Original Article
EPIDEMIOLOGY/GENETICS

Obesity

Built Environment Change and Change in BMI and Waist Circumference: Multi-Ethnic Study of Atherosclerosis

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Objective: To examine longitudinal associations of the neighborhood built environment with objectively measured body mass index (BMI) and waist circumference (WC) in a geographically and racial/ethnically diverse group of adults.

Methods: This study used data from 5,506 adult participants in the Multi-Ethnic Study of Atherosclerosis, aged 45-84 years in 2000 (baseline). BMI and WC were assessed at baseline and four follow-up visits (median follow-up 9.1 years). Time-varying built environment measures (population density, land-use, destinations, bus access, and street characteristics) were created using Geographic Information Systems. Principal components analysis was used to derive composite scores for three built environment factors. Fixed-effects models, tightly controlling for all time-invariant characteristics, estimated associations between change in the built environment, and change in BMI and WC.

Results: Increases in the intensity of development (higher density of walking destinations and population density, and lower percent residential) were associated with less pronounced increases or decreases over time in BMI and WC. Changes in connected retail centers (higher percent retail, higher street connectivity) and public transportation (distance to bus) were not associated with changes in BMI or WC.

Conclusions: Longitudinal changes in the built environment, particularly increased density, are associated with decreases in BMI and WC.

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Introduction

While individual lifestyle changes are necessary for the prevention and reduction of overweight and obesity, policies that change the neighborhood setting may help to create supportive environments that encourage healthy behaviors (1-3). In particular, the built environment, which comprises land-use patterns, the transportation system, and urban design, may encourage physical activity by affecting transportation on foot or by bicycle (4). Studies have shown that Americans are less likely to report having many shops within walking distance or transit stops within 10-15 minutes of their home than their peers in 10 other countries (5,6). As a modifiable component of US communities, the built environment may hold promise for decreasing obesity at the population level by influencing transportation-related physical activity levels.

A majority of evidence linking the built environment to physical activity and obesity remains cross-sectional (7-12). Establishing causation from these studies is problematic as it is impossible to determine whether the built environment encourages health behaviors or whether those with certain health behaviors select residences with certain built environments. Several longitudinal studies have begun to show connections between the built environment and walking (13-20), bicycling (21), and overall physical activity (14,19,22). However, longitudinal studies linking changes in the built environment to changes in obesity remain limited (18,19,23-34). Findings

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from existing longitudinal studies have been mixed, with many failing to detect associations (19,24,26-30,33).

Numerous methodological challenges may impact the utility of the existing longitudinal studies. Several studies examine obesity trajectories in relation to the initial characteristics of a neighborhood environment, giving little insight into the potential impact of changes in the environment on changes in body weight (18,23-25,28,29,32-34). Some rely on residential relocation to examine changes (19,25-27,31), and only one study has examined how longitudinal changes in the environment relate to changes in obesity (30). Few used measured anthropometric characteristics (23,28-30,32-34) or measures of obesity other than body mass index (BMI) (28,33). Moreover, two studies focused on children (23,27), who may be influenced by environmental features in different ways than adults. Additionally many of these studies were limited to non-Hispanic white populations (19,24,28,30) and several to small geographic regions (23,24,28-30,32) or in non-US contexts (18,24,32,34). Additional longitudinal evidence is needed to clarify inconsistencies and to draw firmer conclusions regarding the ways in which the built environment may impact obesity.

This study examines the longitudinal association between the built environment and obesity. To address previous methodological gaps, it uses individual-level built environment measures derived from Geographic Information Systems (GIS), and anthropometric measurements of body mass index (BMI) and waist circumference (WC) in a geographically and racial/ethnically diverse group of middle-age and older US adults. By investigating whether change in obesity outcomes are related to changes in the built environment, this study may clarify the potential causal relationships, giving further insight into the impact of urban planning changes on the health of Americans.

