Weight Control; Health Promoting Community Design

The Urban Built Environment and Obesity in New York City: A Multilevel Analysis

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Abstract

Purpose. *To examine whether urban form is associated with body size within a densely-settled city.*

Design. *Cross-sectional analysis using multilevel modeling to relate body mass index (BMI) to built environment resources.*

Setting. *Census tracts ($n = 1989$) within the five boroughs of New York City.*

Subjects. *Adult volunteers ($n = 13{,}102$) from the five boroughs of New York City recruited between January 2000 and December 2002.*

Measures. *The dependent variable was objectively-measured BMI. Independent variables included land use mix; bus and subway stop density; population density; and intersection density. Covariates included age, gender, race, education, and census tract–level poverty and race/ethnicity.*

Analysis. *Cross-sectional multilevel analyses.*

Results. *Mixed land use (Beta = $-.55$, $p < .01$), density of bus stops (Beta = $-.01$, $p < .01$) and subway stops (Beta = $-.06$, $p < .01$), and population density (Beta = $-.25$, $p < .001$), but not intersection density (Beta = $-.002$) were significantly inversely associated with BMI after adjustment for individual- and neighborhood-level sociodemographic characteristics. Comparing the 90th to the 10th percentile of each built environment variable, the predicted adjusted difference in BMI with increased mixed land use was $-.41$ units, with bus stop density was $-.33$ units, with subway stop density was $-.34$ units, and with population density was $-.86$ units.*

Conclusion. *BMI is associated with built environment characteristics in New York City. (Am J Health Promot 2007;21[4 Supplement]:326–334.)*

Key Words: Body Mass Index, Land Use Mix, Public Transit, Population Density, Prevention Research. Manuscript format: research; Research purpose: modeling/relationship testing; Study design: nonexperimental; Outcome measure: biometric; Setting: local community; Health focus: weight control; Strategy: built environment; Target population: adults; Target population circumstances: education/income level, geographic location, and race/ethnicity

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INTRODUCTION

Since the mid-1970s the United States has experienced an epidemic of overweight and obesity.[1] Recent research suggests that built environment characteristics affect rates of obesity by influencing physical activity patterns.[2,3] Urban planning and public health research suggests that pedestrian-oriented environments, characterized by high street connectivity, mixed land use, and high population density, encourage travel by walking and bicycling. Also, by reducing reliance on privately-owned vehicles, the provision of public transit promotes pedestrian activity. The increase in transportation-related activity associated with these characteristics of the built environment contributes to an overall increase in activities related to daily living. In accordance with previous work regarding urban form and travel behavior, recent research finds an association between environmental characteristics such as population density, availability of nearby destinations, and intersection density and both self-reported and objective measures of physical activity, walking, and biking.[4–6] These features of the built environment are thought to increase active transportation and provide independence from the need for private automobiles to accomplish daily tasks and in turn to lower body size.[4,7]

Such data suggest that compared with automobile-dependent environments, pedestrian-oriented environments should be associated with lower rates of obesity. At the state level, Vandegrift and colleagues have found an association between obesity rates and suburban sprawl.[8] Other analyses of county- or metropolitan-level measures of ''sprawl,'' typically associated with automobile-dependent environments, find positive associations between sprawl and body mass index (BMI), adjusting for individual-level characteristics.[3,9,10]

Further evidence for the association between the built environment and body size is provided by two recent studies that included neighborhood-level measures. A study based in Perth, Australia, found that individuals who resided on a highway or a street with either no sidewalk or a sidewalk on only one side of the street, or who perceived an absence of paths within walking distance, were more likely to be overweight.[11] Associations were also found between overweight and reduced access to recreational facilities as well as the perceived absence of shops within walking distance.[11] Another study by Frank and colleagues measured body mass, time spent walking, and time spent in a car among residents of the Atlanta, Georgia, metropolitan area.[7] Positive associations were found between intersection density and walking among white and Black women and white men. An inverse association was observed between intersection density and BMI in white men. Increasing mixed land use, that is, a greater variety of land uses within a neighborhood, was also significantly and inversely related to obesity and BMI. Additionally, more time spent in a car and less time walking were both associated with obesity.

