Section 2: Access and Surrounding Neighborhood

This section asks about accessing the park and about the neighborhood surrounding the park. Several questions include follow-up responses if you answered yes. There are spaces for comments at the end of the section. **When thinking about the surrounding neighborhood, consider all areas that you can see from inside of the park.**

When rating the access and surrounding neighborhood, please use the following definition:

- **Useable:** everything necessary for use is present and nothing prevents use (e.g., sidewalks are passable)

1. Can the park be **accessed for use?** (e.g., not locked/fenced, available for activity, etc.)  No  Yes
2. Are there **signs** that state the following (could be same sign)? (*check all that are present*)  None present  
 Park name  Park hours  Park contact information  Park/facility rental information  
 Park rules  Park map  Rental equipment information  Event/program information
3. How many **points of entry** does the park have?  More than 5 (or park boundary is open)  2-5  Only 1
4. Is there a **public transit stop** within sight of the park?  No  Yes
5. What types of **parking** are available for the park? (*check all that are present*)  
 None  Parking Lot  On street parking  Bike rack(s)
6. Are there **sidewalks** on *any* roads bordering the park? (could be on opposite side of road)  No  Yes  
If yes ... Are they useable?  All or most are useable  About half  None or few useable  
If yes ... Are there **curb cuts and/or ramps** on *any* sidewalks bordering or entering the park?  No  Yes
7. Is there an external **trail or path** connected to the park?  No  Yes  
If yes ... Is it useable?  No  Yes
8. Are there **bike routes** on *any* roads bordering the park? (*check all that are present*)  
 None  Marked bike lane  Bike route sign  Share the road signs/markers
9. Are there nearby **traffic signals** on *any* roads bordering the park? (e.g., crosswalk, stop light/sign)  No  Yes
10. What are the main **land use(s) around the park?** (*check all that apply*)  None present  
 Residential  Commercial  Institutional (e.g., school)  Industrial (e.g., warehouse)  Natural
11. Which of the following **safety or appearance concerns** are present in the **neighborhood surrounding the park?**  
(*check all that are present in the surrounding neighborhood within sight on any side of the park*)  
 Poor lighting (e.g., low or no lighting on surrounding neighborhood streets)  
 Graffiti (e.g., markings or paintings that reduce the visual quality of the area)  
 Vandalism (e.g., damaged signs, vehicles, etc.)  
 Excessive litter (e.g., noticeable amounts of trash, broken glass, etc.)  
 Heavy traffic (e.g., steady flow of vehicles)  
 Excessive noise (e.g., noticeable sounds that are unpleasant or annoying)  
 Vacant or unfavorable buildings (e.g., abandoned houses, liquor store)  
 Poorly maintained properties (e.g., overgrown grass, broken windows)  
 Lack of eyes on the street (e.g., absence of people, no houses or store fronts)  
 Evidence of threatening persons or behaviors (e.g., gangs, alcohol/drug use)  
 Other \_\_\_\_\_  
 None present

Comments on Access or Surrounding Neighborhood Issues:

### Section 3: Park Activity Areas

This section asks about the activity areas in the park. For each activity area type:

1. **First, mark the number (#) of areas that are present in the park** (if none, write "0").
2. Then, respond to questions about **up to three** of those activity areas. If there are more than three areas for a specific activity area type, **rate the first three you come across during the audit**. If there were no activity areas of that type present in the park, move on to the next type.
3. Finally, use the space provided to note any additional comments about each type of activity area.

When rating the activity areas, please use the following definitions:

- **Useable:** everything necessary for use is present (excluding portable equipment - rackets, balls, etc.) and nothing prevents use (e.g., are there nets up for tennis courts, goals for sport fields, are trails passable, etc.)
- **Good condition:** looks clean and maintained (e.g., minimal rust, graffiti, broken parts; even surface; etc.)

12. Activity Areas	# of Areas (# : _____)	Area 1	Area 2	Area 3
<b>a. Playground</b>				
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Distinct areas for different age groups		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Colorful equipment (i.e., 3+ colors)		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Shade cover for some (25%+) of the area		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Benches in/surrounding area		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Fence around area (i.e., half or more)		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Separation or distance from road		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>b. Sport Field (football/soccer)</b>				
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>c. Baseball Field</b>				
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>d. Swimming Pool</b>				
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>e. Splash Pad</b>				
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>f. Basketball Court</b>				
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>g. Tennis Court</b>				
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				

Activity Areas	# of Areas	Area 1	Area 2	Area 3
<b>h. Volleyball Court</b>	(# : _____)			
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>i. Trail</b>	(# : _____)			
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Connected to activity areas		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Distance markers/sign		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Benches along trail		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
What is the trail surface? <i>(check one)</i>		<input type="checkbox"/> Paved <input type="checkbox"/> Crushed stone <input type="checkbox"/> Dirt/mulch	<input type="checkbox"/> Paved <input type="checkbox"/> Crushed stone <input type="checkbox"/> Dirt/mulch	<input type="checkbox"/> Paved <input type="checkbox"/> Crushed stone <input type="checkbox"/> Dirt/mulch
Comments:				
<b>j. Fitness Equipment/Stations</b>	(# : _____)			
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>k. Skate Park</b>	(# : _____)			
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>l. Off-Leash Dog Park</b>	(# : _____)			
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>m. Open/Green Space</b>	(# : _____)			
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>n. Lake</b>	(# : _____)			
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Is there a designated swimming area?		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				
<b>o. Other</b> <i>(fill in a type description for each)</i>				
Useable		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Good condition		<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes	<input type="checkbox"/> No <input type="checkbox"/> Yes
Comments:				

Comments on Park Activity Areas:



#### Section 4: Park Quality and Safety

This section asks about factors related to comfort and safety when using the park. Several questions include follow-up responses if you answered yes. There are spaces for comments at the end of the section.

