The Relationship Between Transportation Access and Body Mass Index (BMI) for Older Adults: Survey Results from Erie County, New York

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Abstract: The impact of built environment characteristics—such as population density, land use arrangements, and access to public transit—on Body Mass Index (BMI) are assessed for 350 older adults (age 50 and older) in Erie County, New York. Socio-demographic data and information about individuals' health is collected using a random survey of older adults; data about the built environment is calculated for the surroundings of each respondent's home using Geographic Information Systems (GIS). A particular focus of inquiry is how frequency of driving and access to public transportation—and the degree to which various urban forms provide support for these mode choices—relate to BMI for older adults. Results suggest that BMI of older adults may be more influenced by personal characteristics—age, sex, physical functionality—and neighborhood socioeconomic factors—share of population within the respondents' census tract that is white, and median household income—than by neighborhood land use and frequency of driving. Access to public transportation—measured by the density of nearby bus stops—does have an inverse and significant relationship with BMI among older adults, suggesting that transportation access may play a greater role in the overall activity levels and BMI of older adults.

Key words: older adults, physical activity, body mass index (BMI), obesity, transportation access, survey research

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BACKGROUND

The influence of built environment on individual health behaviors such as physical activity levels and subsequent health conditions such as obesity has become a popular research topic across the related fields of public health and urban planning. A flurry of empirical research has emerged to understand and demonstrate this relationship, however the majority of research either focuses broadly on adults of all ages or specifically on subgroups such as adolescents or youth. Evidence about the impact of built environment and transportation access on the health of older adults (age 50 years or more) is still relatively sparse (see Berke, Koepsell, Moudon, Hoskins, Larson, 2007; King, Belle, Brack, Simkin-Silverman, Soska, Kriska, 2005; and Li, Fisher, Brownson, Bosworth, 2004). Like children, older adults are an important sub-group for study because of their reduced willingness and/or ability to drive (Bailey 2004), dependence on others for transportation (Straight 2003, Bailey 2004), and their higher likelihood of living in rural settings and small towns with less extensive public transportation (Bailey 2004). In addition, perceptions about neighborhood conditions among older adults likely play a large role in their activity levels and thus their health outcomes (Balfour and Kaplan, 2002; Doyle *et. al.*, 2006). Indeed, efforts to keep older adults active and at healthy weight are important to personal health and well-being and to communities at large.

For thorough and detailed reviews of the literature and research see Booth *et. al.* (2005), Handy (2004), and Papas *et al.* (2007) among others. Here we highlight key findings from the prior research that inform the design of this study. Relevant literature is summarized in Table 1 and discussed below.

[Table 1]

A relationship between built environment features and physical activity is detected across multiple built environment typologies ranging from the macro scale of regions to the micro scale of neighborhoods. At the metropolitan scale, sprawl is associated with decreased levels of physical activity (Frank *et al.*, 2004; Cervero and Duncan 2003) and higher risk of obesity (Lopez 2004; Ewing *et al.*, 2003; Ross *et al.* 2007; Garden and Jalaludin, 2008), while regions with greater "walkability" measured at the county-wide level are associated with more walking (Rodriguez *et al.*, 2006) and lower body mass (Doyle *et. al.*, 2006) than counties with lesser "walkability". Studies that measure built environment for census tracts suggest that activity

Table 1. Effect of Built Environment on BMI and Physical Activity

Location of Study (*authors, year*) [sample size, age of participants]	**Geographic Scale**	**Dependent Variable(s)**	**Built Environment Measures**	**Findings**
King County, WA (*Berke, Koepsell, Moudon, Hoskins, Larson, 2007)* [n=936, age 65 to 97]	1 km and 3 km buffers around each respondent's home	BMI; physical activity (self-reported)	walkability (determined by land use characteristics; parks; streets; foot and bike trails; traffic; public transit; others	built environment is associated with increased walking for exercise; no statistically significant relationship between built environment and BMI
Atlanta, GA region (*Frank, Andresen, Schmid, 2004)* [n=10,878, adults of all ages]	1 km network distance from respondent's home	BMI	street connectivity (density of intersections); residential density; land use mix (index compares residential, commercial, office, and institutional designations)	increased mixed land uses and corresponding physical activity are associated with reduced odds of obesity; land use mix is most important built environment predictor BMI
nationwide (U.S.) (*Ewing, Schmid, Killingsworth, Zlot, Raudenbush, 2003)* [n=206,992, age 18 and over]	Metropolitan Statistical Area and counties	BMI; physical activity; physical health	metropolitan and county sprawl index; residential density; land use mix; degree of "centering"; street accessibility	subjects in sprawling counties are less physical active (walk less), have higher BMI and greater prevalence of hypertension than those living in compact counties
nationwide (U.S.) (*Lopez, 2004)* [n=104,084, adults of all ages]	Metropolitan Statistical Area	BMI	sprawl index (population density and distribution of density across MSA)	urban sprawl has modest but statistically significant association with increased risk for being overweight or obese
Pittsburgh, PA (*King, Belle, Brach, Simkin-Silverman, Soska, Kriska , 2005)* [n=158, women age 52 to 62]	census block groups	physical activity of older women	year home was built (suggests urban form); proximity to businesses and facilities; socioeconomic status of neighborhood	offers some support that proximity to businesses and services may increase physical activity levels. Also living in medium aged neighborhoods was associated with higher levels of physical activity, while living in an older neighborhood was not.