Methods

The sample included participants from the Multi-Ethnic Study of Atherosclerosis (MESA), a study of 6,814 US adults aged 45-84 years without clinical cardiovascular disease at baseline (35). Participants were recruited between July 2000 and August 2002 from six study sites (Baltimore, MD; Chicago, IL; Forsyth County, NC; Los Angeles, CA; New York, NY; and St. Paul, MN). After a baseline examination, participants attended four additional follow-up examinations occurring at approximately 1.5-2 year intervals (Exam 2, July 2002 to February 2004; Exam 3, January 2004 to September 2005; Exam 4, September 2005 to May 2007; Exam 5, April 2010 to February 2012) (35). Neighborhoods were characterized using GIS and linked to MESA households by the Neighborhood Ancillary Study. All addresses were geocoded using TeleAtlas EZ-Locate web-based geocoding software (Lebanon, NH) and addresses were included if geocoding accuracy was at the street or zipcode + 4 level. Of the 6,814 participants recruited in MESA, 6,191 participated in the Neighborhood Study, 6,027 were accurately geocoded, completed at least one subsequent exam, and were not missing information on obesity outcomes or built environment for the exams they attended. Of these, 521 were missing information on covariates (most missing information on total calories consumed), leaving a final sample size of 5,506. The study was approved by Institutional Review Boards at each site and all participants gave written informed consent.

Anthropometric measures

Time-varying BMI (kg/m^2) was calculated from weight measured to the nearest 0.045 kg (0.1 lbs), and height measured to the nearest 0.1 cm. Time-varying WC (cm) was measured at the umbilicus to the nearest 1 cm.

Neighborhood built environment

Based on previous frameworks (36) we investigated six built environment measures across five built environment domains: population density, land-use patterns (zoned retail and residential uses), access to destinations, public transportation, and street patterns (Table 1). Data were obtained from regional governments and commercially available business listings and processed using ESRI ArcGIS 10.1 (Redlands, CA). Neighborhoods were defined as a buffer around participants' addresses. Primary results are reported for 1-mile buffers as they may represent the most salient environment across MESA's diverse urban contexts. Sensitivity analyses were run with $^1/_2$-mile buffers; results were similar and are not presented. When data was not available for a given year, it was interpolated using a linear estimate between the two nearest measurements. Participants who moved outside of the study areas do not have built environment data post-move and are only included in analyses pre-move.

As built environment metrics may be inter-related and highly collinear, principal component analysis was used to identify their underlying factors and compute composite scores. A composite score was created for each factor based on the weighted sum of the standardized items with heavy loadings (>0.5) for that factor (Table 1).

Covariates

Potential covariates were selected a priori and included both baseline time-invariant (age, gender, race/ethnicity, education) and time-varying (income, employment status, marital status, car ownership, self-rated health, cancer diagnosis) covariates. Information on age, gender, race/ethnicity, and education was obtained by interviewer-administered questionnaire at baseline. Race/ethnicity was classified as Hispanic, non-Hispanic white, non-Hispanic Chinese, and non-Hispanic black. Participants selected their education from eight categories which were collapsed into three categories: less than high school, high school diploma/GED but less than college, and college degree or higher. Time-varying income, employment status, marital status, car ownership, and self-rated health were also collected through interviewer-administered questionnaires at each exam. Participants selected total combined family income from 14 categories and continuous income in US dollars was assigned as the midpoint of the selected category. Employment status was categorized as working at least part-time or not (including employed on leave, unemployed, and retired). Current marital status was dichotomized as "currently married or living with a partner" or "other" (including widowed, divorced, separated, and never married). Car ownership for each participant's household was dichotomized as no car ownership (zero cars) or any car ownership (1 car or ≥2 cars). Participants rated their health compared with others their age as better, same, or worse. Time-varying cancer diagnosis was defined as having a hospitalization due to cancer based on ICD-9 code or self-reported cancer at any time before the exam. Missing information on income, marriage, self-reported health, and car ownership were filled in using the closest available time point. To account for changes that may be due to moving, an indicator of whether participants moved between the previous and current exam was created.

TABLE 1 Built environment measures with calculation method and years of data available by MESA site (MESA neighborhood data from 2000 to 2013)

Domain	Measure	Description	Data source	Data available by MESA site[a]	Factor loadings[e] Factor 1: Intensity of development	Factor 2: Connected retail centers	Factor 3: Public transportation
Population[c]	Population density	Population per square mile within a 1-mile buffer of a participant's home	US census	All sites[a] (2000, 2010)	**0.87**	0.28	−0.04
Land-use[c]	% retail	% of area zoned for retail use in a 1-mile buffer around a participant's home	Local planning departments, city governments, and regional entities	CA (2001, 2005, 2008); IL (2001, 2005); MD (2002, 2008); MN (2006, 2009[b], 2010[b]); NY (2002, 2003, 2004, 2006, 2011); NC (2005, 2010)	0.11	**0.85**	0.00
	% residential	% of area zoned for residential use in a 1-mile buffer around a participant's home			**−0.83**	0.03	0.04
Destinations	Walking destinations	Density[d] of walking destinations (count per square mile) within a 1-mile buffer around a participant's home	Derived from Standard Industrial Classification (SIC) codes in the National Establishment Time Series (NETS) database from Walls and Associates	All sites[a] (2000-2010, each year)	**0.88**	0.34	−0.02
Public transportation	Distance to bus	Euclidean distance (in miles) between participants' addresses and the nearest bus route	Local planning departments, city governments, and regional entities	CA (2005, 2007, 2010, 2012); IL (2005); MD (2009); MN (2005, 2009); NC (2001, 2009); NY (2010)	−0.04	−0.09	**0.99**
Street pattern[c]	Network ratio	The proportion of the 1-mile Euclidean buffer covered by a 1-mile network buffer	StreetMap 03 and from StreetMap Premium 2012 (ESRI, Redlands, CA)	All sites[a] (2003, 2012)	0.22	**0.80**	−0.15