When rating the quality and safety features of the park, please use the following definitions:

- **Useable:** everything necessary for use is present and nothing prevents use (e.g., can get into restrooms, drinking fountains work, etc.)
- **Good condition:** looks clean and maintained (e.g., minimal rust, graffiti, broken parts; etc.)

13. Are there public **restroom(s)** or **portable toilet(s)** at the park?  No  Yes  
If yes ...  
Are the restroom(s) useable?  All or most are useable  About half  None or few are useable  
Are they in good condition?  All or most in good condition  About half  None or few in good condition  
Is there a family restroom?  No  Yes  
Is there a baby change station in any restroom?  No  Yes
14. Are there **drinking fountain(s)** at the park?  No  Yes  
If yes ...  
How many different fountains are there? (i.e., units, not spouts) \_\_\_\_\_  
Are the fountains useable?  All or most are useable  About half  None or few are useable  
Are they in good condition?  All or most in good condition  About half  None or few in good condition  
Are they near activity areas?  All or most are near  About half  None or few are near
15. Are there **bench(es)** to sit on in the park?  No  Yes  
If yes ...  
Are the benches useable?  All or most are useable  About half  None or few are useable  
Are they in good condition?  All or most in good condition  About half  None or few in good condition
16. Are there **picnic table(s)** in the park?  No  Yes  
If yes ...  
Are the tables useable?  All or most are useable  About half  None or few are useable  
Are they in good condition?  All or most in good condition  About half  None or few in good condition  
Is there a picnic shelter in the park?  No  Yes  
Is there a grill or fire pit in the park?  No  Yes
17. Are there **trash cans** in the park?  No  Yes  
If yes ...  
Are they overflowing with trash?  All or most overflowing  About half  None or few overflowing  
Are they near activity areas?  All or most are near  About half  None or few are near  
Are recycling containers provided?  No  Yes
18. Is there **food/vending machines** available in the park?  No  Yes  
If yes ...  
Are fruits and/or vegetables available in the park?  No  Yes
19. If the sun was directly overhead, how much of the park would be **shaded**?  <25%  25-75%  >75%
20. Are there **rules posted about animals** in the park? (e.g., dogs must be leashed)?  No  Yes
21. Is there a place to get **dog waste pick up bags** in the park?  No  Yes  
If yes ... Are bags available at any of the locations?  No  Yes

22. Are there **lights** in the park? (not including neighborhood street lights)  No  Yes  
 If yes ...  
 How much of the park could be lit?  <25%  25-75%  >75%  
 Are the activity areas lit?  All or most are lit  About half  None or few are lit
23. Is the **park monitored?** (e.g., volunteer or paid staff, patrolled by police, cameras, etc.)  Unsure  Yes
24. Are there **any emergency devices** in the park? (e.g., phone, button, emergency directions)  No  Yes
25. From the center of the park, how **visible is the surrounding neighborhood?**  Fully  Partially  Not at all
26. Are there **road(s)** of any type through the park?  No  Yes  
 If yes ... Are there traffic control mechanisms on the roads within the park? (e.g., crosswalk, stop light or sign, brick road, speed bumps, roundabouts)  No  Yes
27. Which of the following **park quality or safety concerns** are present in the park? (*check all that are present*)
- Graffiti (e.g., markings or paintings that reduce the visual quality of the area)
  - Vandalism (e.g., damaged signs, buildings, equipment, etc.)
  - Excessive litter (e.g., noticeable amounts of trash, broken glass, etc.)
  - Excessive animal waste (e.g., noticeable amounts of dog waste)
  - Excessive noise (e.g., noticeable sounds that are unpleasant or annoying)
  - Poor maintenance (e.g., overgrown grass/weeds/bushes or lack of grass in green areas)
  - Evidence of threatening persons or behaviors (e.g., gangs, alcohol/drug use)
  - Dangerous spots in the park (e.g., abandoned building, pit/hole)
  - Other \_\_\_\_\_
  - None present
28. What **aesthetic (i.e., beautiful/pleasing) features** are present in the park? (*check all that are present*)
- Evidence of landscaping (e.g., flower beds, pruned bushes)
  - Artistic feature (e.g., statue, sculpture, gazebo, fountain)
  - Historical or educational feature (e.g., monument, nature display, educational signs, etc.)
  - Wooded area (e.g., thick woods or dense trees)
  - Trees throughout the park (e.g., scattered trees)
  - Water feature (e.g., lake, stream, pond)
  - Meadow (e.g., natural, tall grassy area)
  - Other \_\_\_\_\_
  - None present

Comments on Park Quality and Safety Issues:

**Before you are finished, please make you have answered all questions in the tool.**

**About the Community Park Audit Tool**

The Community Park Audit Tool (CPAT) was developed in 2010 in Kansas City, Missouri by Andrew Kaczynski (Kansas State University) and Sonja Wilhelm Stanis (University of Missouri) in collaboration with the City of Kansas City Missouri Parks and Recreation Department. Development of the CPAT was supported by a grant from Active Living Research, a national program of the Robert Wood Johnson Foundation.