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Does change in the neighborhood environment prevent obesity in older women?

Yvonne L. Michael[a,*], **Corey Nagel**[b], **Rachel Gold**[c], and **Teresa A. Hillier**[c]

Yvonne L. Michael: michaely@drexel.edu; Corey Nagel: nagelc@ohsu.edu; Rachel Gold: rachel.gold@kpchr.org; Teresa A. Hillier: Teresa.Hillier@kpchr.org

[a]Department of Epidemiology and Biostatistics, Drexel University School of Public Health, Philadelphia, PA, USA

[b]School of Nursing, Oregon Health & Science University, Portland, OR, USA

[c]Kaiser Permanente Northwest Center for Health Research, Portland, OR, USA

Abstract

Neighborhood environment is consistently associated with obesity; changes to modifiable aspects of the neighborhood environment may curb the growth of obesity in the US and other developed nations. However, currently the majority of studies are cross-sectional and thus not appropriate for evaluating causality. The goal of this study was to evaluate the effect of a neighborhood-changing intervention on changes in obesity among older women. Over the past 30 years the Portland, Oregon metropolitan region has made significant investments in plans, regulatory structures, and public facilities to reduce sprawl and increase compact growth centers, transit-oriented development approaches, and green space. We used geocoded residential addresses to link data on land-use mix, public transit access, street connectivity, and access to green space from four time points between 1986–2004, with longitudinal data on body mass index (BMI) from a cohort of 2,003 community-dwelling women aged 66 years and older. Height and weight were measured at clinic visits. Women self-reported demographics, health habits, and chronic conditions, and self-rated their health. Neighborhood socioeconomic status was assessed from census data. Neighborhood walkability and access to green space improved over the 18-year study period. On average there was a non-significant mean weight loss in the cohort between baseline (mean age 72.6 years) and the study's end (mean age 85.0 years). We observed no association between neighborhood built environment or change in built environment and BMI. Greater neighborhood socioeconomic status at baseline was independently associated with a healthier BMI at baseline, and protected against an age-related decline in BMI over time. BMI decreases with age reflect increased frailty, especially among older adults with complex morbidities. Future research should consider the influence of the neighborhood environment on additional relevant health outcomes and should include measures of the social environment in conjunction with built environment measures.

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[*]Corresponding author: Department of Epidemiology and Biostatistics, Drexel University School of Public Health, 1505 Race St, MS 1033, Philadelphia, PA, 19102, USA, Tel:+1 215 762 3934; fax: + 1 215 762 1174.

Keywords

built environment; neighborhood SES; obesity; aging

Introduction

The impact of neighborhood environmental determinants on health may increase as adults age. As retirees spend more time near home, physical and mental health decline, and social supports decrease (Johnson & Troll, 1994; Shaw et al., 2007), older adults may grow increasingly dependent on their residential neighborhood. A review of the literature on neighborhood effects among older adults suggested that neighborhood environment can be a primary influence on older adults' health and functioning (Yen et al., 2009).

Increasingly, research is investigating the role of neighborhood built environment in physical activity and obesity (Ding & Gebel, 2012). Results from studies conducted in the general adult population suggest a protective effect of walkable neighborhood environments on obesity although interpretation is complicated by limitations in the design and execution of the studies (Feng et al., 2010). Research specific to older adults is more limited (Kerr et al., 2012). While prior cross-sectional studies evaluating environmental correlates of obesity in samples of older adults support a significant association between neighborhood environment and BMI or other measures of obesity (Berke et al., 2007; Eisenstein et al., 2011; Frank et al., 2010; Grafova et al., 2008; James et al., 2013; King et al., 2011; I. M. Lee et al., 2009; Li et al., 2008), results from longitudinal studies are mixed, with studies suggesting no association, a positive association, and a negative association between BMI and characteristics of the built environment (I. M. Lee et al., 2009; Li et al., 2009; Michael et al., 2013; Sarkar et al., 2013).

Any study examining weight change in a cohort of older adults (in our study, adults 72–85 years) must consider two different outcomes: obesity and weight loss. Walkable neighborhood environments may prevent obesity. Approximately 35% of Americans aged 60 years and older are now overweight or obese (Flegal et al., 2010), and older women are more likely to be obese (13%) than are older men (12%) (Flegal et al., 2010). The prevalence of obesity in adults aged 60 and over increased about 35% between 1990 and 2000 (Arterburn et al., 2004; Villareal et al., 2005); since 2000 the increase has stabilized in older women, but continues to rise in older men (Flegal et al., 2010). Unhealthy body weight is strongly linked to poor health outcomes in older adults (Colditz et al., 2004; Grundy, 2000), including increased risk of chronic diseases such as diabetes mellitus (Apovian et al., 2002), coronary heart disease (Grundy, 2000; Vincent et al., 2010), and breast cancer (Colditz et al., 2004). Obesity also increases the risk of disability (Vincent et al., 2010) and is associated with lower overall quality of life among older adults (Yan et al., 2004).