[a]Counties included in the MESA Study Sites: Los Angeles, CA (Ventura, Los Angeles, Orange, Riverside, San Bernadino); Chicago, IL (Kane, DuPage, Cook, Will); Baltimore, MD (Baltimore City, Baltimore County); St. Paul, MN (Anoka, Hennepin, Ramsey, Washington, Carver, Scott, Dakota); Forsyth, NC (Forsyth); New York, NY (Queens, Kings, New York, Bronx).
[b]Washington County, MN, is the only MN county with data for 2009. The remaining MN counties have data for 2010.
[c]Linearly interpolated between time points.
[d]Simple and kernel densities of destinations within each buffer were calculated, but measures were highly correlated (Pearson correlation coefficients 0.97 for walking destinations, $P < 0.0001$) so only simple density is shown.
[e]Bold values indicate factor loadings >0.5 and which built environment measures are included in each factor.

It is hypothesized that walking for transport, nutrition, smoking and alcohol consumption are some of the mechanisms through which changes in the built environment may influence changes in obesity (37). Therefore, transport walking, nutrition, smoking, and alcohol were examined as mediators in this analysis. An interviewer-administered questionnaire adapted from the Cross-Cultural Activity Participation Study (38) was used to assess physical activity at Exams 1, 2, 3, and 5. Physical activity questionnaires were not administered during Exam 4, so data was interpolated using the nearest physical activity data. Transport walking minutes per week was assessed as walking to get to places such as to the bus, car, work, or store. Participants were asked whether they engaged in transport walking during a typical week in the past month, how many days/week, and time per day. Total dietary calories (kcal/day) were estimated at baseline from the MESA food frequency questionnaire, which was modified from the Insulin Resistance Atherosclerosis study in which comparable validity was observed for non-Hispanic white, African American, and Hispanic individuals (35). Alcohol use (yes/no) and current smoking status (never, former, or current) were assessed at each exam based on self-report. Missing information on transport walking, smoking, and alcohol consumption were filled in using the closest available time point.

Statistical analyses

Descriptive analyses contrasted participant characteristics across the five exams. Correlation between the built environment factors was relatively low (Pearson correlation coefficients all <0.40 with $P < 0.0001$) so all models are mutually adjusted. Econometric fixed-effects models (39) were used to estimate associations of within-person change in all three built environment factors with within-person changes in BMI or WC. This approach capitalizes on within-person variability in exposure to estimate associations by examining the difference in an exposure with the difference in outcome for a given individual (39). These models were only adjusted for time (to allow for trends over time) and time-varying covariates (income, working status, marital status, car ownership, self-reported health, cancer diagnosis, moving indicator), since fixed-effects models tightly control for time-invariant person characteristics. Fixed-effects models cannot, however, be used to examine time-invariant characteristics. Therefore, baseline time-invariant covariates were tested for interactions with time to allow for different trajectories. Baseline age and race/ethnicity had statistically significant differences in obesity trajectories and interactions between these variables and time were retained in all models. To examine mediation of the built environment factors on obesity, time-varying transport walking, smoking and alcohol consumption were added to a final model. Since food consumption patterns were only available at baseline, diet was treated as time-invariant by using an interaction between baseline total calories consumed and time.

To allow for comparison across built environment factors, all variables were mean-centered and scaled so a one-unit increase was equivalent to one standard deviation (SD). All analyses were conducted in 2013 using SAS 9.2 (Cary, NC).