Location of Study (*authors, year)* [sample size, age of participants]	**Geographic Scale**	**Dependent Variable(s)**	**Built Environment Measures**	**Findings**
nationwide (Canada) (*Ross, Tremblay, Khan, Crouse*, et. al., *2007)* [n=32,964, age 20 to 64]	neighborhood census tract areas and Regional Canadian Metropolitan Areas	BMI	dwelling density (suggests walkability); sprawl (dwelling density); share of CMA population in urban core	environmental factors such as sprawl and living in the urban core have incremental effects on BMI
Portland, Oregon (*Li, Fisher, Brownson, Bosworth, 2004)* [n=577, age 65 to 94]	56 Portland neighborhoods (defined using GIS) and 0.5 mile buffer areas around respondent's home	neighbor-hood walking activity	number of residential units; number employers; number of street intersections; green space for recreation; safety for walking; safety from traffic; number of nearby recreational facilities	built environment has a significant influence on walking activity among older adults; neighborhoods with higher residential density, employment density, street intersections and green and open spaces for recreation are associated with more frequent walking activity
New York, NY (*Rundle, Diez Roux, Freeman, Miller, Neckerman, Weiss, 2007)* [n=13,102, age 30 years or more]	census tracts within the five boroughs of New York City	BMI	neighborhood socioeconomic characteristics; land use mix index; bus stop density; street intersection density	modest but significant relationship between urban form and BMI among residents of New York City; subjects in census tracts with higher population density, greater subway and bus stop density, and greater mix between residential and commercial land uses have significantly lower BMI compared with other New Yorkers

Note: 1 kilometer = 0.62 mile

levels increase and BMI decreases among residents who live within walking distance to goods and services (King *et. al.*, 2005) and have access to public transit (Rundle *et. al.*, 2007).

A growing body of evidence suggests that even at the micro-scale of the neighborhood, built environment features have an impact on health and BMI. A positive association between neighborhood walkability—including street connectivity, residential density, recreation amenities, and land-use mix—and physical activity has been established (Berke *et al.*, 2007; Frank *et al.*, 2005; Handy *et al.*, 2002; Li *et al.*, 2005; Greenwald and Boarnet, 2002; Frank *et al.*, 2006; Frank *et al.*, 2004; Smith *et al.* 2008). Although there is variation in researchers' measurement of walkability and neighborhood boundary definition, evidence suggests that residents of neighborhoods that encourage walking through built environment features participate more often in physical activity.

Attempts to subdivide the population into important subgroups beyond adult and child have been limited, though the importance of understanding the impacts of built environment on different age cohorts has been noted by Malizia (2006). While a robust body of literature is developing around childhood obesity and built environment, research on older adults is less common. Published research about older adults and built environment tends to focus on the influence of neighborhood features—including walkability, land uses, and appearance and perceptions of safety—on physical activity levels (Dannenberg *et al.* 2003; Tranter *et al.* 1991) and environmental factors that contribute to more walking (Berke *et al., 2007*; King *et al.*, 2003; Li *et al.*, 2005; Patterson and Chapman, 2004).

Perceptions of neighborhood quality and safety are important factors in understanding how older adults interact with the built environment. Balfour and Kaplan (2002) find that older adults who identify two or more nuisances in their neighborhoods—such as traffic, noise, crime, trash and litter, lighting, and public transportation—were less likely to engage in physical activity than those with indicating no nuisances in their neighborhood (Balfour and Kaplan 2002).

A direct relationship between built environment and BMI among older adults remains unproven despite an association between built environment and physical activity. Berke and colleagues (2007) find that living in a walkable neighborhood does indeed impact physical activity for older adults by encouraging walking for exercise, however, more physical activity in such neighborhoods is not associated with lower BMI because the data do not reveal a statistically significant relationship between built environments and obesity (Berke *et al.*, 2007). Our study builds on these previous studies by further testing the relationship of neighborhood features and physical activity and body mass index of older adults.

METHODS

Study Design

We use cross-sectional multi-level regression analysis to determine whether built environment factors such as density and land use mix, and access to public transit contribute to variation in BMI among adults over the age of 50 years in Erie County, New York. Erie County is located in western New York State and has a 2007 estimated population of 913,000 (U.S. Census Bureau, 2007). Buffalo, the largest city in the county and the second largest city in New York State, has a 2007 estimated population of 264,000 (U.S. Census Bureau, 2007). Erie County has a higher share (31.3 percent) of adults age 50 or more years than the national average (27.2 percent). The population in Erie County is mostly White or African American with a small share describing themselves as Asian, American Indian, or as Pacific Islander. Older adults in Erie County have lower incomes than the national rate, although poverty rates are similar (U.S. Census Bureau 2000).

Individual level data are collected using a survey designed to assess lifecourse decision-making among older adults in Erie County. The survey collected basic demographic information as well as information about behaviors, tastes, and perceptions as they relate to lifestyle and finance. While the term "older adult" usually refers to individuals age 65 and older, our survey recruited subjects age 50 and older—a random sample of phone numbers in Erie County headed by individuals age 50 years or more—as a way to broaden our research scope to assess pre-retirement decision making and behaviors. The sample includes equal shares of subjects in each of four age groups (50 to 64, 65 to 74, 75 to 84, and age 85 or more). We telephoned each subject to verify eligibility and confirm the mailing address. Next, we mailed a paper-and-pencil survey questionnaire to each subject and we received 344 completed surveys for a response rate of 60 percent.[i]

Sample

Descriptive characteristics can be found in Table 2 for the 344 survey responses. After removing surveys for incompleteness (many respondents failed to answer all questions) we identify 207 surveys for detailed study. Survey respondents are overwhelmingly (96 percent) White/Caucasian with an average age of 69 years. Fifty-one percent of respondents are male. In general respondents are well educated with only 6 percent having less than a high school degree and more than 35 percent with a bachelor's degree or higher. The survey is intended to produce a random sample of county residents, and the demographic characteristics of respondents match the demographic profile of Erie County outside the City of Buffalo (including racial composition if Buffalo were excluded from the Erie County measure), but the sample does not match the economic or racial diversity in Buffalo.