Alternatively, neighborhood walkability may result in attenuation of weight loss in older adults. Despite the increased prevalence of obesity among older adults, weight and BMI generally increase until age 60 and then remain stable (Villareal et al., 2005). Over age 75, weight loss is a marker of frailty (Fried et al., 2004). Modest levels of physical activity may attenuate aging-related weight loss because exercise for this age group keeps them stronger and healthier, rather than reducing BMI (Dziura et al., 2004; Stephen & Janssen, 2010). A recent study found that modest amounts of physical activity attenuated age-related weight loss by approximately 25% in a normal healthy cohort of adults aged 65 years and older (Stephen & Janssen, 2010).

Another major challenge related to interpreting evidence of the influence of the neighborhood environment on weight change is the difficulty in establishing a causal association (Ding & Gebel, 2012). Cross-sectional studies represent the most common source of evidence and do not account for temporal precedence. Neither do these studies generally consider competing explanations of the built environment-physical activity relationship, most importantly neighborhood self-selection: as people may select their residence based on a preference to be active, residential selection may inflate or over-estimate the causal influence of neighborhood features on residents' BMI (Smith et al., 2011; Zick et al., 2013).

Evaluation of natural experiments, including opportunistic evaluations of environmental interventions, are recommended to enhance causal inference (Ding & Gebel, 2012). While some studies have evaluated changes in neighborhood environment as a result of individuals moving, these studies have methodological limitations including self-selection, small samples of movers, short follow-up periods, and focus on movers to new housing developments (Giles-Corti et al., 2013; I. M. Lee et al., 2009). Studies examining impacts of changes to neighborhood design provide a stronger test of the influence on obesity (Durand et al., 2011).

Over the past 30 years, the Portland region and the state of Oregon have made significant investments in plans, regulatory structures, and public facilities to reduce sprawl. The region is governed by Metro, a chartered regional government with elected officials. In December 1994 Metro adopted the Metro 2040 Growth Concept, in which city and county growth plans were required to incorporate such strategies as: (1) compact growth centers, (2) affordable housing, (3) open space development, and (4) transit-oriented development approaches. The light rail system in Portland, significantly expanded during the past decade, is intended not so much as a replacement for cars but as an intervention to increase active modes of transportation, including walking. Additionally, a system of green spaces was developed to protect open space resources within the urban area. These policy developments resulted in measurable changes in the built environment characteristics since the early 1990s (Jun, 2008).

We sought to capitalize on the changes in the Portland region's physical environment. Using Metro's comprehensive regional spatial data and a large cohort study of older women residing in the Portland metropolitan region with longitudinal measures of body size and other health factors, we assessed whether change in the neighborhood environment is associated with change in adiposity, measured by BMI, in older women over an 18-year period.

Methods

Study design

We employed a retrospective cohort design examining concurrent change in BMI and neighborhood built environment over an 18-year period among a sample of older women living in Portland, Oregon. We used geographic information system (GIS) tools to merge historical individual-level and neighborhood data from several sources.

Study population

The Portland cohort of the Study for Osteoporotic Fractures (SOF) in women was the source of participant data. The design, enrollment process, and inclusion criteria have been described previously (Michael et al., 2013; Michael et al., 2011).

Participants' first seven visits occurred between 1986 and 2004. Four percent of the Portland cohort had their baseline visit in 1986, 43% in 1987, and 53% in 1988. At their baseline visit and approximately every two years thereafter, the study participants completed a series of structured interviews and clinical examinations. At baseline, there were 2,422 white, non-Hispanic women in the Portland cohort. Participants were excluded from the present analysis if 1) they resided outside the Portland Urban Growth Boundary (UGB) at baseline, or 2) their address could not be successfully geocoded and linked to a valid address/ coordinates in the Regional Land Information System (RLIS) database. These criteria were technical preconditions for calculating the measures of neighborhood built environment. We were unable to geocode addresses for a total of 34 women (1.4%), and 385 women (15.9%) resided outside of the UGB, resulting in a final sample of 2,003 women at baseline.

Neighborhood-level Measures

Neighborhood-level built environment data were provided by the Data Resource Center of Metro, Portland's regional government. We used historical data from the Regional Land Information System (RLIS), a database created by the regional government in 1988 to support transportation modeling and regional planning applications, supplemented with additional data sources, including Metro Transportation Analysis Zones (TAZ) data (households and employment), Trimet (the regional transit agency) archives, Landsat TM data (used to produce a 1991-based land cover map), and US Census TIGER/Line and block group data from 1990. Drawing on multiple data sources allowed for the construction of built environment measures for the years 1988, 1994, and 1998, and 2002, corresponding to SOF study visits.