Despite such evidence, many questions remain about the built environment and its relationship to both physical activity and obesity. The work of Cervero and colleagues illustrates the need for closer examination of cross-neighborhood variation within densely populated cities.[12] Most national studies employ measures of the built environment at the county- or metropolitan-level, which fail to capture the variability within cities. Further, most studies that have focused on individual cities are sited in lower-density places such as Austin, Texas; Atlanta, Georgia; and Portland, Oregon.[7,13–15] It is unknown whether variation in built environment characteristics is associated with BMI in densely settled areas such as New York City. It is possible that at an extreme high end of population density, relative variation in built environment characteristics no longer influences physical activity patterns. A firm understanding of how physical activity and BMI associate with variation in built environment characteristics across the range of built environments is required before local policy and planning initiatives can be designed in this area.

METHODS

Design

Using a cross-sectional design, the present study addresses this gap in our knowledge by examining whether built environment characteristics similar to those shown in other locales to be associated with physical activity and/or body size are associated with BMI in New York City. Results presented here are from secondary data analyses of existing survey data on socio-demographic characteristics and objectively measured height and weight obtained from 13,102 residents of New York City. The home addresses of survey participants were geographically linked to census tracts and contextual measures were constructed to examine the association between the individual and urban form. The study used multilevel analysis to relate common indicators of the built environment, such as population density, land use mix, and access to public transit, to BMI, while controlling for individual- and neighborhood-level sociodemographic characteristics.

Sample

New York City, through the Academic Medicine Development Company (AMDeC), set out to establish a prospective cohort study of residents of New York City and the surrounding suburbs.[16] The analyses presented here are of data collected during the baseline enrollment of subjects into the cohort, which is referred to as the New York Cancer Project (NYCP). A convenience sample of 18,187 volunteers was recruited between January 2000 and December 2002. Recruitment took place across the five boroughs of New York City with the goal of recruiting an ethnically and socioeconomically diverse population reflective of the city and its suburbs. Data collection took place at six community-based health centers, two community hospitals, and six medical centers, and through the New York Blood Center. Volunteers who presented themselves at these sites were enrolled. Research staff conducted extensive recruitment efforts in community settings such as health and neighborhood fairs. The study was also extensively publicized in the city to encourage volunteers to participate.[16] Qualifications for enrollment included literacy level high enough to complete a follow-up questionnaire and an age of at least 30 years. At the time of enrollment into the cohort, written informed consent was obtained in person by research staff. The baseline data are maintained by the Herbert Irving Comprehensive Cancer Center at Columbia Presbyterian Medical Center. Analyses of body mass index, individual demographic variables, and appended neighborhood characteristics were approved by the Columbia Presbyterian Medical Center Institutional Review Board.

To investigate how representative the NYCP is of New York as a whole, demographic characteristics were compared to the 2000 Census.[17] Because there are selection processes that influence people to take part in health surveys, comparisons were also made to the 2002 New York Community Health Survey (NYCHS), a random-digit-dial health survey of New Yorkers conducted by the New York City Department of Health.[18]

Measures: Individual Level

Questionnaire data on socio-demographic variables and home address were gathered and height and weight were objectively measured using clinical scales and rigid stadiometers available at the medical centers and hospitals. Demographic data such as age, race/ethnicity, gender, pretax income, educational attainment, and address of residence as well as height and weight measures were available. The questions regarding ethnicity provided two categories for Blacks: African-American and West Indian/Caribbean. For statistical analyses, six categories for racial background/ethnicity were created based on study subjects' response to questions: Asian American; Black—

African American; Black—Caribbean American; Caucasian; Hispanic; and Other race. Response categories for income were: less than $15,000, $15,000 to $29,000, $30,000 to $49,000, $50,000 to $99,000, and $100,000 or more. Categories for educational attainment included eighth grade or less, some high school, high school graduate, vocational school, some college, college graduate, and graduate school. Reliability and validity analyses on the questionnaire were not conducted by AMDeC. Dummy variables indicating income and education were entered into the statistical models. Overweight was defined as a BMI greater than or equal to 25 and less than 30, and obese was defined as a BMI greater than or equal to 30.

