Research Articles

Obesity Relationships with Community Design, Physical Activity, and Time Spent in Cars

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Background: Obesity is a major health problem in the United States and around the world. To date, relationships between obesity and aspects of the built environment have not been evaluated empirically at the individual level.

Objective: To evaluate the relationship between the built environment around each participant's place of residence and self-reported travel patterns (walking and time in a car), body mass index (BMI), and obesity for specific gender and ethnicity classifications.

Methods: Body Mass Index, minutes spent in a car, kilometers walked, age, income, educational attainment, and gender were derived through a travel survey of 10,878 participants in the Atlanta, Georgia region. Objective measures of land use mix, net residential density, and street connectivity were developed within a 1-kilometer network distance of each participant's place of residence. A cross-sectional design was used to associate urban form measures with obesity, BMI, and transportation-related activity when adjusting for sociodemographic covariates. Discrete analyses were conducted across gender and ethnicity. The data were collected between 2000 and 2002 and analysis was conducted in 2004.

Results: Land-use mix had the strongest association with obesity (BMI≥30 kg/m^2), with each quartile increase being associated with a 12.2% reduction in the likelihood of obesity across gender and ethnicity. Each additional hour spent in a car per day was associated with a 6% increase in the likelihood of obesity. Conversely, each additional kilometer walked per day was associated with a 4.8% reduction in the likelihood of obesity. As a continuous measure, BMI was significantly associated with urban form for white cohorts. Relationships among urban form, walk distance, and time in a car were stronger among white than black cohorts.

Conclusions: Measures of the built environment and travel patterns are important predictors of obesity across gender and ethnicity, yet relationships among the built environment, travel patterns, and weight may vary across gender and ethnicity. Strategies to increase land-use mix and distance walked while reducing time in a car can be effective as health interventions.
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Introduction

In the United States, obesity has steadily increased from the 1980s across all states, genders, age groups, ethnicities, and education levels.[1] There are, however, significant disparities in the prevalence of obesity by ethnicity, with blacks—especially black women—more likely to be obese than their white counterparts.[2,3] Estimated at 31% of U.S. adults,[2] obesity is commonly associated with poor health status.[3] With an estimated 280,000 deaths of U.S. adults per year attributed to obesity,[4] overweight and obesity have been found to be significantly associated with diabetes, high blood pressure, high cholesterol, asthma, arthritis and poor health status.[5] Obesity-related morbidity was estimated to account for 9.1% of total annual U.S. medical expenditures in 1998.[6] Modest but attainable increases in the level of physical activity, especially for those who are currently inactive or sedentary, could have important positive health effects. For instance, one estimate predicts that these diseases would be reduced by almost one third if the most inactive portions of the population increased their activity levels.[7]

Recent research has begun to focus on the link between public health and the built environment in an effort to combat increasing rates of overweight and obesity found in many Westernized nations.[8] The urban planning and transportation literature has investigated the relationship between the built environment

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and transportation mode choice, including walking and bicycling,[9,10] and research in leading medical and public health journals advocates increased walking and bicycling as good forms of moderate-intensity physical activity to improve public health.[11–13] Public health practitioners have also begun working with researchers in urban planning and related fields, and several resulting studies are beginning to bear fruit.

In a recent national study, Ewing et al.[14] found that the probability of being overweight or obese, and to a lesser extent of being physically active, is significantly associated with the overall urban form of the county in which a person lives. This important study controlled for education, a strong covariate of income, but did not control for income due to missing data, which would have significantly reduced the power of the analysis. The aggregate data used in this study required that the built environment be measured at the county level. The walkability of the built environment varied considerably from one neighborhood street to the next, suggesting that whole counties may not capture the unique urban form stimuli experienced by each person at their place of residence.[15] This study did not test the differential effects of these urban form features on population subgroups, such as by gender and ethnicity.

The present study provides a much more localized, observation-specific assessment of urban form relationships with transportation activity patterns and obesity, adding new information by looking at the effects by ethnicity and gender, while controlling for age, education attainment, and, for the first time, by income as well.

An increasing body of evidence shows that the physical design of the places where people live and work affects their overall travel choices and how much they walk or bike for utilitarian travel.[10,16–21] Research thus far has had limited ability to show any causation between environmental correlates and transportation-related physical activity levels.[19] To date, little research has been performed that uses individual-level data and objective measures of the built environment at a scale relevant to those individuals. One recent study[22] used objective physical activity data and environmental characteristics based on perceptions of study participants and found significantly higher physical activity levels and lower obesity in a more walkable environment. Even though we address some of these limitations, the current cross-sectional study also cannot show causation.