Our selection of built environment measures was informed by prior research conducted by our team indicating that older women living in neighborhoods characterized by high population density, high street connectivity, convenient access to amenities, and especially access to transit and commercial areas, were most likely to walk for exercise and transport (Siu et al., 2012). These findings are consistent with prior research finding that infrastructure and design features, such as availability of transit services, relatively short distances from residences to parks and commercial businesses, and high street connectivity, encourage people to navigate around the area (Coogan et al., 2009; Ewing & Cervero, 2010; Frank et al., 2010; Kerr et al., 2012; McCormack & Shiell, 2011; Nagel et al., 2008; M. Wen & Kowaleski-Jones, 2012).

Objective measures of land-use mix, public transit availability, street connectivity, and green space proximity were derived from these historical data sources and linked to participants' residential addresses using a geographic information system (GIS). Land-use mix was operationalized as the Euclidian distance from a participant's residential address to the nearest area zoned for commercial (not including industrial or institutional) use. Street connectivity was operationalized as the density of intersections in a quarter-mile radius around each participant's residence. Availability of public transit was operationalized as (1) the Euclidian distance to the nearest transit stop from the participant's residence and (2) the density of transit stops within a quarter mile buffer around each participant's residence. In calculating the measure of public transit density, a single stop was counted once for each route that it served, to more accurately reflect the availability of public transit choices within the buffer. Green space proximity was operationalized as the Euclidian distance from a participant's residence to the closest edge of the nearest park or green space. Only publicly accessible areas categorized as 'park', 'open space', 'greenway', or 'trail' in the RLIS were included in this measure.

Walkability and access to parks—Each participant's raw score was converted to a decile score. Raw scores at each time point were ranked according to the baseline deciles in order to reflect the degree of change from baseline over time. These decile scores were coded so that a higher score (range 0–9) indicated increasing density (intersection, public transit stop density) or proximity (distance to public transit stop, commercial area, park/green space).

Scores for land-use mix, street connectivity, and public transit access were averaged to create a single index of neighborhood walkability at the time of each visit, with a higher score indicating greater walkability (Cronbach alpha = 0.69). Access to parks and green spaces was retained as a distinct variable.

Neighborhood SES—We constructed a summary measure of baseline neighborhood SES by geocoding participants' residential address at their first visit to the corresponding 1990 block group census measures of unemployment, occupation in managerial or professional roles, poverty, education, median home price, and median household income. These measures were combined into a standardized z-score (Krieger et al., 2002).

Individual-level Measures

Outcome

BMI: The primary measure of participants' body mass index (BMI, kg/m^2) was computed based on weight and height measured in the clinic using standardized procedures at baseline and each follow-up visit. In addition to the continuous measure of BMI used in the primary analyses, categorical indicators of obesity ($BMI \geq 30$), overweight or obesity ($BMI \geq 25$), and underweight ($BMI < 18.5$) were constructed. We also used baseline height to calculate BMI at all visits (rather than updated measured height) in a secondary analysis to evaluate the possible measurement error introduced by age-related height change during follow-up (Hillier et al., 2012). Results using this measure were not different from the measure of BMI using updated height so we report the results from the primary analysis.

Covariates

Age: Participants' age in years at the baseline visit was included in the analysis as a continuous variable.

Educational attainment: At the baseline visit, participants reported the highest year of education they completed and were categorized as completing less than high school, high school graduate, ≤ 3 years college, and ≥4 years of college, resulting in a response scale of 0–4, with a higher score indicating greater educational attainment.

Occupational manual labor: At visit 4, participants were asked a series of questions relating to occupational manual labor. Participants who reported engaging in manual labor 10–20 times per day for at least 10 years were categorized as positive for a history of occupational manual labor.

Comorbid conditions: We assessed the presence of comorbid conditions with a combination of self-report and interviewer assessments at baseline and follow-up. Cancer, chronic obstructive pulmonary disease, diabetes, heart disease, hypertension, myocardial infarction, and stroke were assessed via participant self-report. Cognitive impairment was assessed using the mini–mental state examination (MMSE), with a score of ≤ 20 indicating moderate to severe cognitive impairment (Folstein et al., 1975). Depression was assessed using the Geriatric Depression Scale (GDS), with a score of >5 indicating depression (Yesavage & Sheikh, 1986). Raw counts of comorbid conditions present at the baseline visit and those occurring during the follow up period were included as continuous variables in the analyses.

Smoking: We assessed smoking at each visit. Participants who reported smoking at any visit were classified as smokers. Reported smoking at each visit was used to construct a binary indicator of smoking status at baseline and a binary indicator of continued smoking during the follow-up period.