[Table 2]

Dependent Variable: BMI

A key focus of inquiry is Body Mass Index (BMI) of survey respondents. In this study, self-reported height and weight are used to calculate BMI using the following formula: weight (lb)/[[height (in)]^2 x703 (Centers for Disease Control and Prevention, 2008b). The average BMI for survey respondents is 27.5 and falls within the overweight BMI range of 25 to 30.[ii] Figure 1 shows a scatterplot of respondents' height and weight as reported in the survey for the full responding sample (n=327). Superimposed on the scatterplot are contours for four World Health Organization health categories (World Health Organization, 2000): in Erie County, 27 percent of respondents are obese (BMI equal to or greater than 30.0), 38 percent of respondents are overweight (BMI between 25.0 and 29.9), 34 percent of respondents are normal weight (BMI between 18.5 and 24.9) and less than 1 percent of respondents are underweight (BMI less than 18.5). Among the Erie County respondents classified as obese, 11 percent are subclassified as morbidly obese (BMI greater than 40.0).

[Figure 1]

Independent Variables

Using previous literature and findings from other studies as a guide, this study uses three vectors of contributing factors believed to influence BMI outcomes: 1) personal characteristics and capacity, 2) neighborhood demographic measures, and 3) transportation, access, and

Table 2. Descriptive Statistics

All survey respondents	344	
Surveys with complete responses for regression analysis		207
Race		
White	96 %	97 %
Non-white	4 %	3 %
Age (years)		
Minimum	50	50
Maximum	90	89
Mean	69	68
Sex		
Male	51 %	56 %
Female	49 %	44 %
Educational attainment		
Less than High school graduate	6 %	5 %
High School Graduate	31 %	33 %
Some college/university (1-3 years)	22 %	22 %
Trade/technical/vocational training	6 %	5 %
College graduate/bachelor's degree	20 %	20 %
Master's degree or PhD or other higher degree training	15 %	15 %

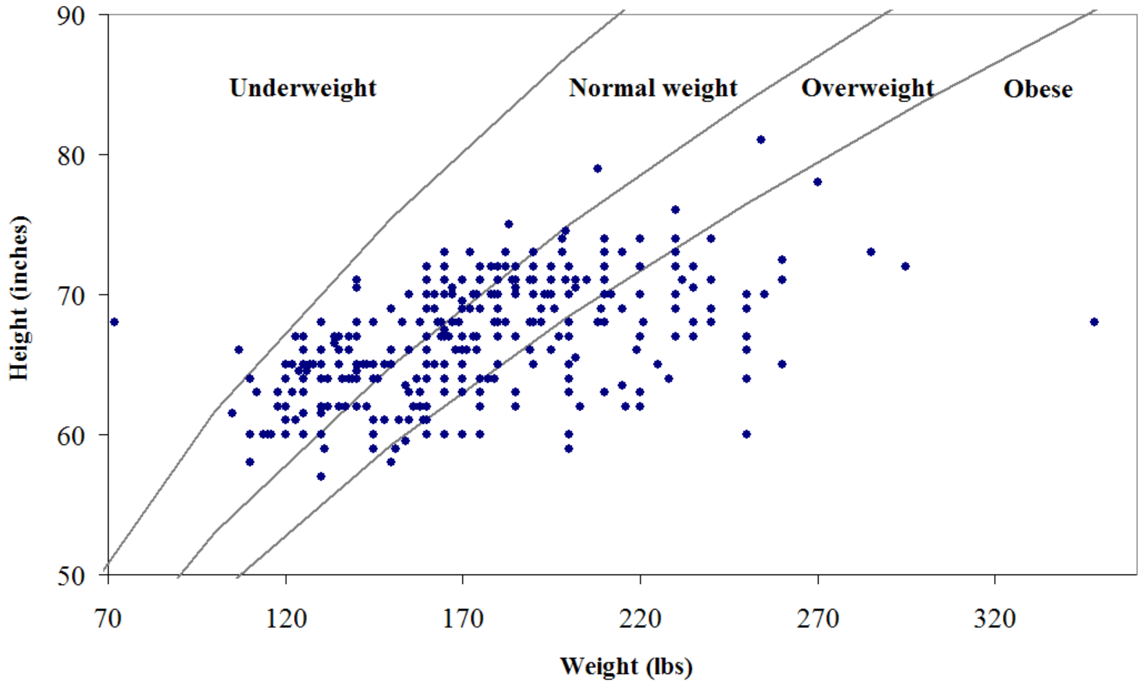

Figure 1. Scatterplot of Height and Weight of Survey Respondents
1 centimeter = 0.39 inch; 1 kilogram = 2.20 pounds

neighborhood urban form measures. Variable definitions and data sources for all variables are presented in Table 3. A summary of descriptive statistics for the variables can be found in Table 4.[iii]

[Table 3]

[Table 4]

Individual Characteristics and Capacity

Individual level information is obtained from survey responses. As previously noted, respondents reported their height in feet and inches and their weight in pounds and BMI is calculated using the standard formula. Respondents were asked to report what year they were born and age is calculated from reference year 2006. Questions about race, sex, and education were also included in the demographic portion of the survey.[iv]

The physical functionality variable is computed as a composite score (unweighted) of respondents' self-assessed ability to perform 15 basic tasks. The survey question asked respondents to respond to the question: "Please indicate how difficult it is to do each of the following tasks. How difficult is it for you to…." by choosing one of the options: "not that difficult, somewhat difficult, very difficult, cannot do, I don't do this activity, or don't know." The 15 tasks relevant to this study are: 1) run or jog about a mile, 2) walk about a mile, 3) walk one block, 4) walk across a room, 5) sit for about 2 hours, 6) get up from a chair after sitting for long periods, 7) climb one flight of stairs without resting, 8) climb several flights of stairs without resting, 9) lift or carry weights over 10 lbs, like a heavy bag of groceries, 10) stoop, kneel, or crouch, 11) reach or extend your arms above your shoulder level, 12) pull or push large objects like a living room chair, 13) balance on one foot for a minute or so without touching any support 14) walk several blocks, 15) pick up a dime from a table. Reponses are weighted equally and summed to create a composite score of physical functionality. A low score indicates a person possesses limited physical functionality, while a high score indicates a person can perform various tasks with ease.