Methods

This analysis used cross-sectional travel survey data from the Strategies for Metro Atlanta's Regional Transportation and Air Quality (SMARTRAQ) study and included 10,878 participants. Study participants were recruited from the 13-county Atlanta region, using a computer-aided telephone interview that screened and selected people based on household income, household size, and residential density (the number of households per square kilometer) in which the household was located. Recruitment based on household size and income was consistent with the state of the art for self-reported household travel surveys, and with subsequent analysis techniques derived from the sampling plan for this study.[23] Phone numbers were obtained through a commercial reverse directory of listed phone numbers and addresses, and computer-generated phone numbers based on area codes.

Table 1. Net residential density for Atlanta region

	Atlanta region		SMARTRAQ sample	
	Percent	Cumulative percent	Percent	Cumulative percent
0≤2	75.6	75.6	37.8	37.8
2≤4	17.5	93.1	27.7	65.5
4≤6	4.4	97.5	15.9	81.4
6≤8	1.2	98.7	6.7	88.1
>8	1.3	100	11.9	100

Sources: U.S: Census 2000, and Atlanta Regional Commission 2000 land cover data.
SMARTRAQ, Strategies for Metro Atlanta's Regional Transportation and Air Quality.

The introduction of residential density as a stratification tool was new to this study. The 13-county region in Atlanta, Georgia has a low proportion of high-density, mixed-use, interconnected environments that support walking for utilitarian travel.[24] An oversampling in higher-density locations was done to ensure a statistically significant sample of households within a range of different types of urban environments. *Net* residential density—the number of households divided by the land area within residential use—provides a proxy for mixed use and street connectivity. The distribution of households for the region and the sample across net residential density is shown in Table 1.

Most noteworthy was the limited number of observations to draw a sample from the higher limits of the residential density continuum: a comparison of residential density with other regions documents that Atlanta is a very low-density environment.[14,24] All observations were weighted accordingly, based on density and sociodemographic covariates. Weights were developed based on the actual distribution of households in the 13-county Atlanta region by residential density, and for each sociodemographic covariate using data from the 2000 census. The response rate was calculated for recruitment and retrieval of data. The overall response rate was determined by multiplying the two resultant rates. The recruitment rate was 44.8% and the retrieval rate was 67.8%, for an overall rate of 30.4%. The 2000 U.S. Census and land use data from the Atlanta Regional Commission and parcel level land use data developed for the project were used in a geographic information system (GIS) to measure net residential density.

Gender and Ethnicity Classification

In this study, the relationship between urban form and health was directly assessed across ethnicity (black and white) and gender. Previous studies have reported significant differences in obesity rates between ethnic and gender categories, where black females have higher obesity rates and different levels of