Average self-reported health: Participants were asked to rate their health relative to others their age as very poor, poor, fair, good, or excellent at baseline and follow-up. The response categories 'poor' and 'very poor' were collapsed into a single category for this analysis, resulting in a response scale of 0–4, with a higher score indicating better health. Both self-reported health at baseline and the average of participants' responses to self-reported health items during the follow-up period were included in the analyses.

Mobility disability: At each visit, participants reported difficulty walking 2–3 blocks on level ground or climbing up 10 steps without resting. A participant who reported significant difficulty or inability to complete either of these tasks at any visit was categorized as experiencing mobility disability. Two binary indicators were constructed for use in this analysis, one indicating mobility disability at baseline, and one indicating mobility disability at any time during the follow-up period.

Data Analysis

We constructed parallel-process latent growth models in Mplus (L. K. Muthén & Muthén, 2010), following a step-wise approach to model the concurrent change in BMI and neighborhood built environment during the study period, and to determine whether changes in the built environment were associated with changes in participant BMI.

First, we constructed linear and quadratic univariate growth models of BMI, neighborhood walkability, and green space proximity, to describe their average trajectories across the study period, determine the degree of intra-individual variation from their mean trajectories, and identify the functional form that best approximated the observed data. Second, we constructed unconditional, parallel-process models of BMI and neighborhood walkability and BMI and proximity to green spaces to examine the association between neighborhood built environment at baseline and baseline BMI and change in BMI over time.

To determine whether change in neighborhood environment during the study period predicted change in participant BMI, the BMI slope factors were regressed on the slope factors for the built environment variable. We added covariates to control for potential confounders of the relationship between BMI and neighborhood built environment. The BMI intercept factor was regressed on age, educational attainment, history of manual labor, and several baseline factors— number of comorbid conditions, self-reported health, smoking status, mobility disability, and neighborhood SES. The BMI slope factors were regressed on age, educational attainment, history of manual labor, number of baseline and incident comorbid conditions, smoking status during follow-up, mobility disability during follow-up, and baseline neighborhood SES. Because the covariates were selected for inclusion in the model based on a priori theoretical concerns, they were retained in the final model regardless of statistical significance. A similar process was used to develop categorical growth curve models to determine whether changes in the built environment were associated with risk of becoming obese, overweight, or underweight during follow-up. Additional models regressed BMI on each of the raw variables included in the walkability index in order to assess the influence of scoring to create a single index on the findings.

We stratified by BMI group at baseline (normal, overweight, obese) to evaluate whether the influence of neighborhood built environment on change in weight varied by baseline status (Lee et al., 2013). This stratified analysis allowed us to distinguish between factors that functioned to protect non-frail "at-risk" overweight women by reducing BMI rather than unhealthy decreases in BMI associated with frailty. In light of prior studies that identified differences in the association between neighborhood built environment and BMI based on neighborhood socioeconomic status (SES) and length of residence (Berke et al., 2007; Casagrande et al., 2011; Grafova et al., 2008; King et al., 2011), we conducted additional analyses stratified by neighborhood SES and moves during the follow-up period. Finally, we evaluated whether mobility status modified the results by excluding any woman with mobility limitation at baseline or at any time point during follow-up (Clarke & George, 2005).

We assessed model fit by evaluating several fit statistics, including the Comparative Fit Index (CFI), the Tucker-Lewis Index (TLI), the Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). For both the CFI and TLI, a value >.95 indicates good model fit. Conversely, an RMSEA or SRMR value of ≤.05 indicates good model fit (Hu & Bentler, 1999; Iacobucci, 2010). Statistical significance for all statistical tests was set at $p<.05$.

Missing Data and Sensitivity Analyses

We calculated the amount of missing data for each variable and tabulated missing data patterns prior to the latent growth modeling analysis. We observed intermittently missing data and data missing due to participant attrition. A conservative assumption is that intermittent missing data and attrition are potentially attributable to distinct missing data mechanisms (Diehr et al., 2005). When the probability of missingness is associated with the unobserved value of the missing variable, non-ignorable missing data can result in biased estimates (Yang et al., 2008). To adjust for ignorable missingness, we employed full-information maximum likelihood estimation procedures that produce unbiased estimates when data are either missing completely at random or missing at random (Enders, 2010). Additionally, we used a pattern-mixture modeling approach to adjust final models for attrition-related differences in BMI trajectory potentially unaccounted for by the models estimated using full-information maximum likelihood (Enders, 2011). We conducted sensitivity analyses by comparing the parameter estimates, standard errors, and plots of the estimated growth curves from full-information maximum likelihood models to pattern-mixture models with differing identifying restrictions—in this instance, the complete case restriction and the neighboring case restriction (B. Muthén et al., 2011).