The physical activity variable is used to measure a respondents' level of activity by asking the respondent to indicate the number of days in a typical week he or she exercises or performs a physical activity for at least 20 minutes in duration. The question asked respondents to consider *all* activities during usual weekly routines that made them sweat or breathe hard

Table 3. Variable Definitions

Variable	Operational Definition	Data Source
Dependent Variable		
BMI	body mass index calculated as respondent's weight (lbs) multiplied by 703 and divided by the square of respondent's height (in)	survey
Independent Variables		
Personal Characteristics and Capacity		
age	age of respondent expressed as continuous variable	survey
sex	sex expressed as dichotomous variable: 0=male, 1=female	survey
edu_highschool	education expressed as dichotomous variable: 0=less than high school education; 1=high school education	survey
edu_college	education expressed as a dichotomous variable: 0 = less than high school education; 1 = some college/technical or vocational training/ bachelor's degree	survey
edu_masters	education expressed as a dichotomous variable: 0 = less than high school education; 1 = master's degree, PhD, or other post grad/higher degree training	survey
physicalactivity	number of days in a typical week a respondent exercises or performs a physical activity for at least 20 minutes in duration expressed as a continuous variable from 0 to 7	survey
physicalfunction	composite score of self-assessed ability to perform 15 tasks (run a mile, walk a mile, climb stairs, pick up a dime, etc.) expressed as a categorical variable: 0=don't know or I don't do this; 1 = very difficult, cannot do; 2=somewhat difficult; 3=not that difficult	survey
Neighborhood Demographic Characteristics		
tractrace	white population as share of total population of census tract where respondent resides	U.S. Census
tractincome	median household income of households within census tract where respondent resides	U.S. Census
tractpopdensity	persons per square mile within census tract where respondent resides	U.S. Census
Transportation, Access, and Neighborhood Land Use		
driveless	stated frequency of driving a personal vehicle expressed as a dichotomous variable: 0=never drive; 1 = drive less than once per day	survey
drivemore	stated frequency of driving a personal vehicle expressed as a dichotomous variable: 0=never drive; 1= drive once per day or more	survey
busstops	number of bus stops for all bus routes within half mile radius of respondent	NFTA, GIS calculation
landusemix	index of land use mix within one-half mile radius of respondents (compares land area designated residential use to land area designated for commercial use); ratio ranges from 0 to 1 (1=perfectly mixed (balanced) between residential and commercial land; values that tend toward 0 mean either residential land use or commercial land use dominates (homogenous land use)	GIS calculation

Notes: NFTA = Niagara Frontier Transportation Authority
1 kilometer = 0.62 mile; 1 centimeter = 0.39 inch; 1 kilogram = 2.20 pounds

Table 4. Variable Characteristics

	mean	min, max (st. dev)
Dependent variable		
BMI	27.54	17.27, 52.91 (5.31)
Independent variables		
Individual Characteristics and Capacity		
age	69	49, 90 (11)
sex	0.48	0, 1 (0.50)
edu_highschool	0.31	0, 1 (0.46)
edu_college	0.49	0, 1 (0.50)
edu_masters	0.15	0, 1 (0.36)
physicalactivity	3	0, 7 (2)
physicalfunction	37	20, 45 (6)
Neighborhood Demographic Characteristics		
tractrace	0.91	0.05, 1 (0.17)
tractincome (divided by 1,000)	46	14, 110 (15)
tractpopdensity (divided by 1,000)	4.32	0.06, 18.20 (3.90)
Transportation, Access, and Neighborhood Land Use		
driveless	0.29	0, 1 (0.46)
drivemore	0.63	0, 1 (0.48)
busstops	17	0, 102 (19)
landusemix	0.27	0, 1 (0.25)

including playing a sport, swimming, dancing, housework, or chores. The variable is expressed as a continuous variable ranging from zero to seven with a mean of three.

Area level variables

Individual level data is combined with area level data through geo-coding and geographic analysis. Residential location is assessed as part of the survey by asking a respondent to identify the street on which he or she lives and the nearest cross street. Since the survey is confidential and anonymous, respondents' addresses are not recorded. Street and intersection information is geo-coded using Geographic Information Systems software ArcMAP version 9.2 and spatially linked to census tracts. Figure 2 shows the geographical distribution of respondents throughout Erie County representing urban, suburban, and rural locations. Each dot represents the location of one completed survey and the census tract coverage of the county is shown as background; 13 percent of respondents are located in the City of Buffalo, and the remainder of respondents are scattered throughout the county's suburbs, towns, villages, and rural places.

[Figure 2]

A ½-mile (0.8 kilometer) buffer area is established around each respondent's geographic location to calculate built environment measures such as land use mix and transportation access. A ½-mile (0.8 kilometer) buffer—captures reasonable "walkable" distances for older adults—mirrors previous research using older adults as subjects as demonstrated by Li and colleagues (2004) (see Table 1). Figure 3 shows the land use distribution within a ½-mile (0.8 kilometer) buffer for four place typologies in Erie County.[v] In addition, *residential land use, commercial land use* and *community services land use* is depicted in Figure 3 to demonstrate the variation in land uses. We focus in this analysis on the proportion of *residential land use* and *commercial land use*.