Results

Participant characteristics

Follow-up time for participants ranged from 1.1 (completing only exams 1 and 2) to 11.4 years (completing through exam 5) with a median follow-up time of 9.1 years (Inter Quartile Range [IQR] 4.6; mean 7.8 years, SD 2.6 years). The number of moves ranged from 0 to 8, with 71.0% never moving, 19.8% moving once, and 9.3% moving $\geq$2 times. Between 6.7% and 11.4% moved between the previous exam and the current one (Table 2). Participants' age at baseline ranged from 44 to 84, with a mean of 62.0 years (SD 10.2). Over time, the sample became slightly more female, non-Hispanic white, with a higher socioeconomic status (higher percent with college education or above and higher income). Smoking and alcohol use declined in the sample and both BMI and WC increased over time.

Built environment characteristics

A three-factor model was chosen for the six built environment measures (Table 1). Initial eigenvalues indicated that the first three factors explained 37%, 19%, and 15% of the variance, respectively. Solutions for two and three factors were each examined using varimax rotations of the factor loading matrix. The three factor solution, which explained 81% of the variance, was preferred because of: (a) the "leveling off" of eigenvalues on the scree plot after three factors; and (b) clarity of interpretation of the factor solution. Three measures (density of walking destinations, population density, and percent residential) were primarily loaded onto the first factor, representing "intensity of development." Two measures (street connectivity and percent retail) were primarily loaded onto the second factor, representing "connected retail centers." Only distance to bus loaded onto the third factor, representing "public transportation." Throughout follow-up, intensity of development generally increased, connected retail centers decreased and public transportation fluctuated, but ultimately increased.

BMI and WC trajectories

At the mean baseline age and the race/ethnicity distribution of the sample, and after adjustment for other individual-level covariates, BMI increased a mean of 0.04 kg/m^2 per 10 years (95% confidence interval [CI]: -0.02, 0.10) and WC increased a mean of 1.60 cm per 10 years (CI: 1.38, 1.82). However, patterns varied by baseline age and race/ethnicity. Higher age at baseline was associated with a less pronounced increase such that at the higher ages no increase over time (or a decrease over time) in BMI and WC was observed (mean differences in 10 year change per SD increase in baseline age: -0.61 kg/m^2 [CI: -0.67, -0.55] and -1.69 cm [CI: -1.89, -1.47] for BMI and WC, respectively). Compared with non-Hispanic whites, non-Hispanic black and Chinese participants experienced less pronounced increases in BMI and Hispanics experienced less pronounced increases in WC (not shown).

Adjusting for time-varying confounders and all measured and unmeasured time-invariant confounders, increases over time in intensity of development was associated with decreases in BMI and WC (Table 3). A SD increase in intensity of development was associated with a mean BMI decrease of 0.15 kg/m^2 (CI: -0.26, -0.05) and a mean WC decrease of 0.46 cm (CI: -0.83, -0.09) even after controlling for the other built environment factors. These changes in BMI are equivalent to 0.40 kg (0.89 lbs) less for an average woman (164.1 cm average height) and 0.48 kg (1.05 lbs) less for an average man (178.2 cm average height). Changes in connected retail centers and public transportation were not associated with changes in BMI or WC at the 0.05 level in models including all built environment features. While change in smoking status and alcohol consumption were

TABLE 2 Selected characteristics of participants at baseline and follow-up exams (MESA, 2000-2012)