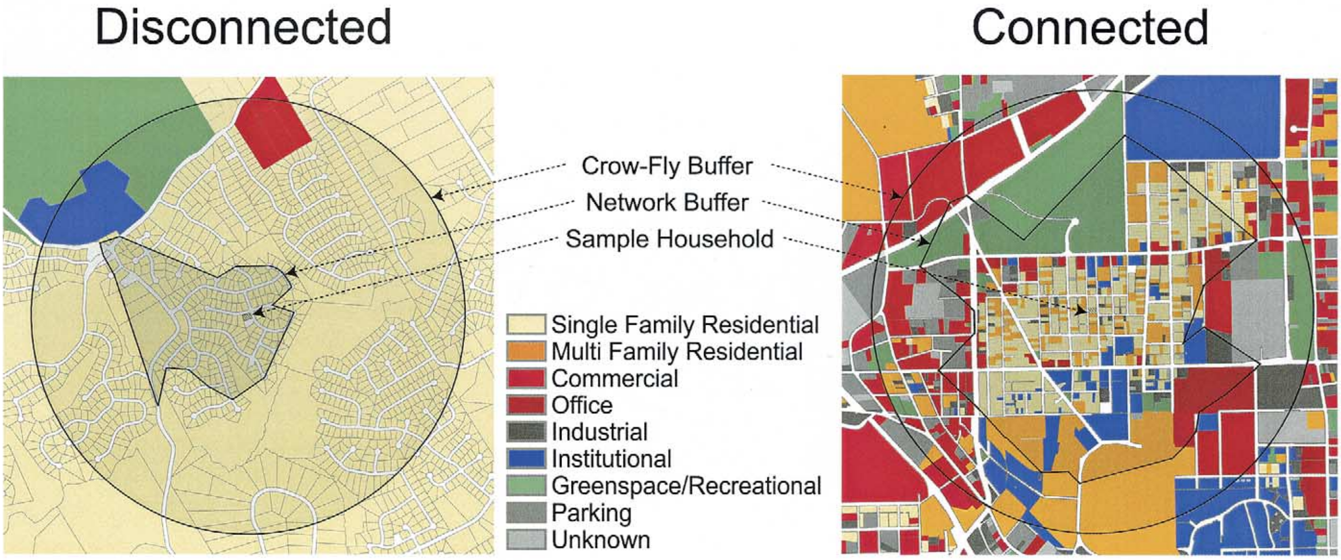

Figure 1. Disconnected and connected community environments.

risk factors for obesity.[2] Ethnic/gender combinations were controlled using dichotomous variables indicating black male, black female, and white female; white male was the reference category. These four ethnic/gender classifications comprised 91% of the entire sample and a similar proportion of the region's population. The remaining 9% were excluded from the analysis.

Dependent Variable

Height and weight were self-reported. Obesity was measured using the body mass index (BMI), or weight in kilograms divided by height (in meters) squared. Obesity was defined as BMI≥30.[25]

Independent Variables

Sociodemographics. Sociodemographic variables were self-reported. Previous studies have found that sociodemographic variables are strongly associated with travel mode choice (e.g., drive, walk, cycle).[26–29] To measure the independent effect of urban form on the probability of being obese, we controlled for age, education, and household income. Age was measured in years as a continuous variable; education was coded as ordinal (high school, high school graduate, some college, vocational/technical, undergraduate degree, graduate/professional degree); and household income was ordinal, with eight categories (0–19,999, 20,000–29,999, 30,000–39,999, 40,000–49,999, 50,000–59,999, 60,000–74,999, 75,000≥100,000). A positive relationship was expected between obesity and age, and a negative relationship between obesity and education and household income.[2]

Physical activity. Two indicators of transportation-related activity levels were used: (1) time spent in a car (car time), and (2) distance walked. Data were obtained to support these two measures through a 2-day travel diary, which is the standard practice for collecting travel data.[23] Car time as passenger or driver was measured in minutes and, as a sedentary form of behavior, expected to have a positive association with obesity. Conversely, the number of kilometers walked (distance walked) is an active form of transportation, and was expected to have a negative association with obesity.

Car time and distance walked were calculated using GIS software, ARCINFO Workstation 8.01 and Custom Visual Basic Programming with Map Objects (ESRI Inc., Redlands CA), and a street network. For each trip, the origin and destination obtained from the self-reported travel diary were placed on the street network. The shortest path between the origin and destination was found, and actual network distances were calculated for each trip. Expected travel times were developed based on time of day and direction of travel to capture actual facility performance (e.g., congestion level), using data from the Atlanta Regional Commission's Regional Travel Model.

Built Environment Measures

County-level tax assessor's data, regional land use data from digital aerial photography, street network data, and census data were spatially integrated within a GIS to measure urban form characteristics for each household. Household-specific buffers have been used in urban form and travel behavior research.[30] Figure 1 conveys the 1-kilometer network buffer size around a household within a disconnected urban environment (small buffer) and a household within connected (large buffer) urban environment. Connectivity and mixed use were measured within the 1-kilometer network buffer around each respondent's place of residence, while net residential density was measured at the census block-group scale. These variables are described in greater detail below and are the most common measures of urban form in the travel behavior literature.[10]

Connectivity. Connectivity equals the number of intersections with more than three legs per square kilometer within the household buffer. Street networks capture the degree to which destinations can be reached in a direct, rather than an indirect pathway, and predict the relative ease of walking, which is highly sensitive to distance.[19]

Net residential density. Net residential density equals the number of persons per residential acre within the household's census block group. Block groups allow census data to be used for population estimates and are a far a more accurate data source than data available at the 1-kilometer buffer level. Research has demonstrated that density promotes transit ridership and walking as a transportation mode and was, therefore, expected to have a negative impact on obesity.[17–19]

