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The built environment and risk of obesity in the United States: Racial–ethnic disparities

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ABSTRACT

Using data from the 2003–2008 waves of the continuous National Health Nutrition Examination Survey merged with the 2000 census and GIS-based data, this study conducted genderspecific analyses to explore whether neighborhood built environment attributes are significant correlates of obesity risk and mediators of obesity disparities by race–ethnicity. Results indicate that the built environment is a significant correlate of obesity risk but is not much of a mediator of obesity disparities by race–ethnicity. Neighborhood walkability, density, and distance to parks are significant covariates of obesity risks net of individual and neighborhood controls. Gender differences are found for some of these associations.

1. Introduction

Obesity increases risk for morbidity and mortality (Gelber et al., 2008; Majed et al., 2008; Mokdad et al., 1999), and is also socially stigmatizing and alienating in many settings (Carr and Friedman, 2005; Dejong, 1980; Panotopoulos et al., 2007), leading to negative mental outcomes such as depression and self-disapproval (Carr and Friedman, 2005; Gavin et al., 2010; Luppino et al., 2010). The prevalence of overweight and obesity in the United States has long reached an epidemic level and has caught widespread attention of the research and policy communities, the media, and the American public (Saguy and Gruys, 2010; U.S. Department of Health and Human Services (USDHHS), 2001). Based on measured or reported body mass index (BMI) data from several repeated cross-sectional national surveys (Flegal et al., 2002; Schoenborn et al., 2002; Truong and Sturm, 2005), evidence is clear that obesity prevalence rates have increased dramatically in major socio-demographic segments of the US population during the past three decades with no signs of reversing the trend in any subgroups.

While similar temporal trends in weight gain have been observed across socio-demographic groups (Truong and Sturm, 2005), obesity disparities by race–ethnicity have been especially persistent. For example, based on measured BMI, the 1988–1994 National Health and Nutrition Examination Survey (NHANES III) showed that approximately 21.2% of non-Hispanic white adults were obese as were 30.2% of non-Hispanic black adults and 28.4% of Mexican American adults (Ogden et al., 2006). By contrast, the corresponding figures in the 2003–2004 NHANES data were 30.0% for whites, 45.0% for blacks and 36.8% for Mexican Americans. Therefore, despite the increasing trends across the board, the racial–ethnic ordering of obesity risk has remained unchanged over time. These disparities are apparently more pronounced and persistent among women (Flegal et al., 2002; Seo and Torabi, 2006) but also exist among men in many samples (Barrington et al., 2010; Do et al., 2007).

The federal 'Healthy People 2010' initiative has established an overarching goal of eliminating health disparities across social-demographic groups (National Center for Health Statistics, 2000). Unfortunately, this goal is far from being achieved in the US—a resource-rich society that has substantially invested in promoting public awareness of the obesity epidemic and its associated health costs. To reverse the obesity trend, we need to better understand causes of obesity and mechanisms underlying the observed disparities.

Although a range of social environmental factors of obesity have been documented, most of them have not been examined specifically as potential mediators of racial–ethnic disparities in obesity. The few existing studies have primarily focused on individual- or neighborhood-level socioeconomic status (SES) and neighborhood ethnic composition as potential mediators (Boardman et al., 2005;

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Chang, 2006; Robert and Reither, 2004; Voorhees et al., 2009). Moreover, white-Hispanic disparities have been less investigated than the white–black contrast, and research on gender-specific mechanisms is lacking. The present study attempts to fill a gap in the literature by conducting gender-specific analyses to examine racial–ethnic disparities in objectively measured obesity and explore how neighborhood built environment attributes contribute to obesity disparities by race–ethnicity net of individual influences and neighborhood socio-demographic contexts, using data from a nationwide survey merged with other neighborhood data. To the best of our knowledge, this is the first gender-specific analysis of the contribution of neighborhood built environments to black–white and Hispanic-white disparities in objectively measured obesity using a nationally representative sample of adult non-institutionalized Americans.

2. Background

There is a rapidly growing literature on the race–ethnicity and obesity link (Bleich et al., 2010; Bruce et al., 2007; Chang and Lauderdale, 2005). Among a myriad of possible individual-level factors, SES, typically measured by income, education and occupation in the U.S. literature of health stratification, has been most frequently examined as possible mediator. The majority of findings point to considerable residual effects of race–ethnicity on obesity net of individual or household SES (Chang and Lauderdale, 2005; Scharoun-Lee et al., 2009; Smith et al., 1998).

Besides SES, other individual factors have also been linked to obesity including but not limited to age (Flegal et al., 2002; Mokdad et al., 1999), marital status (Kahn and Williamson, 1991; Umberson et al., 2009), immigrant status (Berrigan et al., 2006; Jackson, 2011; Park et al., 2009), and health behaviors such as smoking (Kornhuber et al., 1989; Ravenna et al., 2011). They are typically conceptualized as confounders of the race–ethnicity and obesity link.

Beyond individual-level factors, neighborhood, as an important domain of one's immediate social environment, also matters for obesity (Grafova et al., 2008; Harrell and Gore, 1998). According to the neighborhood institutional model (Jencks and Mayer, 1990), neighborhood contexts are important for individual health and well-being because different geographically-based communities offer different levels of health-promoting resources such as supermarkets, parks, and walkable destinations while bearing differential environmental hazards such as crime and exposure to environmental pollution. Since mid-1990s there has been a rapidly growing literature of neighborhood effects on health (Kawachi and Berkman, 2003b) where neighborhood institutional resources are often tapped by neighborhood SES as the most frequently studied aspect of neighborhood contexts (Kawachi and Berkman, 2003a). Most studies in this literature report significant but smaller effect sizes of neighborhood SES compared to individual or household SES (Pickett and Pearl, 2001; Robert, 1998), although there are exceptions particularly on BMI-related outcomes (Drewnowski et al., 2007; Wen et al., 2007).