Results

Descriptive Statistics

Of the 2,003 women in this analysis at baseline, 1,729 (86%) completed 4 visits and contributed an average of six years of follow-up data, 1,369 (68%) completed six visits and contributed an average of 10 years of data, and 700 (35%) completed seven visits and contributed an average of 15 years of data. Similar to other cohorts of older adults, death was the primary reason for loss to follow-up (Hardy et al., 2009). Compared to women who were alive at the end of the study (n=987), women who died (n=1016) were older at baseline (mean age: 74.6 years versus 70.6 years) and more likely to report fair, poor, or very poor self-rated health during the study period (45% versus 40%). Women who died were no different with regard to baseline BMI (26.6 versus 26.5), number of comorbid conditions, neighborhood socioeconomic status, or measures of built environment.

The average age of the study population at baseline was 72.6 ± 5.5 years. While participants reported more than two chronic conditions on average and 42% reported mobility disability, 82% reported their health as excellent or good (Table 1). The average BMI of the sample at each wave is presented in Table 2. A slight trend towards decreased average BMI over time was observed, although the change was quite small.

Neighborhood characteristics—On average, walkability increased slightly over time (Table 3). At baseline, no participant lived more than 1.3 miles from the nearest green space; by 2002, this decreased to 0.9 miles. Similarly, in 1988 all participants lived within 3 miles of the nearest transit stop; by 2002, this distance had decreased to 1 mile. The average distance to the nearest commercial area also decreased. The intersection density increased very slightly, reflecting the relative stability of the street grid over time.

BMI and Characteristics of the Neighborhood Environment over Time

Univariate latent growth models were used to model key parameters over time. The quadratic model was a significantly better fit to the BMI data than the linear model. Average BMI at baseline was 26, above the threshold for overweight. On average, BMI decreased 0.03 percent per year over the study period, although the average change was not statistically significant. Inter-individual variation in baseline BMI and change in BMI over time was significant.

A linear model was fit to neighborhood environment. We observed a small, statistically significant increase in average neighborhood walkability over time and proximity to parks and green space. Variability in baseline and change in neighborhood environment over time were significant. Areas with lower walkability scores at baseline were associated with the greatest improvement over time.

Effects of Neighborhood Environment on BMI Over Time

We observed no association between neighborhood walkability or parks and green spaces and inter-individual variation in baseline BMI or change in BMI over time after adjusting for covariates (Table 4). Results from models using each of the raw built environment variables separately in relation to BMI were not qualitatively different (data not shown). Age, educational attainment, history of manual labor, number of comorbid conditions, mobility disability, self-reported health, tobacco use, and neighborhood SES were significantly associated with baseline BMI. Of those, only education and history of manual labor were not significantly associated with the BMI trajectory over time.

In subgroup analyses by baseline weight status, we observed a marginally significant inverse association between baseline neighborhood walkability and baseline BMI ($B=-.063$, $p=.07$) among the normal weight group only. Change in BMI was not associated with either baseline neighborhood walkability or change in walkability over time among normal weight women. There were no significant associations between BMI and neighborhood built environment among women who were overweight or obese. Additional analyses compared the relationship between BMI and neighborhood built environment among participants who moved versus those who did not, among participants who were obese or overweight versus normal weight, among participants who were free of mobility limitations versus those with mobility limitations, and among participants who lived in low SES neighborhoods versus those in high SES neighborhoods. In each case, associations between built environment and BMI in the subgroup analyses were generally nonsignificant and suggested no meaningful pattern.

Neighborhood SES was negatively associated with BMI at baseline and positively associated with BMI change over time. Greater SES was associated with less decline in BMI during follow-up. In subgroup analyses by baseline weight status, the magnitude of the relationship between baseline neighborhood SES and baseline BMI was greater among overweight/obese women than among normal weight women—B=−.80, p=.001 vs. B=−.39, p=.005, respectively. Similarly, the inverse association of baseline SES and decrease in BMI over time was statistically significant in each subgroup but the decline was greater among overweight/obese women than among normal weight women.

Missing Data Sensitivity Analyses

The parameter estimates and standard errors were similar between pattern-mixture models fit with various identifying restrictions and models without a pattern-mixture component and estimated using full-information maximum likelihood procedures. The results of this sensitivity analysis indicate that attrition-related missingness was adequately accounted for using analytic strategies assuming these data were missing at random (MAR), and suggest that participant BMI was not systematically related to the probability of attrition or that the probability of attrition was also related to other covariates in the model (B. Muthén et al., 2011).