Land-use mix. The measure of land-use mix follows:

$$(LUM = -\sum_{i=1}^{n} p_i \ln p_i \Big/ \ln n),$$

where p_i is the proportion of estimated square footage attributed to land use i, and n is the number of land uses. The measure represents the evenness of distribution of square footage of development across four types of land uses within a 1-kilometer distance from each participant's household. The four land uses used to calculate this measure were residential, commercial, office, and institutional. The proportion of estimated square footage obtained from the county tax assessment database (proportional to the size of the network buffer) controls for land uses within the network buffer that were not considered to encompass walkable destinations such as industrial areas. This method of measurement prevents an area that is evenly distributed with respect to the four land uses, but has a relatively small area occupying this mixed use to have the same value as an area that is also evenly distributed with respect to the four land uses, but has mixed land use over a relatively larger portion of the network buffer. Land-use mix ranges from zero to one, with zero representing a single land-use environment, such as a purely residential neighborhood, and one representing a perfectly even distribution of square footage across all four land uses with several destinations within walking distance. Mixed land use has been found to be a good predictor of pedestrian travel.[16,18,31,32] The hypothesis was that individuals living in households located in areas with more commercial and other nonresidential land use walk more to accomplish their daily activities, get more physical activity, and are less likely to be obese. Therefore, land-use mix was expected to have a negative association on obesity. Mixed land use was organized in quartiles for the logistical regression model analysis.

Statistical Analysis

Logistic regression was employed to test the impacts of specific measures of urban form on a dichotomous measure of BMI, obese or not, using a general-to-specific testing methodology for the final model selection. All variables presented here were included in the original model. Insignificant variables were removed based on both individual and joint significance testing, using a critical p value of 0.05 for variable retention in the final model. Vehicle ownership rates and having a driver's license were also tested. A parametric approach using a Pearson correlation test was employed to assess the linear relationship between urban form, a continuous measure of BMI, time spent in a car, and distance walked for each gender/ethnicity classification when adjusting for age, income, and education attainment. Mean BMI values were then calculated across the ranges of land-use mix, net residential density, and street connectivity.

Results

Sample Characteristics

Table 2 shows the descriptive statistics by gender/ethnicity classification for BMI, and the independent variables in the final estimated model. The mean BMI was highest among blacks, with the average for all groups being 25.6; 33% of those observed were classified as overweight (BMI of ≥25 and <30), and 17% of those observed were classified as obese (BMI≥30). As stated above, education and income were measured as categorical variables. The average black person had some technical/vocational training and an income range of \$40,000 to \$49,999, and the average white person had some college and an income range of \$60,000 to \$69,999. The average walking distance was greater for blacks than whites. Of those people who reported any walking (12.9% of blacks and 6.3% of whites), the average walking distance per day was 2.52 kilometers for blacks, and 2.33 kilometers for whites. The number of minutes spent in a car as either a passenger or driver was higher among whites. More than 1 hour per day was spent in a car across all ethnic/gender categories, and the standard deviation for time spent in a car was >1 hour for all four groups combined, with 31% of the sample spending >90 minutes per day in a car. Land use mix was markedly low, with an average of 0.15 when its possible maximum was 1.

Odds of Obesity

The weighted results of the final logistical model estimating the odds of being obese are presented in Table 3. The connectivity and net residential density variables were eliminated from the final model by use of significance testing at the 95% confidence level (CI) (p =0.05). The insignificance of connectivity and net residential density in the final model was, in part, due to spatial collinearity between land use mix and net residential density (Pearson r =0.64) and street connectivity (Pearson r =0.46). A combined measure of the three urban form variables was tested and found to be insignificant. Age, education, and income remained in the final model, and the associations were in the expected direction. Walk distance also remained in the model, with each kilometer walked translating into a 4.8% reduction in the odds of being obese (odds ratio [OR]=0.95; CI=0.91–0.99). Time spent in the car as a passenger or driver was positively associated with obesity, and an additional 60 minutes per day in the car translated into an additional 6% odds of being obese (OR=1.001; CI=1.001–1.002). Each quartile increase