	Baseline mean (SD) or percent	Exam 2 mean (SD) or percent	Exam 3 mean (SD) or percent	Exam 4 mean (SD) or percent	Exam 5 mean (SD) or percent
Sample (*n*)	5,506	5,395	5,143	4,825	3,785
Time elapsed since baseline	-	1.6 (0.3)	3.2 (0.3)	4.8 (0.3)	9.4 (0.5)
Age	62.0 (10.2)	63.7 (10.1)	65.1 (10.0)	66.6 (9.9)	70.0 (9.5)
Gender (%)[a]					
Female	52.7	52.6	53.0	53.2	53.6
Race/ethnicity (%)[a]					
Non-Hispanic white	40.2	40.4	40.8	41.0	41.5
Non-Hispanic black	25.6	25.5	25.4	25.2	24.5
Non-Hispanic Chinese	12.7	12.8	12.8	12.6	12.8
Hispanic	21.4	21.4	21.0	21.2	21.2
Education (%)[a]					
HS/GED or less	34.6	34.4	33.9	33.7	31.6
Some college	27.9	27.9	28.2	27.9	28.2
BA or above	37.5	37.7	37.9	38.4	40.2
Income (in thousands)	49.9 (34.3)	49.7 (34.6)	50.1 (34.7)	50.8 (34.8)	53.8 (35.6)
Currently employed (%)	53.9	51.5	50.5	48.1	43.4
Currently married (%)	62.3	62.0	62.5	62.8	59.5
Own at least one car (%)	83.2	83.2	82.6	82.8	85.3
Cancer diagnosis (%)	8.0	9.7	11.3	13.1	15.2
Moved between previous and current exam (%)	-	7.3	8.1	6.7	11.4
Transport walking (min/week)	296.2 (416.5)	251.5 (367.2)	247.9 (366.6)	250.8 (369.2)	303.5 (416.5)
Total calories consumed[a]	1,527.2 (791.7)	1,525.9 (790.8)	1,525.4 (788.3)	1,525.2 (789.1)	1,533.2 (795.4)
Smoking status (%)					
Never	51.0	47.3	46.4	45.8	45.9
Former	36.9	42.1	43.5	45.1	46.8
Current	12.1	10.6	10.1	9.1	7.3
Currently using alcohol (%)	56.48	51.2	49.4	45.1	43.4
Health compared with others					
Better	60.4	60.6	60.3	58.3	59.8
Same	34.7	34.6	34.8	36.8	35.1
Worse	5.0	4.8	4.9	4.9	5.1
Obesity					
Body mass index (kg/m^2)	28.2 (5.3)	28.2 (5.4)	28.2 (5.5)	28.3 (5.5)	28.3 (5.6)
Waist circumference (cm)	97.69 (14.1)	97.53 (14.4)	98.02 (14.4)	98.62 (14.6)	98.87 (14.7)
Change in built environment[b]					
Intensity of development	-	0.1 (0.3)	0.2 (0.5)	0.3 (0.6)	0.3 (0.9)
Connected retail centers	-	−0.1 (0.5)	−0.2 (0.7)	−0.3 (0.9)	−0.6 (1.4)
Public transportation	-	0.0 (0.8)	0.1 (1.0)	0.0 (0.9)	0.1 (1.6)

Abbreviations: BA, Bachelor of Arts; HS/GED, High School or General Education Development; SD, standard deviation.
[a]Gender, race, education, and total calories consumed only measured at baseline. Changes across exams reflect changes in the composition of the cohort not changes in these characteristics at the individual level.
[b]Change in built environment factors since baseline. Created by subtracting factor score at exam 1 from factor scores at exams 2-5.

TABLE 3 Estimated mean change in BMI and WC associated with a standard deviation increase in built environment factors (MESA, 2000-2012 [$n = 5,506$])

	Body mass index (BMI)		Waist circumference (WC)	
	Model 1[a] estimate (CI)	Model 2[a] estimate (CI)	Model 1[a] estimate (CI)	Model 2[a] estimate (CI)
Factor 1: Intensity of development (SD increase)	−0.15 (−0.26, −0.05)	−0.16 (−0.26, −0.05)	−0.46 (−0.83, −0.09)	−0.47 (−0.84, −0.10)
Factor 2: Connected retail centers (SD increase)	0.02 (−0.03, 0.07)	0.02 (−0.02, 0.07)	0.12 (−0.05, 0.29)	0.12 (−0.05, 0.29)
Factor 3: Public transportation (SD increase)	0.01 (−0.01, 0.03)	0.01 (−0.01, 0.03)	0.02 (−0.06, 0.10)	0.03 (−0.05, 0.11)

[a]All fixed-effects models include time-varying working status, current marital status, car ownership, cancer diagnosis, self-rated health compared with others, income, and an indicator of moving between the previous and current exam. Also include a time trend and interactions of time trends with selected covariates (baseline age and race/ethnicity) allowing time trends to vary by these characteristics. Model 2 also includes potential mediators: time varying transport walking minutes/week, time varying smoking status, time varying alcohol consumption status, and an interaction allowing time trends to vary by baseline calorie consumption.

associated with changes in BMI and WC (smokers decreased BMI and WC; current alcohol drinkers increased BMI and WC), they did not change the strength or significance of the association between change in built environment factors and change in BMI or WC. Neither time-varying self-reported transport walking nor baseline total calories were associated with changes in BMI or WC and also did not change the strength or significance of the association between change in built environment factors and change in BMI or WC.

Discussion

This study found evidence of a longitudinal association between within-person change in the built environment and within-person change in measured obesity in a multi-ethnic and multi-city sample. Increases in the intensity of development (higher density of walking destinations and population density and lower percent residential) were associated with decreases in BMI and WC. However, changes in connected retail centers (higher percent retail, higher street connectivity) and public transportation (distance to bus) were not associated with changes in BMI or WC. Associations persisted after controlling for potential mediators and confounders.