Discussion

We observed no association between neighborhood built environment, or change in built environment, and change in BMI over time among a cohort of older, white, community-dwelling women. The population in this study was overweight at baseline but BMI decreased over the follow-up period. BMI may decrease with age, especially among older adults with complex morbidities (Dziura et al., 2004). Increased neighborhood SES at baseline was independently associated with healthier BMI at baseline and protected against a decrease in BMI over time. In this population of older women with increasing frailty, this may suggest that neighborhood SES mitigates the impact of age-related weight loss.

While land-use mix, connectivity, and overall neighborhood design are important determinants of transportation-related physical activity (McCormack & Shiell, 2011), the results of this research and similar studies suggest these factors are not consistently associated with BMI among older adults. The current results are consistent with null results from three prior longitudinal analyses (Li et al., 2009; Michael et al., 2013; Sarkar et al., 2013). An analysis of a subset of the current study population that used a limited set of measures of built environment and did not consider changes in the built environment reported no association (Michael et al., 2013). Similarly, Li and colleagues reported no overall association between baseline walkability and change in weight or waist circumference in a population of men and women aged 62 years on average (mean BMI = 29.1). However, they reported a significant interaction between physical activity and neighborhood walkability, indicating that living in walkable neighborhoods was associated with a decrease in measured weight and waist circumference during 1-year follow-up among people who engaged in vigorous physical activity (Li et al., 2009). The study by Li and colleagues did not address the question of whether the physical activity behaviors were related to the neighborhood environment in which the participants lived (Michael & Yen, 2009). Also, the population observed in the study by Li et al. was younger and heavier on average at baseline than the population included in the current study. Sarkar and colleagues reported no association between access to green space and change in BMI among older men over a 12-year period (Sarkar et al., 2013).

In contrast, results of two longitudinal studies of older men provide evidence that environments characterized by greater land-use mix and street connectivity are associated with increased BMI over time (I. M. Lee et al., 2009; Sarkar et al., 2013). Sarkar et al. included men living in South Wales at baseline who were younger than our population (mean age of 61.5 years) but similar in BMI (mean BMI = 26.89). Lee et al. included men who were similar in age to our population (mean age of 70 years) but less obese (mean BMI = 24.9) and evaluated change in BMI over a 5-year follow-up period in relation to change in sprawl as a result of a move (I. M. Lee et al., 2009). It is not entirely clear whether the BMI change in these studies reflects an unhealthy increase or an increase consistent with protection against frailty.

Taken in the context of this prior research, our results may suggest that the increased physical activity associated with the built environment among older adults is not sufficient in duration or intensity to translate into reductions in BMI except among those who are the most vigorous exercisers (Fogelholm & Kukkonen-Harjula, 2000; Morabia & Costanza, 2004). Further, because we studied older women, the influence of their naturally occurring increased frailty may overshadow the relatively modest effects of the built environment on weight change. The association between built environment changes and attenuation of weight loss may be stronger among older men.

Rather than a true effect, the absence of significant findings for neighborhood environment may reflect measurement error, selection bias, or uncontrolled confounding. Measurement error in the assessment of neighborhood environment could reflect that we measured the factors of interest with error and/or assessed the wrong built environment characteristics; either error may bias the effect estimate towards the null. The built environment measures developed for this project demonstrated reasonable reliability and validity (Siu et al., 2012). The process of creating an overall score for neighborhood environment may have introduced measurement error and loss of inherent variability of these measures. However, we evaluated each of the raw built environment variables in relation to BMI and the results were not qualitatively different, suggesting that our scoring method is not responsible for the null results. We selected walkability measures based on prior research, availability, and consistency in measurement/assessment across the years of interest. Other measures, including specific amenities, sidewalk quality and connectivity, and safety characteristics, such as adequate lighting, are also relevant, but were not available consistently in the historical data (Kerr et al., 2012; C. Lee et al., 2013).

Limitations

As with any longitudinal study, to the extent that people who were lost to follow-up were systematically different, selection bias would result; if women who died and were thus lost to follow-up were more likely to lose weight and live in less walkable environments, it could bias our results towards the null. Our sensitivity analyses indicate that the lack of observed association between BMI and the neighborhood built environment variables was not explained by bias related to attrition, but this possibility cannot be completely eliminated.

Uncontrolled or residual confounding by a negative confounder could bias the effect estimate towards the null. While we were able to control for a number of important confounders, we were not able to control for the length of time the participants lived in their residence prior to the study period. The direction of any potential bias resulting from prior unmeasured neighborhood exposure is difficult to ascertain. While we were able to evaluate neighborhood SES and control for some individual-level measures of SES including occupation and education, we did not have data on participants’ income or wealth. If wealthy older adults were more likely to live in walkable neighborhoods, the potential beneficial effects of living in a more walkable neighborhood could be attenuated without adequate control for personal income.