Table 2. Descriptive statistics

	Mean	SD	Minimum	Maximum
Black males (weighted *n* = 1519)				
Body mass index	27.31	4.97	15.25	42.6
Age	41	15.99	16	95
Income ($)	45,000.00	20,000.00	<10,000.00	>100,000.00
Walk distance (Kilometers)	0.25 [2.39][a]	1.27	0	20
Car time, minutes/day	64.15	66.37	0	535
Land-use mix	0.148	0.08	0	0.63
Black females (weighted *n* = 2245)				
Body mass index	27.21	5.52	14.11	42.51
Age	41	16.87	16	96
Income ($)	35,000.00	20,000.00	<10,000.00	>100,000.00
Walk distance (Kilometers)	0.38 [2.59][a]	1.67	0	20
Car time, minutes/day	60.24	61.44	0	565
Land-use mix	0.147	0.07	0	0.63
White males (weighted *n* = 3504)				
Body mass index	26.83	4.37	12.01	42.6
Age	46	15.25	16	96
Income ($)	65,000.00	20,000.00	<10,000.00	>100,000.00
Walk distance (Kilometers)	0.15 [2.51][a]	1.20	0	20
Car time, minutes/day	80.38	64.46	0	631
Land-use mix	0.13	0.08	0	0.64
White females (weighted *n* = 3630)				
Body mass index	23.99	4.55	10.97	42.51
Age	47	16.33	16	99
Income ($)	65,000.00	20,000.00	<10,000.00	>100,000.00
Walk distance (Kilometers)	0.15 [2.18][a]	1.21	0	20
Car time, minutes/day	71.82	53.58	0	483
Land-use mix	0.13	0.08	0	0.63

[a]Figures in brackets represent average walking distance for those who actually walk.
SD, standard deviation.

in land use mix was associated with a 12.2% reduction in the odds of being obese (OR=0.878; CI=0.839–0.919).

The effects of land use mix, time spent driving, and distance walked on the probability of being obese are shown in Figures 2, 3, and 4, each holding the other variables constant at their average values in the model. Unlike the results presented in Table 3, the logistical regression results shown in Figure 2 are based on a model that employs a continuous measure of mixed use. The change from a land use mix of zero (residential only) to the average land use mix in the region (0.15) decreases the odds of obesity for the average person by 4.65%. Increasing the land use mix to 0.25, the 90th percentile in the Atlanta metropolitan area, decreases the odds of obesity by 6.85%. Although these

Table 3. Logistic regression estimation results with obesity (body mass index ≥30) as dependent variable

	Coefficient	SE	WALD	*p* value	OR	95% CI
Age (years)	0.012	0.002	6.00	<0.000	1.012	1.009–1.015
Education[a]	−0.080	0.017	−4.71	<0.000	0.923	0.893–0.954
Income[b]	−0.057	0.012	−4.75	<0.000	0.945	0.923–0.966
Walk distance[c]	−0.049	0.024	−2.04	0.034	0.952	0.910–0.997
Car time[d]	0.001	0.000	2.87	0.003	1.001	1.0001–1.002
Land-use mix[e]	−0.130	0.023	−5.65	<0.000	0.878	0.839–0.919
Black male[f]	0.311	0.079	3.93	<0.000	1.36	1.174–1.585
Black female[f]	0.372	0.073	5.09	<0.000	1.45	1.263–1.665
White female[f]	−0.871	0.073	−11.93	<0.000	0.418	0.364–0.481
Constant	−0.467	0.210	−2.22	<0.026		

[a]Education: 1 ≤ high school, 2 = high school graduate, 3 = some college, 4 = vocational/technical, 5 = undergraduate degree, 6 = graduate/professional degree.
[b]Eight categories (0–19,999, 20,000–29,999, 30,000–39,999, 40,000–49,999, 50,000–59,999, 60,000–74,999, 75,000–99,999, ≥100,000).
[c]Kilometers walked per day.
[d]Minutes spent in car as driver or passenger per day.
[e]Quartiled range from 0 to 1.0.
[f]White male as base category.
CI, confidence interval; OR, odds ratio; SE, standard error.

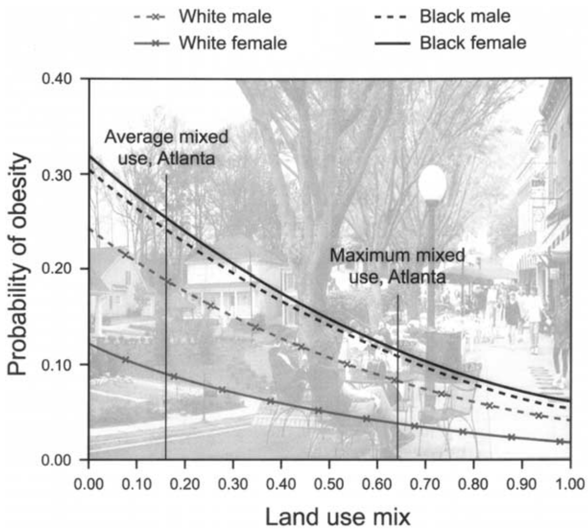

Figure 2. Probability of obesity in relation to land-use mix.

changes appear small, the relative decrease in the actual probabilities of obesity fell by approximately 24% and 35%, respectively. This test suggests that increased land use mix is associated with a greater overall reduction in the probability of obesity among blacks than whites.