[Figure 3]

Transportation, Access, and Neighborhood Land Use

Within the context of this study, we are particularly interested in the balance between residential land use and commercial land use such as retail establishments, grocery stores, banks, restaurants, and other commercial properties. Using a property tax code spatial data file we categorize parcels by their land use type within the ½-mile (0.8 kilometer) buffer around each

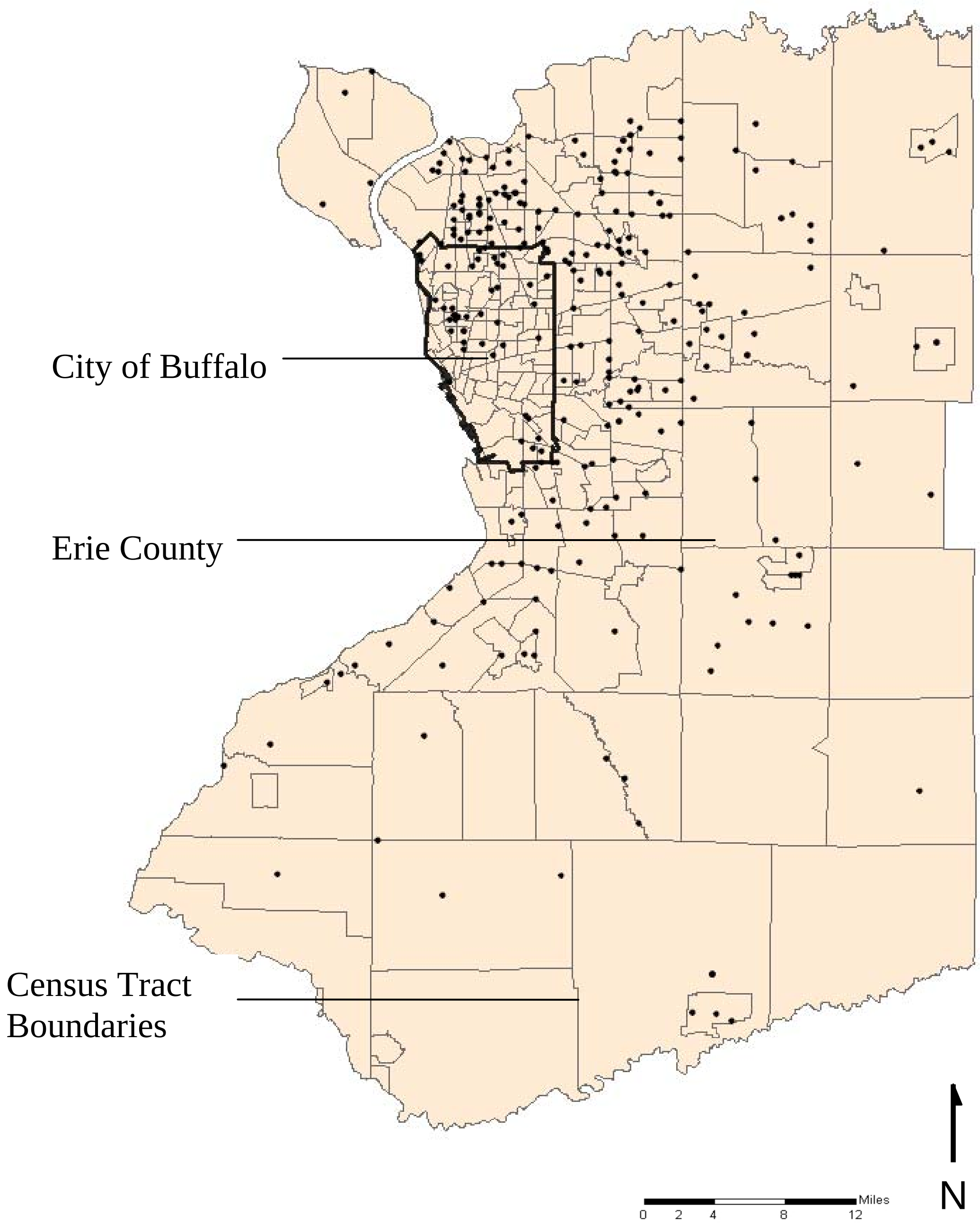

Figure 2. Study Area Map and Location of Respondents
1 kilometer = 0.62 mile

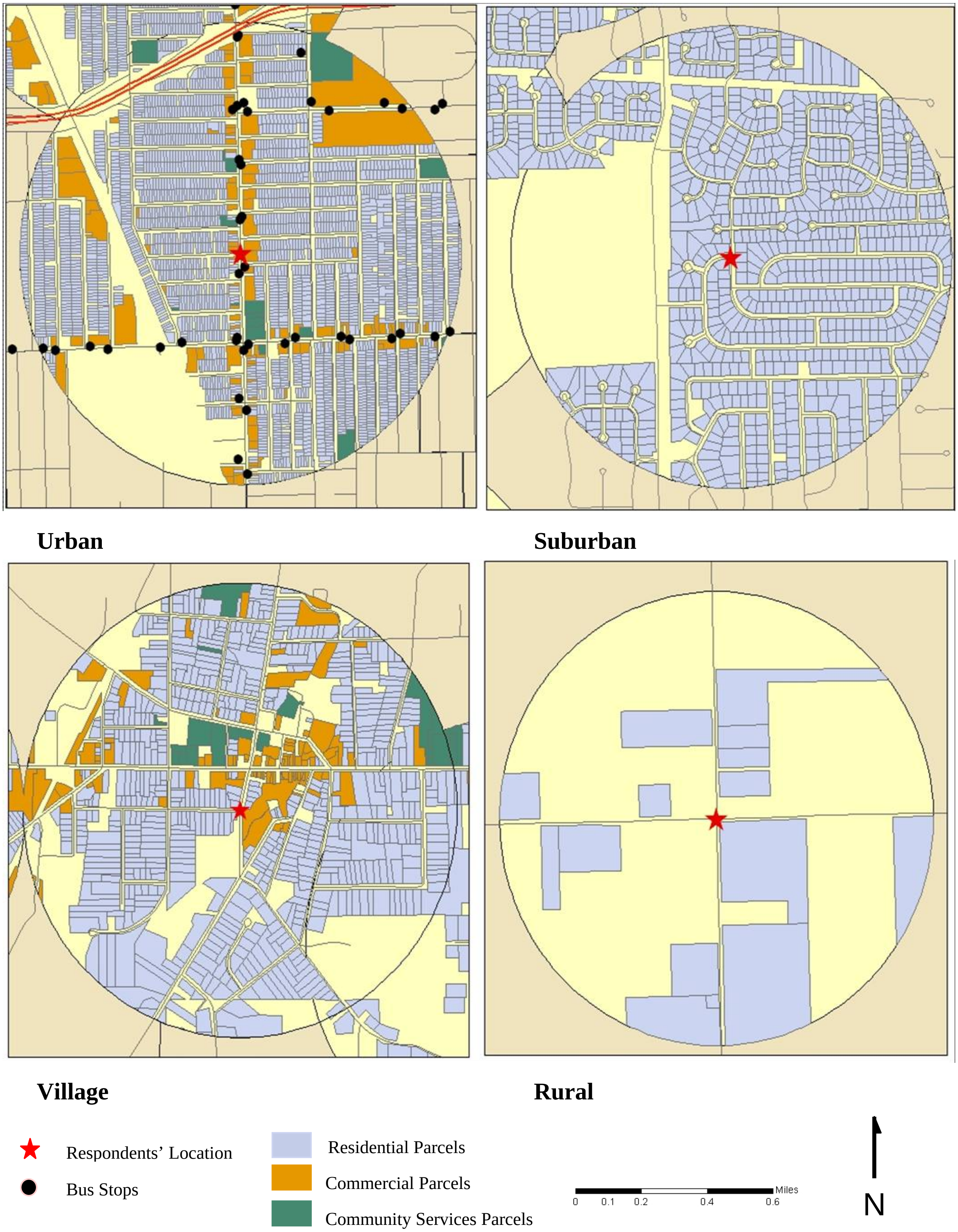

Figure 3. Half-Mile Buffer Areas for Four Place Typologies
1 kilometer = 0.62 mile

respondent's location. The area of residential land use and commercial land use is summed within each buffer area. We calculate the ratio of land area dedicated to residential uses by dividing the residential area by the sum of residential and commercial land area for each buffer area. A ratio of land area dedicated to commercial property is calculated by dividing the commercial land use area by the sum of residential and commercial land uses area. Following previous studies (Frank, *et al.*, 2004; Rundle, *et al.*, 2007) we create a land use mix index ranging from 0 to 1. The two ratios are multiplied together and then multiplied by four. A single value results. A perfectly mixed area is equal to one, suggesting land use area is balanced between residential and commercial properties; scores that tend toward zero suggest that one land use dominates.

Two measures are used to assess transportation access. The first is an individual level variable that reports how often respondents drive a personal automobile. Responses are grouped into two dichotomous variables—those driving less than once per day and those driving once or more per—both compared to a control group who never drive a vehicle. A second variable measures access to public transit as expressed by number of bus stops within a ½-mile (0.8 kilometer) buffer area surrounding a respondent's location.[vi]

Neighborhood Demographic Characteristics

Individuals are influenced by both their physical environment and socioeconomic factors. Data were gathered from the 2000 U.S. Census for census tracts and linked to individual cases through geographic overlay. Neighborhood demographics include median household income and the share of the census tract population that is White/Caucasian.

Population density is obtained from 2000 U.S. Census at the census tract level. The U.S. census calculates population density for each census tract by simply dividing the total population by land area for a census tract. We assigned a census tract population density to each census tract using GIS software; consequently, each respondent is assigned a population density (measured as people per square mile) for a home census tract.

Crime rates (both property crime and violent crime) are omitted from the final model due to poor performance as an explanatory variable. Excluding crime is not meant to suggest that crime does not influence physical activity and BMI, but rather that our data insufficiently demonstrates a relationship due to data limitations.[vii]