Measures: Built Environment

Contextual measures were created within a geographic information system environment and assigned to census tracts. The census tracts used in this project were obtained from a 2003 database created by Geographic Data Technology, Inc. (Lebanon, New Hampshire) and distributed by Environmental Systems Research Incorporated (Redlands, California). Home addresses of participants residing in the five boroughs of New York City (Bronx, Brooklyn, Manhattan, Queens, and Staten Island) were geocoded to longitude and latitude coordinates and matched to census tracts in New York City. Of the 18,187 respondents in the NYCP database, 14,147 subjects were geocoded to census tracts in New York City; the rest lived outside the city. New York City has 2190 residential census tracts in which the 2000 Census recorded the presence of residents who were 30 years of age or older. Of these census tracts, 2008 were represented in the NYCP data set.

Because neighborhood socio-demographic characteristics may predict BMI and also may be associated with built environment characteristics, the analysis included census tract-level poverty rates and racial and ethnic composition (percentage Black and percentage Hispanic) from 2000 Census data. Data sources and variable construction for our built environment measures are described below.

Land Use Mix. Because we were specifically interested in the balance of commercial and residential uses, we created a measure indexing these two types of development. Using tax assessor data, we obtained precise measures of the building area in each tract devoted to commercial or residential uses. Using the sum of commercial and residential building area in each census tract as the denominator, we calculated the ratio of building area devoted to commercial use and the ratio of building area devoted to residential use for each tract. The two ratios were multiplied by one another and then scaled by a factor of four so that the index ranged from zero to one. In a perfectly mixed area—containing equal areas of residential and commercial space—this index is equal to one. If either type of use dominates the index will tend towards zero.[4,7]

Access to Public Transit. Using data from the New York City Department of City Planning, we measured access to public transit by assigning bus stops and subway stations to the census tracts in which they fell and then calculating their density per km^2 in each tract.

Population Density. Population density for each census tract was calculated using Census 2000 population data. The number of residents of each census tract was divided by the land area of the tract. Population density was expressed in residents per km^2.

Intersection Density. The number of street intersections per census tract was calculated using the Department of City Planning LION Single Line Street Base Map files of New York City. A street intersection that occurred where census tracts bordered each other was assigned to each census tract having a border at the intersection. Intersection density is expressed as intersections per km^2.

Analysis

The data had a clustered structure with individuals grouped within census tracts; any given census tract characteristic had the same value for all subjects in that tract. Multilevel analysis was employed, allowing for the simultaneous estimation of the effects of group-level and individual-level factors, accounting for nonindependence of observations within tracts.[19] Statistical analyses of the cross-sectional baseline data were performed using SAS Proc Mixed.[19] As this is not a probability sample, our tests for statistical significance indicate the magnitude and precision of our results. After excluding subjects with missing data for BMI or individual-level demographic characteristics and those with extreme outlying BMI data (BMI $>$70), 13,102 subjects residing in 1989 census tracts were included in the analyses.

The initial analyses tested for associations between BMI and individual-level demographic variables. In separate models, income and educational attainment were both negatively associated with BMI. However, in models including both income and education, income was no longer associated with BMI whereas education remained predictive. Thus, all further models controlled for education. Finally, land use mix, access to public transit, population density, and intersection density were assessed in separate models as predictors of BMI, controlling for individual-level race/ethnicity, gender, age, education, and census tract measures of percentage in poverty, percentage Black, and percentage Hispanic. All multilevel models included a random intercept for each census tract so that the percentage of total variance in BMI explained by between-tract variance could be calculated and so that the percentage of between-tract variance in BMI explained by individual- and tract-level variables could be estimated.[19]

RESULTS

Descriptive statistics for the New York City residents in the study sample are shown in Table 1, as are similar descriptive statistics for New York City residents 30 years or older derived from the 2000 Census and the 2002 NYCHS conducted by the New York Department of Health.[17,18] Compared to Census 2000 data for New York City residents aged 30 and older, the NYCP sample is slightly younger and includes a higher prevalence of women, Caucasians, and individuals with higher levels of educational attainment. Compared to the NYCHS, the NYCP sample has

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Table 1

Characteristics of the Study Population and New York City Overall, As Depicted in the 2000 Census and the 2002 New York City Community Health Survey*