Figure 3 shows increased walk distances to be associated with a reduced probability of being obese for all four groups, when holding the other variables constant at their average values in the model. Approximately 544 (0.05%) of the participants walked >1 kilometer, while approximately 130 (0.01%) walked >5 kilometers in a day. These results, based on a logistical regression model, are similar for all four groups, suggesting that there is no interaction between walk distance and these gender/ethnic categories.

Figure 4 shows increased time spent driving to be associated with an increased probability of being obese

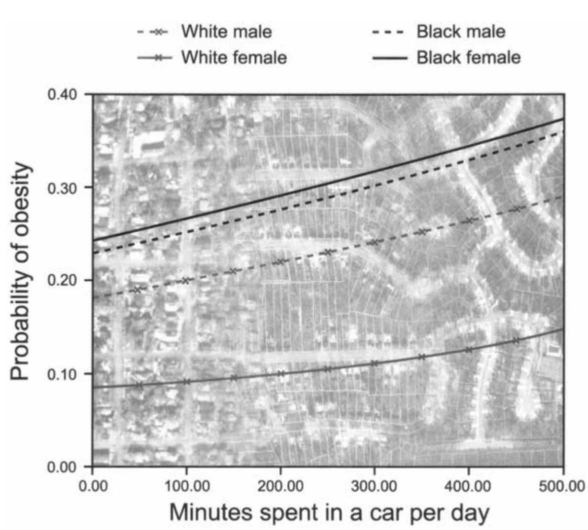

Figure 3. Probability of obesity and distance walked.

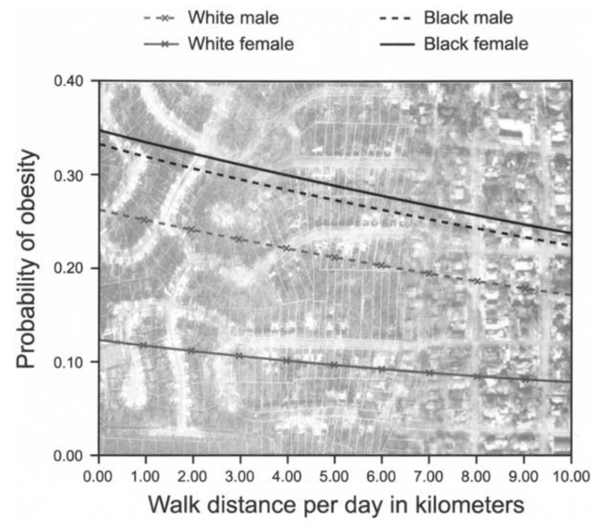

Figure 4. Probability of obesity in relation to time spent driving or as a passenger.

for all four groups, when holding the other variables constant at their average values in the model. Approximately 2265 participants (21%) spent >100 minutes a day in a car, while approximately 648 (6%) participants spent >300 minutes a day in a car.

Testing Specific Gender/Ethnicity Classifications

Linear Pearson correlations (controlling for age, income, and education attainment) were conducted to test associations between a continuous measure of BMI, car time, and distance walked and urban form (mixed use, intersection density, and net residential density) for each of the four gender/ethnicity classifications. The distribution of walk distance and car time is highly skewed in the sample. However, subsequent analyses using nonlinear exponential and natural log transformations of BMI, walk distance, and car time, found little change in the correlations presented below for each of the gender/ethnicity classifications.

Body mass index. Significant negative correlations were found between BMI and urban form for whites, as shown in Table 4. For white males, all three urban form variables—mixed use, intersection density, and net residential density—were inversely correlated with BMI. Mixed use and residential density were negatively associated with BMI for white females. No linear relationships were found between BMI and urban form for blacks in this analysis.

The strongest association between urban form and BMI was for white males. Mean BMI for white males decreased significantly as mix, density, and connectivity increased. As mixed use increased from the lowest to highest quartile, mean BMI decreased from 27.32 to 25.98. As density increased from zero to two, to more than eight dwelling units per acre, mean BMI de-

Table 4. Correlations[a] between urban form, body mass index, walked distance, and car time