Analysis

Individual level survey data is combined with built environment data from geographic analysis conducted using ArcMAP version 9.2. Data are then combined into a single database to allow for regression analysis. Following previous study designs (Li *et al.*, 2005; Frank *et al.*, 2006; Rundle *et al.*, 2007, among others) we use multi-level linear regression modeling to capture individual level effects, such as BMI, and group level effects such as census tract demographics. SPSS version 16.0 is used to conduct statistical analysis and regression modeling. Subjects with missing information for BMI, location intersection, or other information are excluded, leaving 207 observations in the regression analysis. Variables were operationalized and then tested for association with BMI using Pearsons' correlation analysis. Variables with low correlation ($r <$ 0.10) were tested in separate models as predictors of BMI; variables with low correlation and no explanatory power were excluded in the final multiple regression models. In addition, we use Pearson's correlation coeffecient 'r' to evaluate multicollinearity among independent variables. A few desired variables were omitted due to low response for a particular question, such as income, race, and frequency of riding public transit.

FINDINGS

A summary of regression model results can be found in Table 5. The adjusted r-square value suggests that independent variables explain 27 percent of the variation in BMI among older adult respondents in Erie County. Nine variables (including the constant) are statistically significant at the 0.90 level or greater. The positive or negative signs of *statistically significant* estimated regression coefficients are in anticipated directions, confirming hypothesized relationships between dependent and independent variables. The final model indicates that BMI can be partially explained by the confounding effects of age, sex, obtaining a high school diploma, having some college training, physical functionality, share of population within the respondents' census tract that is white, the census tract's median household income, and the number of bus stops within respondents' ½-mile (0.8 kilometer) "neighborhood" buffer. The remaining variables, having a masters degree or higher, amount of weekly physical activity, population density, frequency of driving, and land use mix are not found to be statistically significant, however these variables contributed to the robustness of the model.

[Table 5]

At the individual level, age and physical functionality have a statistically significant relationship with BMI outcomes at the 0.01 confidence level. Age has an inverse relationship with BMI indicating that as people get older their body mass index decreases, all else being equal. As expected, physical functionality has a statistically significant and inverse relationship with BMI. As respondents' physical functionality score increases (suggesting greater ability to perform physical tasks), BMI decreases. The estimated coefficient suggests that as physical functionality score increases by one, BMI will decrease by 0.44, thereby decreasing the chance of being overweight or obese.