Demographic Variables	Study Population†	Census Data‡	Demographic Variables	Respondents to the New York City Community Health Survey§
Age			Age	
30–39	31	29	30–39	23
40–49	32	25	40–49	19
50–60	25	19	50–60	14
60+	12	27	60+	23
Gender			Gender	
Men	36	45	Men	41
Women	64	55	Women	59
Race/ethnicity			Race/ethnicity	
Asian	12	10	Asian	5
Black—African American	14	25	Black	24
Black—Caribbean	5	NA	Black—Caribbean	NA
Caucasian	47	27	Caucasian	44
Hispanic	20	23	Hispanic	24
Other	2	16	Other	3
Education			Education	
Eighth grade or less	6	13	Less than high school	18
Some high school	7	16	Some high school/ high school degree	26
High school graduate	22	25		
Vocational school	2	NA	Vocational school	NA
Some college	21	20	Some college	20
College graduate	24	14	College or graduate degree	36
Graduate school	18	12		
Body size			Body size	
Underweight (BMI below 18.5)	1	NA	Underweight (BMI below 18.5)	NA
Normal weight (BMI 18.5–24.9)	34	NA	Normal weight (BMI 18.5–24.9)	53
Overweight (BMI 25.0–29.9)	37	NA	Overweight (BMI 25.0–29.9)	33
Obese (BMI 30.0 and above)	28	NA	Obese (BMI 30.0 and above)	20

* Values are percentages of the total population for each data source.
† Sample size of 13,102 study subjects.
‡ Census data restricted to those 30 years of age or older (N = 4,612,166).[17]
§ A random-digit-dial survey of New York City residents aged 18 years or older; analyses of the public use data set were restricted to those respondents 30 years of age or older (N = 7410).[18]

a similar distribution of gender, race, and education, but is somewhat younger, and there is a higher prevalence of overweight and obesity.[18] However, because prevalence of overweight and obesity in the NYCHS is based on self-reported height and weight, there is likely to be underestimation of overweight and obesity. The average BMI for the study subjects in the NYCP was 27.73 with a standard deviation of 5.78. The percentage of New York city residents living in each census tract, as measured by Census data, and the percentage of the study sample with complete data living in each census tract were strongly associated (beta = .96, $R = .61$, $p < .001$), indicating that the NYCP sample is geographically representative.

Table 2 reports means, standard deviations, ranges, and correlation coefficients of the census tract–level variables for the tracts represented in the study. These statistics indicated considerable variation in neighborhood characteristics. Some areas conformed to the popular stereotype of Manhattan, with extremely high population density, mixed land use, and ready availability of bus and subway lines. Others had a lower density and much more limited access to transit. As expected, census-tract poverty rates were correlated with percentage Black ($r = .30$) and percentage Hispanic ($r = .55$). The four built environment variables had relatively modest correlations with each other, between .03 and .31.

The built environment measures were added to a baseline model that included individual-level predictors and tract-level demographic descriptors. Models 1 through 4 add measures of land use mix, access to public transit, population density, and intersection density, examining the effects of each individually. Results of these multilevel models are presented in Table 3, which also shows the predicted difference in BMI associated with a 90th to 10th percentile difference in the predictor variable. In an

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Table 2

Correlations and Mean, Median, Range Values for Census Tract Level Variables for 1989 Census Tracts, New York City

Census Tract Characteristic‡	Correlation Coefficient†								Descriptive Statistics of Census Tracts		
	% Black	% Hispanic	% Poverty	Land use mix	Bus stop density	Subway stop density	Population density	Intersection Density	Mean	Median	Range
% Black	1								27.53%	9.48%	0.00–100%
% Hispanic	−0.10***	1							24.51%	15.67%	0.00–96.10%
% Poverty	0.30 ***	0.55***	1						20.00%	16.93%	0.00–100%
Land use mix	−0.12***	0.17***	0.10***	1					34.54%	27.52%	0.00–100%
Bus stops/km^2	0.01	0.15***	0.17***	0.21***	1				19.82	17.31	0.00–131.87
Subway stops/km^2	−0.01	0.10***	0.12***	0.25***	0.14***	1			1.19	0	0.00–37.15
Population density (10,000 people/km^2)	−0.03	0.32***	0.33**	−0.03	0.25***	0.15***	1		1.95	1.62	0.00–8.87
Intersections/km^2	−0.06*	0.17***	0.09***	0.15***	0.31***	0.09***	0.16***	1	121.07	116.15	5.91–408.33

* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.
† Correlations by Pearson's product moment except correlations with subway stop density, which are presented as Spearman's rho.
‡ Total observations 1989.