	Body mass index		
	Land-use mix[b]	Intersection density[b]	Residential density[b]
Black male			
Weighted n=1514	−0.026 (0.31)	0.010 (0.69)	−0.026 (0.32)
Black female			
Weighted n=2240	−0.039 (0.07)	−0.027 (0.21)	−0.035 (0.09)
White male			
Weighted n=3499	−0.110 (<0.001)	−0.089 (<0.001)	−0.096 (<0.001)
White female			
Weighted n=3625	−0.086 (<0.001)	−0.018 (0.28)	−0.039 (0.02)
	Walked distance, kilometers		
	Land-use mix	**Intersection density**	**Residential density**
Black male			
Weighted n=1514	−0.003 (0.92)	0.00 (0.96)	−0.002 (0.99)
Black female			
Weighted n=2240	0.059 (0.01)	0.051 (0.02)	0.031 (0.14)
White male			
Weighted n=3499	0.046 (0.01)	0.062 (<0.001)	0.050 (<0.001)
White female			
Weighted n=3625	0.051 (<0.001)	0.084 (<0.001)	0.065 (<0.001)
	Car time, minutes per day		
	Land-use mix	**Intersection density**	**Residential density**
Black male			
Weighted n=1514	−0.037 (0.15)	0.004 (0.89)	−0.076 (<0.001)
Black female			
Weighted n=2240	0.042 (0.05)	−0.046 (0.03)	−0.050 (0.02)
White male			
Weighted n=3499	−0.107 (<0.001)	−0.039 (0.02)	−0.074 (<0.001)
White female			
Weighted n=3625	−0.108 (<0.001)	−0.046 (0.01)	−0.090 (<0.001)

[a]Correlations control for age, income, and education.
[b]All p values are reported in parentheses.

creased from 27.13 to 25.91. As connectivity increased from the lowest to the highest quartile, mean BMI decreased from 27.26 to 26.05. Each of these decreases in BMI corresponded with an approximate reduction in weight, from 190 to 180 pounds for a 5’10″ tall white male.

Walk distance. Walk distance was positively associated with all three urban form variables for whites, while land use mix and intersection density were positively associated with walk distance for black females. No linear relationships were found between urban form and walk distance for black males. The distribution of walk distance was particularly skewed, with 87.1% of blacks and 93.7% of whites not reporting any walk distance at all. However, logarithmic and exponential transformations of the walk distance variable resulted in comparable findings.

Car time. Car time was negatively associated with all three urban form variables for whites. Intersection density and residential density were inversely associated with car time for black females, while mixed use was positively associated with car time for black females. Net residential density was inversely associated with car time for black males.

Discussion

Both logistical regression and linear Pearson correlation approaches to data analysis are presented. Logistical regression results, weighted to be generalizable to the Atlanta region’s population, revealed that land use mix, car time, and distance walked were significantly associated with obesity when adjusting for age, income, and education attainment for all gender/ethnicity classifications. While no causality can be affirmed, these results lend considerable support to a very limited evidence base to date linking urban form with activity levels and obesity.[14,22]

Results presented are based on a specific localized assessment of urban form around each participant’s place of residence, and represent an ecologically sound method for assessing interactions between urban form, travel patterns, and obesity.[30] The odds of obesity declined by 12.2% for each quartile increase in mixed use and by 4.8% for each additional kilometer walked, but conversely increased by 6% for each hour spent in a car per day. Furthermore, the proportion of obese persons in the sample declined from 20.2% in the lowest to 15.5% in the highest land-use-mix quartile. These results support the primary hypothesis that increased levels of mixed use and corresponding moderate physical activity (i.e., walking) are associated with reduced odds of obesity. They further affirm that increased time spent driving, a sedentary form of behavior associated with other environmental and economic costs, is associated with increased odds of being obese.

Nonlinear relationships were found between urban form, travel patterns, and obesity for both whites and blacks. However, linear correlation tests using a continuous BMI measure showed significant relationships between urban form (mixed use, connectivity, and residential density) and activity patterns (walk distance and car time) for whites but not for blacks. For white males, BMI declined by >1 across the ranges of mix, density, and connectivity. The stronger associations between urban form and BMI for whites may be a function of the increased correlation between urban form and transportation-related activity patterns for whites. However, different linear relationships between urban form, BMI, walk distance, and car time across ethnicities, or even genders, are more likely a function of a wider set of economic, cultural, genetic, dietary, perceptual, and other daily activity patterns. More research will be required to assess relationships among the built environment, physical activity, and obesity across these and other sociodemographic variables.