Sex and educational attainment have a statistically significant relationship with BMI outcomes at the 0.05 confidence level. The inverse relationship for the dichotomous sex variable suggests that female older adults are likely to have a lower BMI than their male counterparts. The dichotomous educational attainment variables were significant for the high school and college variables suggesting that individuals with at least a high school degree or some vocational training or college degree are more likely to have a lower BMI than those with less than a high school degree. Interestingly, the benefits of educational attainment stop at the college level. Those with a master's degree or higher show no statistically significant odds of having lower BMI than those without a high school diploma.

Perhaps surprisingly, there is no statistically significant relationship between physical activity level and BMI in our model. This is not to suggest that physical activity is not an important variable in influencing BMI levels. Indeed past research (and logic) suggest a strong relationship between physical activity and BMI. Perhaps however, in the subpopulation of older adults, physical activity is less important than other factors.

At the neighborhood level, the share of white population and median household income are found to be statistically significant at the 0.01 level and the 0.10 level respectively. As the share of the census tract population that is white increases by one percent, BMI decreases by 0.088 all other things being equal. Though this variable has a modest impact it is consistent with previous research. Median household income also demonstrates a modest but statistically significant relationship. The estimated coefficient suggests that as median monthly household income increases by $1,000, average BMI for individuals in the census tract decreases by 0.055. Census tract population density shows no statistically significant relationship with BMI.

Table 5. Model Estimation

	Estimated Parameter
Independent variables	
constant	+ 68.343 ***
Personal Characteristics and Capacity	
age	- 0.157 ***
sex	- 1.416 **
edu_highschool	- 3.333 **
edu_college	- 3.397 **
edu_masters	- 1.911
physicalactivity	+ 0.041
physicalfunction	- 0.444 ***
Neighborhood Demographic Characteristics	
tractrace	- 0.088 ***
tractincome	- 0.055 *
tractpopdensity	+ 0.145
Transportation, Access, and Neighborhood Land Use	
driveless	+ 2.343
drivemore	+ 1.555
busstops	- 0.062*
landusemix	- 1.639
Model Characteristics	n = 207
	df = 14
	r^2 = 0.325
	adj. r^2 = 0.276

* $p < 0.10$, significant at the 0.10 level
** $p < 0.05$, significant at the 0.05 level
*** $p < 0.01$, significant at the 0.01 level

The transportation, access, and neighborhood land use variables do not perform as well as neighborhood socioeconomic variables. Driving frequency is not found to be statistically significant, while the number of nearby bus stops is found to be statistically significant at the 0.10 level. There is little variation in the driving frequency variable, which is what likely caused it to not be significant. The number of bus stops has a modest but statistically significant inverse relationship with BMI. As the number of bus stops within a respondent's ½-mile (0.8 kilometer) buffer area increases, BMI decreases, all other things equal. The estimated coefficient suggests that with one additional bus stop within a ½-mile (0.8 kilometer) radius, a respondent's BMI will decrease by 0.06. Although it is a modest impact, it demonstrates that transportation access does indeed influence BMI, possibly through an intervening variable that is not measured here. Finally, the land use mix variable is not statistically significant suggesting that in this sample of older adults, BMI is not influenced by neighborhood land use mix.

CONCLUSION

Overall, our model performs as expected and all independent variables (whether significant or not) matched our hypothesized directional relationships with BMI. In general, the magnitude of observed effects is modest. The results of our regression analysis suggest that individual characteristics and socioeconomic factors play a larger role in determining BMI of older adults than do built environment or transportation factors.

Although the relationship between BMI and built environment has been investigated aggressively over the last few years, scholars have not yet reached a consensus about the significance or magnitude of such a relationship. This inconsistency is further complicated when subjects' age is taken into account. Studies that include adults of all ages (18 and over) typically confirm the relationship between built environment, physical activity, and BMI (Frank *et al.*, 2004; Ewing *et al.,* 2003; Ross *et al.,* 2007; Rundle *et al.*, 2007). When older adults are studied separately, however, the relationship is not as clear. While research confirms that factors of the built environment do influence older adults physical activity levels (Berke *et al.,* 2007; King *et al.,* 2005; Li *et al.,* 2004), findings *do not* confirm a direct relationship between built environment and BMI and older adults. For example, Berke *et al.* (2007) found that built environment is associated with increased walking for exercise among older adults age 65 to 97.

The study found, however, *no* statistically significant relationship between built environment and BMI among the older adults.

In our study, the key built environment variable—land use mix—shows no statistically significant relationship with variation in BMI. This contradicts a number of previous studies that found land use mix to be a neighborhood features that encourages "active travel"—biking or walking to work, for recreation, shopping, or completing other daily tasks—and consequently contributes to an increase in physical activity, overall health, and reduced body sizes (Ewing *et. al.*, 2003; Berke *et. al.*, 2007; Cervero and Duncan, 2003; Frank *et al.*, 2005; Handy *et. al.*, 2002; Li *et. al.*, 2005; Lovasi *et al.*, 2008; Greenwald and Boarnet, 2002; Handy and Clifton, 2001; Frank *et. al.*, 2006).

Unexpectedly, the individual level variable that measures respondents' frequency of driving is not statistically significant. This challenges previous studies that confirm that "passive" mobility (usually driving an automobile as opposed to walking to a transit stop or to work) is associated with an increase in BMI. Our study results thus opposes the findings of Frank *et. al.*, (2004) and Lopez (2004) who document a detectable positive relationship between location in sprawling places (where people depend on automobiles for virtually all travel) and increased body size and risk of obesity as measured by body mass index. Interestingly, previous studies include subjects' frequency of driving indirectly such as assuming that those that live in sprawling areas drive more. When driving frequency is tested on an individual basis it does not appear to be significant. Perhaps the measure used to test people's propensity to drive versus using "active" travel should be developed further in future research.

Our study adds an important and often overlooked built environment variable—access to public transportation. Results of the regression analysis reveals that access to public transportation—measured by the density of nearby bus stops—may play a greater role in predicting BMI of older adults than other built environment measures. This is compelling for two reasons. First, this finding underscores the importance of public transportation as a component of the built environment and physical activity levels of older adults. The significance of this variable suggests future research centered on physical activity, transportation access, built environment, and BMI among older adults is valid and necessary.