Table 3

Adjusted Mean Differences in BMI Associated With One-Unit Differences in Census Tract Built Environment Variables, New York City, 2000–2002†

	Model 1	Model 2	Model 3	Model 4	Model 5
Land use mix	−0.55** (−0.96, −0.14) −0.41				−0.46* (−0.88, −0.04) −0.34
Bus stops/km^2		−0.01** (−0.02, −0.003) −0.33			−0.002 (−0.01, 0.01) −0.07
Subway stops/km^2		−0.06** (−0.10, −0.02) −0.34			−0.04* (−0.08, −0.004) −0.23
Population density (10,000 people/km^2)			−0.25*** (−0.32, −0.18) −0.86		−0.24*** (−0.31, −0.17) −0.82
Intersections/km^2				−0.002 (−0.005, 0.0002) −0.19	−0.0001 (−0.003, 0.003) −0.01
Percentage of between–census tract variation explained‡	77	81	87	77	87

† Data are expressed as beta, (95% confidence interval), and Δ BMI. Beta is the mean difference in BMI for a one-unit change in the predictor variable adjusting for individual level age, race/ethnicity, gender, interactions between gender and race/ethnicity and categories of education, and Δ BMI is the predicted difference in BMI for a 10th to 90th percentile change in the independent variable. BMI indicates body mass index.
‡ Percentage of variation in census tract mean BMI explained by the individual and census tract level variables. Calculated as (between census tract variance from the null model—between census tract variance from the full model)/ between census tract variance from the null model.[19]
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

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unconditional means model the between–census tract variance was statistically significant ($p < .001$), indicating that census tracts differ significantly in average BMI, although census tract–level differences accounted for only a modest 6.0% of the total variance. Table 3 also shows the percentage of the between–census tract variation in mean BMI explained by the individual- and census tract–level predictor variables. To provide context, the variables for age, gender, race, education, and the demographics of the census tract (percentage black, percentage Latino, and percentage in poverty) together explain 77% of the between–census tract variance.

When the built environment measures were introduced separately, land use mix, public transit density, and population density had a statistically significant inverse association with BMI, controlling for the individual-level and census tract socio-demographic characteristics. Model 1 shows that residents of tracts that were more evenly balanced between commercial and residential uses (i.e., had higher values on the land use mix variable) had significantly lower BMI than those in areas that were predominantly residential or predominantly commercial. In model 2, increasing density of both subway and bus stops was negatively associated with BMI. Results from model 3 show that individuals living in areas with higher levels of population density had significantly lower BMI. Model 4 shows that the density of intersections within a census tract was not significantly associated with BMI. In model 5 the association between BMI and all five built environment variables was assessed simultaneously. In this model land use mix, subway density, and population density were inversely associated with BMI and remained statistically significant. Neither bus stop density nor intersection density were significantly associated with BMI in this full model.

DISCUSSION

This study found that measures of urban form similar to those commonly investigated in the literature had a significant association with BMI among residents of New York City, adjusting for individual and neighborhood socio-demographic characteristics. 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— in short, in those tracts that were more pedestrian-friendly—had significantly lower BMI compared with other New Yorkers. From a public health perspective, if each study subject's BMI were reduced by a half unit—a fraction consistent with the magnitude of associations reported in Table 3—an appreciable shift in the BMI distribution would occur. Such a shift would move 10% of the overweight subjects in our sample into the normal BMI range, and 10% of obese subjects would shift into the overweight category. These findings are consistent with current literature relating the built environment to travel mode, physical activity, and obesity; their distinctive contribution lies in showing that these relationships hold within a high-density urban environment. That is, the dose responses seen elsewhere with population density and land use mix persist even in areas that are very densely settled.