Few studies have evaluated neighborhood SES and change in obesity, especially among older adults (Dubowitz et al., 2012; Stoddard et al., 2012). Neighborhood SES is associated with food and recreational resources (Auchincloss et al., 2012), aesthetic quality and natural spaces (Ming Wen et al., 2013), and other aspects of the social environment including neighborhood safety and social cohesion (Franzini et al., 2010; Rios et al., 2012). Perceived neighborhood safety and social cohesion were identified in qualitative research as important correlates of active aging (Michael et al., 2006) but were not available in the current study.

It is important to note that our study population was restricted to older, white women. The effect of neighborhood characteristics on obesity risk may vary by age, gender, and race. Data from a limited number of cross-sectional studies suggest similar associations regardless of age or gender (Kerr et al., 2012; M. Wen & Kowaleski-Jones, 2012), although it is not possible to eliminate some effect modification. A recent cross-sectional study conducted in the Nurses' Health Study reported that age modified the association between sprawl and BMI such that the association was stronger for younger women than for older women, possibly suggesting that older adults' physical activity levels are determined by other non-environmental factors (James et al., 2013). Cross-sectional studies evaluating possible differences by race support significant associations among white participants, but not African-American participants (Frank et al., 2004; James et al., 2013; Lovasi et al., 2009). However, in recent longitudinal research conducted among African American women aged 21–69 living in New York City, Chicago, or Los Angeles, greater neighborhood walkability was significantly associated with walking for transportation, inversely associated with weight gain, and protected against obesity over a six-year follow-up period (Coogan et al., 2009; Coogan et al., 2011). More research is needed that includes diverse populations of older adults given the increasing population of minority older adults in the U.S. (Yen et al., 2009).

As identified by a recent review of research on the built environment, physical activity and obesity (Ding & Gebel, 2012), a primary limitation of the literature is the difficulty establishing causality given the limited number of longitudinal studies and the lack of feasibility of experimental designs. Our study's longitudinal design and repeated measures during a time of change in the built environment provide an advantage over cross-sectional analyses. However, we examined concurrent change in BMI and neighborhood built environment; some neighborhood level changes may not have an immediate impact on some health outcomes, especially those that are not typically quickly modified such as obesity. In this case, our analysis may under-estimate any true effect. Additionally, our design is limited by the absence of a distinct control community. This area of research will benefit from future quasi-experimental designs with appropriate controls. Finally, while our index of walkability is similar to walkability indices evaluated in prior research, future research may consider the development and evaluation of other more policy relevant measures (Siu et al., 2012).

Conclusion

Our results contribute to the understanding of the association between changes in the built environment and changes in BMI in older women. Our findings do not support an association between improvements in the neighborhood built environment and BMI in older, white women over an 18-year period. Importantly this study addresses many of the limitations of prior research through the linkage of repeated objective measures of standard environmental characteristics with repeated objective measures of BMI along with rich information on important covariates, including health status. Longitudinal, quasi-experimental research designs such as this are important to help evaluate possible causal relations between neighborhood environment and health outcomes such as obesity. Future research should consider other demographic groups including non-whites and younger adults. Also, because the importance of built environment variables may differ by health outcome, future research should consider additional health outcomes relevant to older adults, such as mobility (Rosso et al., 2011; Yen et al., 2009).

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- Changes to modifiable aspects of the neighborhood environment may reduce obesity.
- Most studies of the influence of neighborhood environment are cross-sectional.
- Portland region’s changes to physical environment offer unique research opportunity.
- Change in neighborhood built environment was not associated with BMI in older women.
- Greater neighborhood SES protected against an age-related decline in BMI over time.

Table 1

Characteristics of the Study Participants, SOF Neighborhood Study, 1986–2002, N=2003

Characteristic	Mean ± SD or N (%)
Age (years)	72.6 ± 5.5
Education	
Less than high school	445 (22)
High school	749 (37)
At least 1 year of college	807 (40)
History of Manual Labor	383 (26)
Health Conditions	
Cancer	507 (35)
Chronic obstructive pulmonary disease	348 (21)
Congestive heart failure	294 (16)
Cognitive impairment	171 (9)
Depression	564 (30)
Diabetes	258 (13)
Hypertension	1313 (66)
Myocardial infarction	322 (17)
Stroke	398 (20)
Number of Comorbid Conditions	2.1 ± 1.4
Baseline Self-Reported Health	
Excellent	617 (31)
Good	1029 (51)
Fair	325 (16)
Poor/Very poor	32 (2)
Smoke Tobacco	196(10)
Mobility Disability	801 (42)
Moved During Follow-up	848 (42)

Note: Percent is calculated from available data.