Second, bus stop density may be an indicator of other built environment features not captured by the vector of built environment measures, suggesting that a significant relationship between older adults' BMI and built environment may exist. For example, bus stop density could be considered a measure of walkability. Higher bus stop density is often found in neighborhoods with higher population density, a higher density of streets and short blocks, and intersecting bus lines on a network of routes. Lower bus stop density is found in suburban and rural places with longer blocks and less walkability.[viii]

In addition, the bus stop density variable shows great variation across our sample and closely follows the variation in urban, suburban, rural, and village settings of the region. As expected, the urban core of the county and surrounding suburbs contain more bus stops and bus routes than the rural places and villages in Erie County. This variation is captured at the very finite scale of ½-mile (0.8 kilometer) buffers used to define a neighborhood. Variation in population density, however, is not captured at a comparable scale since our population density figures represent the *census tract* population density. This could explain why bus stop density is statistically significant, while population density is not statistically significant. The built environment features of a person's immediate neighborhood buffer may be more accurately captured by bus stop density than population density in our model.

The main limitations of our study relate to our small sample size, which limits the power to determine relationships between certain variables and limits our ability to apply these conclusions to the general population. Urban dwellers and non-whites—likely public transit users—are under-reported in the respondents. Using self-reported (rather than objectively measured) height and weight can be viewed as a limitation of this study; however, the variation of calculated BMI that follows national trends suggests that respondents reported accurate measures—to the best of their knowledge and ability—of height and weight. In addition, using self-reported height and weight to calculate BMI is common practice within literature about urban planning and health outcomes (Frank *et al.*, 2004; Giles-Corti and Donovan, 2003; Frank *et al.*, 2006; Ewing *et al.*, 2003).

Other potential weaknesses of the study include the use of self-reported data, recall bias, and possible response bias. This study does not control for self-selection among the respondents. That is, a willingness to engage in active transportation (and conversely, a desire for automobile dependency) may influence housing location choice. Older adults with greater proclivity for walking may live in neighborhoods where there are more convenient and comfortable walking environments.

Our future research will seek to link behaviors with outcomes, and we would like to add access to healthy food and eating behavior to our dataset. We urge more research about how built environments—including analysis at a fine-grained neighborhood scale—influence physical activity and BMI for older adults, as healthier older adults are more likely to be independent, and independence enhances quality of life and increases longevity. Furthermore, understanding the link between access to public transportation and older adults' physical activity levels provides a robust field of future research. This research should be conducted for geographic scales (neighborhoods, districts, municipalities) that researchers believe are appropriate for intervention.

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[i] Initial contact was made from a purchased name and telephone directory. Consequently, demographic information is not available for those to whom a survey was mailed but a response was not received.

[ii] The survey data compares reasonably well to local data from the Western New York Public Health Alliance shows that 2.4 percent of the population in Erie County is underweight, 39 percent is healthy weight, and 37 percent is obese (Western New York Health Risks Assessment, 2008).

[iii] In Table 4, the tractrace mean of 0.91 differs from the race variable in Table 3 because most of the 207 survey responses used in the regression analysis are located in areas dominated by Whites (182 of 207 responses (or 88 percent) are located in census tracts that are 84 percent or more White. Because not all Erie County census tracts are represented in the group of responses used for regression analysis, tractrace is higher than the county share of Whites.

[iv] Respondents were asked to indicate their individual and annual household income. Unfortunately the response rate for this question was low and consequently the measure could not be included in the final sample in order to preserve sample size. Median household income for the respondent's census tract is used in place of individual income.

[v] The four settings are discussed in clockwise fashion beginning with the upper-left hand corner. The urban site is located in Buffalo 4.3 miles (6.9 km) northeast of Buffalo's CBD (landusemix = 0.47; residential density = 6.8 dwelling units per acre). The suburban site is located in Amherst 13.5 miles (21.7 km) northeast of Buffalo's CBD (landusemix = 0.00; residential density = 2.3 dwelling units per acre). The rural site is located in Eden 24.6 miles (39.6 km) due south of Buffalo's CBD (landusemix = 0.00; residential density = 0.5 dwelling units per acre). The village site is located in Spring 30.4 miles southeast of Buffalo's CBD (landusemix = 0.54; residential density = 0.25 dwelling units per acre). Note: 1 acre = 0.40 hectares.

[vi] Bus stop locations are obtained from spatial data files from the Niagara Frontier Transportation Authority (the region's public transit agency) and joined to the ½-mile buffer overlay resulting in a count of bus stops.

[vii] While crime data is available at the census tract level for the city of Buffalo (Buffalo Police Department, 2004), crime data is only available in aggregate for municipalities (towns or villages outside the City of Buffalo) in the remainder of Erie County. Consequently, crime rates would be assigned for respondents across large land areas, masking variation within each municipality; some respondents are located in places outside a municipality for which a crime rate can be calculated, and assigning these respondents a general Erie County crime rate introduces inaccuracy.

[viii] This reasoning is confirmed by Rundle and colleagues (2007) in a study that included bus stop density as a built environment variable. When tested in univariate regression models bus stop density is negatively associated with BMI, however in a multivariate regression model which included bus stop density and population density, bus stop density is insignificant while population density remains significant. In addition, bus stop density and population density are highly correlated (0.25) in their correlation analysis suggesting multi-collinearity between the two variables (Rundle *et al.,* 2007). Despite problems with multi-collinearity, Rundle and colleagues (2007) cite bus stop density as an important

factor in predicting BMI: “Although the variation in BMI across census tracts represents only a modest portion of the total variation in BMI, individuals living in tracts with higher population density, greater density of subway and bus stops, and a more even mix of residential and commercial land uses had significantly lower BMI compared with other New Yorkers” (Rundle *et al.*, 2007, p. 331).