Pedestrian behavior and activities of daily living are believed to be influenced by variation in characteristics of the built environment. Specifically, mixed commercial-residential land use that places goods and services near residences and the availability of public transit are thought to promote walking and independence from private automobiles. Accumulating research suggests that increased time spent driving is associated with obesity, whereas increased walking and active commuting are inversely associated with BMI and obesity.[7,20–26] Mixed land use and public transit are thought to be positively influenced by population density, with a density of >3500 persons per square mile posited as the threshold at which residents begin to use nonmotorized means of transportation.[9] Among the 1989 census tracts represented in the data set 98% had a population density that exceeded this threshold. The analyses presented here suggest that the effect of increasing population density on BMI holds even well above the threshold suggested to cause major changes in transportation behavior. Population density remained significantly associated with BMI after control for land use mix and access to public transit, suggesting an effect on BMI that is not explained by the greater land use mix and public transit options promoted by increased population density. It is possible that a higher population density also supports increased recreational opportunities and food outlets offering a better supply of nutritious foods, elements of the built environment not assessed in these analyses that may explain associations between BMI and population density. Alternately, as discussed below, it is possible that the census tract is not the appropriate scale at which to best understand the interrelations between built environment characteristics and their associations with BMI. Increased intersection density is thought to promote walking because it provides more route options and may calm traffic. In our analyses, intersection density did not predict BMI, perhaps because this single measure alone insufficiently describes street design. In other respects, however, the data presented here are consistent with the hypothesis that characteristics of the built environment impact body size through their connection with physical activities of daily living. Other features of the city landscape, for example recreation centers, health clubs, and parks, may impact body size via their effect on planned physical or recreational activities; our future research will examine the influence of these urban features as well.[27,28]

The correlations we observed among the four built environment measures were reflected in weaker associations with BMI in the model including all four measures. The nature of the relationships among these variables is not clear; they could be described as mutual confounders, intermediate variables, or both. For example, public transit may promote mixed land use; alternatively, new commercial destinations may invite expansion of public transit; or the relationship could be reciprocal. When a variable acts as a mediator or as both an intermediate variable and a confounder, entering

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the variable into a statistical model will not control for potential confounding effects, and may obscure associations between more distal predictors and the outcome.[29,30] Thus, the appropriateness of including all four built environment measures in the model in order to provide unbiased estimates of the associations with BMI is in question. In response to this problem, which has been observed elsewhere in the literature, researchers have employed strategies including principal component analysis to define ''walkability'' indexes that merge various aspects of the built environment into a single scale.[3,4,7,12] We expect to pursue this strategy in future research.

A strength of this study is the objective measurement of height and weight, which allows a more valid measure of BMI. Prior descriptive studies of obesity in New York City have relied primarily on self-report[31]; such data may understate true BMI, especially among individuals who are heavier and older.[32–34] The lower prevalence of obesity indicated by New York City Department of Health data may be because of such underreporting.[31] Importantly, underreporting could also result in bias toward the null for analyses of predictors of BMI. Additional strengths of this study are the large sample size, the ethnic diversity of the study population, and the focus on an understudied urban environment. It is one of few studies to link the built environment with either physical activity or obesity in a large, densely-settled city, and to our knowledge it is the only study of its kind to be sited in New York City.

Despite these strengths, the results should be interpreted cautiously. There is an inverse association between socioeconomic status and body size in developed countries, especially among women.[35,36] Here we controlled for the potential confounding effects of socioeconomic status using income and educational level ascertained by questionnaire, in conjunction with census tract-level poverty rate.[37] Simultaneous analyses of variables for income and education as predictors of BMI yielded a significant association only for education. Controlling for education reduced the magnitude of the association between built environment characteristics and BMI, signifying that socioeconomic status acted as a positive confounder. Further control for income had little to no effect on the results. However, controlling for these indicators of socioeconomic status cannot rule out the possibility of positive residual confounding by other aspects of socioeconomic status.

It is recognized that the data are derived from a convenience sample of volunteers and that the idiosyncrasies of volunteer populations may bias results. However, to generate bias, selection forces would have to be related to both body size and neighborhood characteristics. The analyses of population distribution by census tract in the 2000 Census and the study population show that the study subjects are geographically representative of New York City. Table 1 also shows that the socio-demographic characteristics of the study subjects are similar to those of the city overall, as measured by the 2000 Census.[17,18] Our study population has a higher prevalence of Caucasians and women than the 2000 Census, but this is typical of health-related surveys.[38] The prevalence of Caucasian respondents in the 2002 NYCHS is 47% and the prevalence of women is 60%, and this is consistent in subsequent annual surveys.[18] Table 1 shows that the NYCP population is very similar to the NYCHS respondents, who took part in a random-digit-dial–based health survey designed to include a representative sample of New York City. In fact, despite its convenience sample, it appears that the NYCP sample represents a reasonable demographic and geographic cross-section of New York City residents.