Table 2

Mean participant BMI at each visit
SOF Neighborhood Study, 1986–2002, N=2003

	N	**Mean (SD)**	**Range**
Visit 1	2003	26.5 (4.7)	15.2–50.6
Visit 2	1667	26.1 (4.6)	15.6–51.5
Visit 3	1502	26.3 (4.6)	15.1–46.2
Visit 4	1238	26.5 (4.6)	14.7–47.0
Visit 5	1182	26.5 (5.1)	14.5–62.3
Visit 6	928	26.6 (4.8)	12.4–49.3
Visit 7	533	26.4 (4.8)	15.8–45.6

Table 3

Neighborhood Characteristics by Year
SOF Neighborhood Study, 1986–2002, N=2003

Variable	Year	Mean (SD)	Range
Bus density (qm)			
	1988	33.7 (30.2)	0–152
	1994	38.5 (33.9)	0–180
	1998	41.3 (36.7)	0–184
	2002	43.9 (37.1)	0–185
Distance to transit (ft)			
	1988	989.1 (1789.8)	29.1–16000.0
	1994	889.0 (1297.1)	36.1–11650.0
	1998	771.6 (863.2)	19.6–7110.0
	2002	745.6 (748.0)	7.9–5508.0
Intersection density (qm)			
	1990	201.7 (94.0)	5–591
	1994	194.0 (96.1)	0–591
	1998	196.1 (90.5)	0–583
	2002	198.5 (86.6)	0–576
Distance to commercial area (ft)			
	1990	1094.8 (1281.4)	0–8000
	1994	1005.4 (1267.6)	0–8010
	1998	963.9 (899.8)	0–5300
	2002	864.6 (865.6)	0–4841
Distance to Park (ft)			
	1988	1495.3 (1092.5)	0–7000
	1994	1321.4 (823.3)	0–5000
	1998	1104.6 (696.2)	0–4500
	2002	1018.5 (642.8)	0–3500
Walkability Score			
	1988	4.5 (2.2)	0–9
	1994	4.6 (2.2)	0–9
	1998	4.7 (2.2)	0–9
	2002	4.8 (2.2)	0–9
Neighborhood SES	1990	−0.03 (4.8)	−17.3–17.8

SES = socioeconomic status

Table 4

Covariate-Adjusted, Parallel-Process Model of BMI and Neighborhood Walkability
SOF Neighborhood Study, 1986–2002, N=2003

	BMI		
Parameter Estimates	**Intercept b (SE)**	**Slope b (SE)**	**Quadratic b (SE)**
Walkability Intercept	−.012 (.053)	−.001 (.016)	.000 (.003)
Walkability Slope	--	−.113 (.142)	.031 (.023)
Neighborhood SES	−.112 (.022)**	.013 (.006)*	−.003 (.001)*
Age	−.104 (.019)**	−.024 (.006)**	.000 (.001)
Education	−.442 (.135)**	.001 (.040)	.010 (.006)
History of Manual Labor	.855 (.270)**	.094 (.073)	−.016 (.011)
Number of Comorbid Conditions	.290 (.111)**	.023 (.022)	−.008 (.010)*
Mobility Disability	2.327 (.348)**	−.097 (.064)	.033 (.010)**
Self-Reported Health	−.340 (.147)*	.166 (.054)**	−.012 (.009)
Tobacco Use	−1.645 (.350)**	−.322 (.139)*	−.002 (.025)

X^2=338.678(122)*, CFI=.990, TLI=.985, RMSEA=.030, SRMR=.025

Note: parameter estimates are unstandardized.

* $p < .05$,

** $p < .01$

Table 5

Covariate-Adjusted, Parallel-Process Model of BMI and Proximity to Parks/Green Spaces SOF Neighborhood Study, 1986–2002, N=2003

	BMI		
Parameter Estimates	**Intercept b (SE)**	**Slope b (SE)**	**Quadratic b (SE)**
Parks/Green Spaces Intercept	−.011 (.049)	−.001 (.015)	−.003 (.002)
Parks/Green Spaces	--	−.143 (.128)	.001 (.020)
Neighborhood SES	−.110 (.021)**	.012 (.006)*	−.002 (.001)*
Age	−.104 (.019)**	−.025 (.006)**	.000 (.001)
Education	−.440 (.135)**	−.003 (.040)	.011 (.006)
Manual Labor	.857 (.272)**	.098 (.074)	−.018 (.120)
Number of Comorbid Conditions	.289 (.111)**	.023 (.022)	−.009 (.004)*
Mobility Disability	1.982 (.224)**	−.091 (.065)	.032 (.011)**
Self-Reported Health	−.337 (.147)*	.167 (.054)**	−.013 (.009)
Tobacco Use	−1.642 (.350)**	−.310 (.026)	−.001 (.025)

X^2=3714.934 (122)*, CFI=.986, TLI=.979, RMSEA=.032, SRMR=.026

Note: parameter estimates are unstandardized.

[*] $p < .05$,

[**] $p < .01$