By showing an association between change in the built environment and change in BMI and WC this study adds important additional evidence to the complex and inconsistent literature on longitudinal built environment change and change in obesity. The use of a fixed-effect approach provides strong evidence as these models rely solely on within-person differences, effectively controlling for any time-invariant covariates, both measured and unmeasured. The association we found between increases in intensity of development and decreases in BMI and WC is consistent with cross-sectional (18,25,28,34) and longitudinal (18,23,25,31,32,34) evidence showing the importance of the environmental context in maintaining a healthy weight. However, other work has failed to find these associations (18,19,23-34). Our findings that intensity of development (but not connected retail centers or public transportation) influenced obesity may help to explain a lack of consistency in previous work. Of the studies that failed to confirm cross-sectional associations (19,24,26-30,33), several used composite indices of land-use mix, street characteristics, public transit stations, and design elements that may be masking stronger associations with density (28,30). Other analyses were restricted to single elements of the built environment, such as street characteristics (29), which showed no association with changes in obesity in our results. Similarly, some analyses used measures of the built environment at the county level, a scale that may not be relevant to the lives and disease processes of participants (19,27).

In our analyses, further adjustment for mediators (transport walking, total calories, smoking, alcohol use) did not change the strength or significance of the association between change in built environment factors and change in BMI or WC. While this may indicate that changes in density are acting through separate pathways to influence obesity, the intermediate role of transport walking, dietary habits, smoking, and alcohol use cannot be dismissed based on these results as measurement error likely provided incomplete adjustment. Dietary information was only available at baseline and was treated as a time-invariant measure. While it is unlikely total calories consumed changed dramatically within person, changes in BMI or WC may be due to changes in food intake from altered access to destinations. However, since our analyses utilized change in other time-varying mediators within participants, stable over- and under-estimates by a given person will be accounted for. Previously, changes in these built environment measures were shown to be associated with changes in self-reported transport walking in this sample (40). It is possible that changes in these mediators resulting from changes in the built environment are too small to affect weight (e.g., only a slight increase in physical activity). There may also be unmeasured time-varying factors that mediate built environment changes' influence on BMI or WC. Social factors, such as advertisements or pressure to maintain a body type, could change with built environment changes and influence BMI or WC through increased leisure physical activity or reduced caloric intake not captured in the measured mediators. Similarly, unmeasured changes in economic conditions, such as food prices or neighborhood socioeconomic status, may act as potential mechanisms linking changes in the built environment to BMI or WC.

Limitations

Although the use of fixed-effects models is an important advance over prior work, residual confounding by time-varying individual-level factors or other built environment features cannot be completely ruled out. Specifically, change in the built environment may be the result of a move in which an individual is actively seeking a lifestyle change. In addition, equal intensity of development may be attained in different ways and the form of development was not measured or accounted for in these analyses. Several additional limitations are inherent to the built environment data we used. First, we relied on land-use and transportation information collected from various sources at various years. Second, using parcel area for land-use patterns penalizes vertical development (e.g., this method treats a parcel with a four-story building the same way as a parcel with a one-story building). Third, the use of zoning to infer existing land-uses may not accurately reflect what is on the ground. Finally, although sensitivity analyses with 1/2-mile buffers showed similar results, the use of 1-mile buffers may have led to misspecification of the relevant geographic area in some cities. While this study used a multi-ethnic and geographically diverse sample, results may not be generalizable to younger populations or individuals in other cities or countries. Additionally, loss to follow-up may create a more select sample and lead to bias if patterned by built environment and obesity.

Conclusion

This study illustrates the longitudinal association between change in the built environment, particularly increased intensity of development (density of walking destinations, population density, lower percent residential), and decreases in measures of obesity (BMI and WC). However, transport walking, nutrition, smoking, and alcohol use may not be the mechanisms through which increased density decreases BMI and WC. Altering the neighborhood built environment context may be an important point of intervention for obesity. While mean changes in obesity may appear small, the changes in the environment have the potential to influence a broad population, shifting the overall distribution of obesity and decreasing chronic disease burden. By identifying which elements are and are not associated with changes in obesity these results help clarify inconsistencies in prior work. Future research should continue to identify which specific features of the built environment, at what scale, influence which individuals. Continued collaboration between public health and urban planning is essential for clarifying the complex connection between the environments we build and the health of our populations. O

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