An additional concern, particularly in the more densely-settled sections of New York City, is that census tracts represent relatively small geographic areas. The median size of the tracts in our study area is .18 km^2, with the 10th percentile being .13 km^2 and the 90th percentile being .60 km^2. Past work on health disparities has shown that associations between area socioeconomic characteristics and health outcomes are stronger for smaller area units such as census tracts.[37,39,40] However, the use of very small area units may not be appropriate and may result in misspecification of the area unit most relevant for physical activity. Urban planners assume that pedestrians will readily walk one quarter mile (.4 km). Thus, from any point within a median-sized census tract of .18 km^2, locations in adjacent tracts are close enough to be within walking distance. Likewise, commercial locations are often concentrated on major avenues; when census tracts are small, they may not adequately reflect the mixture of land uses within walking distance of a residence. Future research will develop alternative contextual measures based on larger-size radial buffers or gravity-type measures.

We also plan to further examine our measure of mixed land use. As in some previous research, the measure used here indexes the balance between commercial and residential land uses.[4,7] As such, tracts that are less mixed are treated as equivalent whether they are highly residential or highly commercial. Increased mixing of commercial and residential land uses is thought to increase active transportation because it places goods and services within walking or bicycling distance. However, areas that are distinct in their predominant land use may also differ in dietary resources, opportunities for exercise, and activities of daily living. Future work will develop neighborhood typologies that distinguish between predominantly residential and predominantly commercial areas.

Finally, the current study is observational and based on cross-sectional data, which raises a number of caveats. The built environment variables depict an individual's census tract at the time of enrollment, regardless of length of residence at that address. A high BMI, however, may reflect years of positive energy balance; we lack information on the neighborhoods in which our study subjects may have lived over those years. Furthermore, we lack data about the built environment surrounding individuals' places of work and other key destinations within the city. Another caveat related to the cross-sectional nature of the data is that it cannot be discerned whether built environment factors cause individuals to maintain a lower body weight or whether health-conscious individuals with lower body weights choose to live

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in neighborhoods with particular built environment characteristics. Built environment characteristics may merely cause a sorting of certain types of individuals into particular areas. Thus, proposed public health interventions targeting built environment factors may reshuffle people across neighborhoods without impacting the overall prevalence of obesity. The last caveat is that the study subjects vary considerably in their age, and the etiology of high BMI may vary across birth cohorts. In a purely cross-sectional study birth cohort effects may bias results and may not be fully controlled for by adjustment for age and socioeconomic factors.[41] Like nearly all studies in this literature, our analysis does not demonstrate a causal relationship between environmental characteristics and individual outcomes. However, it does provide a strong rationale for further prospective or time series studies that allow for stronger causal inference.

A causal demonstration that the urban environment influences patterns of diet, physical activity, and body mass would provide policy strategies for tackling the problem of obesity and associated health issues. Making automobile-dependent environments less obesigenic is a daunting and expensive task, but may be cost-effective in environments such as New York City that already have a public transit infrastructure. Feasible near-term policies might aim to improve connectivity of bus routes, enhance frequency of bus and subway service, and reduce fares. Additionally, proposals to construct new subway lines, or to extend existing lines, may include cost-benefit analyses of the impact on obesity.

Cities might aim to promote mixed land use and increase population density through the renovation of vacant or underused land and the redevelopment of brownfields. Encouraging mixed land use in established neighborhoods may be accomplished by relaxing zoning regulations to allow for commercial development and introduction of recreational facilities. Zoning may also be useful in avoiding giant superblocks that create dead space and hinder pedestrian activity. The use of civic institutions as focal centers for neighborhoods may also promote pedestrian activity by creating lively public spaces.

The results of our preliminary research on the built environment in New York City support an association between variation in neighborhood characteristics and body size. Further analyses of other neighborhood characteristics, such as access to parks and recreational facilities, crime rates, and the distribution of grocery stores and fast food restaurants are likely to result in additional recommendations for local policymakers.

SO WHAT? Implications for Practitioners and Researchers

Variation in land use mix, access to public transit, and population density across census tracts are associated with differences in BMI after accounting for personal demographic characteristics and the demographic characteristics of the census tract. These dimensions of the built environment are thought to impact pedestrian travel activity and activities of daily living. The results suggest that transportation policy, zoning, and other city planning policies may offer tools to promote physical activity and encourage maintenance of a healthy body size.

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