We propose that land use mix is an important variable in terms of its association with obesity, but how do the other variables compare to land use mix for the actual implementation of policy? For comparison, we investigated the level of change needed in the independent variables from their average values to decrease the odds of obesity by 5%, holding all other variables constant at their average values. While these observations were based on cross-sectional data, and are generally not feasible, it is salient to reflect on the other options derived from this model, which include a decrease in the average age of Atlantans by 5 years, an increase of the average education level to a college graduate, or an increase in the average income by >$10,000. Increasing walking to about 2 kilometers per day is roughly equivalent to the public health goal of at least 30 minutes of moderate activity. This goal may be achieved through a variety of policy options that include shorter-term incentives for walking for both utilitarian and recreational purposes, and longer-term changes in the built environment, such as increased mixed use, density, and street connectivity that make walking an attractive and viable option. Those who reported that they walked averaged >2 kilometers per day; however, 91.4% of the respondents reported no walking at all during the 2-day survey period.

The average household with a land use mix of 0.15 had 18 nonresidential destinations, whereas the average household with a land use mix of 0.30 had 67 nonresidential destinations in its 1-kilometer buffer. Commercial destinations increased from 13 to 51, respectively. In this study, land use mix was clearly the most important aspect of the built environment related to obesity. The change in land use mix from 0.15 to 0.30, although a substantial increase, was not outside policy control in certain areas of the Atlanta region. Other regions of the country show a much greater land use mix. For example, a study of the central Puget Sound region used a slightly different measure of the evenness of land use distribution, with a range of 0 to 0.845, and found that the land use mix averaged 0.44 to 0.48, or more than half of the maximum value.[32] Even if only the maximum value (0.64) of the land use mix measure in Atlanta was considered, rather than the maximum value (1.0) of the measure itself, the value of 0.30 mentioned above was not exceptionally high.

This model presents the built environment's association with obesity, which is expected to be mediated by physical activity and the sedentary behavior of driving and riding in a car. The results of this model have been favorable from both a theoretical and a policy standpoint, but there has been a somewhat unexpected result: Even when variables capturing one aspect of physical activity were included in the model, specifically walking distance, land use mix was still a significant and meaningful variable. Similar to the finding of Ewing et al.,[14] when the model was run without both of the physical activity variables, the effect of land use mix became greater but only by 5%; thus, physical activity did mediate the effect of the built environment on obesity. As expected, there must be more to land use mix affecting obesity than car time or walk distance.

If it is not just car time or walk distance, then what else is it about land use mix (WALD $=-5.65$, $p=0.001$) that is so strongly associated with obesity? While there are numerous ways in which land use mix may affect obesity, such as access to other forms of physical activity including parks and recreational facilities.[33] Access to food may also play an important role. Based on income levels, poorer areas of cities have fewer food establishments, restaurants, and grocery stores that serve healthy foods,[34] and supermarkets, a source of a variety of healthy foods, are four times more prevalent in white neighborhoods than in black neighborhoods.[34] Although these examples are discussed in the context of income and ethnicity, rather than in an explicit spatial context, they clearly show that there is not an even spatial distribution of healthy food choices within cities. By definition, the land use mix measure used above does measure spatial distribution, and since it includes commercial land use (i.e., food outlets), the land use mix variable may be capturing the availability of healthy food choices near home. Because of the magnitude of the land use mix variable after controlling for physical activity, this issue needs to be addressed in future research.

This study had five main limitations. First, there was a potential for item selection and participation bias and individual item nonresponse. Second, we relied on self-reported height and weight to calculate BMI. Third, Atlanta has a limited range of urban forms; future research on obesity and the built environment should be undertaken in geographical areas with greater urban form diversity. Fourth, the study did not consider time associated with transit use or the relationship among transit service, walking, and driving. Finally, this study used a cross-sectional research design. A longitudinal research design that assesses physical activity and BMI of study participants before and after moving to different types of urban environments, or of residents before and after pedestrian improvements are made to their community, may produce more conclusive results.

This study used individual survey data and land use data at the neighborhood level to evaluate the built environment's relationship with BMI and obesity. Even in one of the most sprawling regions of the nation, people who live in more mixed use neighborhoods are less likely to be obese, drive less, and walk more. Although not all of the variables measuring the built environment were significant predictors of obesity, land use mix has sufficient explanatory power to warrant closer investigation. Future research will necessarily disentangle land use mix into its component parts for policy evaluation, such that the places in which people live, work, and play can have a positive effect on their health.

What This Study Adds . . .

This paper presents the first assessment of urban form around each participant's place of residence, with travel patterns, body mass index (BMI), and obesity status.

It further delves into unique relationships between urban form (land use mix, residential density, and street connectivity) with specific travel choices (distance walked and time spent driving) and BMI by gender and ethnicity.

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