Specific to neighborhood-level mediators underlying racial–ethnic disparities in obesity, three multilevel national studies are noteworthy. Robert and Reither (2004) used data from the 1986 American's Changing Lives Study (ACL) combined with tract-level community data from the 1980 census to examine the contributions of both individual SES and community disadvantage in explaining the higher BMI of black adults in the US. They found independent roles of individual SES and community disadvantage in explaining the race effect but large residual effects of race remained. Proportions of black residents and lifestyle and psychosocial factors did little to explain black women's higher BMI. In this sample, no race effect was found among men. The second relevant study also examined the impact of residential areas on race differentials in obesity, using data from the individual- and neighborhood-level 1990–1994 National Health Interview Survey (NHIS) (Boardman et al., 2005). They found 17% of the elevated risk of obesity among blacks compared to whites was due to socio-demographic differences in the two groups; and an additional 20% of the race effect was explained by neighborhood black concentration which was further attributable to neighborhood SES and prevalence of overweight. Although both studies provided valuable evidence on neighborhood mechanisms of race differentials in obesity, they shared two limitations. First, data used were relatively old; and second, no Hispanics were included. With Hispanics being the largest and fastest growing minority group in the United States, and considering their higher prevalence of excessive weight compared to whites and national averages, it is important to include them in studies of obesity etiology and disparity.

The third study also used relatively older data but provides an innovation by including two additional racial–ethnic groups, Mexican Americans and others exclusive of whites, blacks and Mexican Americans (Do et al., 2007). The authors examined data from the 1988–1994 NHANES III survey and reported that neighborhood SES and racial–ethnic segregation were both significantly associated with BMI although the magnitude of the observed neighborhood associations varied across racial–ethnic and gender groups. Moreover, adjusting for multiple neighborhood contexts resulted in an increase in observed ethnic disparity for women, with a reduction for men. The observed neighborhood mediating patterns were mixed and the variations across gender in neighborhood associations were not consistent. All three studies focused on neighborhood structural factors such as deprivation and racial–ethnic segregation and one of them (Boardman et al., 2005) addressed the sociocultural aspect of neighborhood contexts. None of the three studies examined built environment attributes.

Clearly, the current literature is constrained in that neighborhood contexts are mainly operationalized by socio-demographic indicators due to convenient accessibility of census data (Yen et al., 2009). This is particularly true in national analyses. As an important aspect of neighborhood context, the built environment has not been well examined in conjunction with neighborhood socio-demographic features in nationally representative samples.

The built environment is an umbrella term, defined as "human-formed, developed, or structured areas" (Centers for Disease Control and Prevention, 2005), referring to a range of designed physical features of local places. Evidence is growing to link the built environment with obesity (Black and Macinko, 2007; Booth and Pinkston, 2005; Papas et al., 2007). Examples of health-enhancing features of the built environment are esthetics and greenery (Ellaway et al., 2005), amenities and destinations (Giles-Corti et al., 2003; Morland et al., 2006; Rutt and Coleman, 2005; Zhang et al., 2011), and walkability (Aytur et al., 2007; Doyle et al., 2006; Patterson and Chapman, 2004). However, most obesity studies relied on self-reported BMI and inconsistent associations of the built environment with obesity were observed across different socio-demographic groups and settings (Frank et al., 2004; Wen and Zhang, 2009). In addition, few studies have specifically addressed mechanisms underlying obesity disparities by race–ethnicity in representative samples. Thus, further research is needed to determine how neighborhood built environments are linked to obesity and contribute to obesity disparities.

Racial–ethnic disparities in obesity seem to be stronger and more consistent among women, as compared to men (Baltrus et al., 2005; Flegal et al., 2002; Seo and Torabi, 2006). A number of studies have also reported stronger neighborhood effects for women compared to men. For example, Robert and Reither (2004) revealed significant associations between neighborhood factors and BMI only among women. Wen and Zhang (2009) also reported stronger neighborhood associations with exercise among women than among men. That neighborhood influences on BMI may be stronger on women than men is theoretically plausible in that women tend to spend more time in the neighborhood because of their lower labor market participation rate and heavier family duties (Robert, 1999; Wen and Zhang, 2009). Relative to men, women may also be more responsive to social environments given their stronger tendency to adhere to prevailing norms regarding thin body images (Rand and Kuldau, 1990). That said, neighborhood associations with health outcomes are not always stronger for women. For example, two studies have reported stronger associations between neighborhood low SES and higher risks of mortality among men than among women (Nordstrom et al., 2003; Sundquist et al., 2004). Gender-specific racial–ethnic disparities and neighborhood associations with obesity need to be further studied (Bruce et al., 2007).

The purpose of the present study was to extend previous studies of obesity disparities in the USA by providing recent national evidence on disparities in objectively measured obesity by four racial–ethnic groups: whites, blacks, Hispanics, and others, examining how neighborhood built environment attributes were associated with risk of obesity net of neighborhood SES and ethnic composition, and whether racial–ethnic disparities in obesity were partly attributable to neighborhood built environment attributes after controlling for potential confounders at both the individual and neighborhood levels.

3. Methods

3.1. Data and measures

Individual-level data used in this study were from the 2003–2004, 2005–2006, and 2007–2008 waves of the continuous National Health and Nutrition Examination Survey (NHANES) merged with the 2000 census data along with other neighborhood data sources constructed using the geographic information system (GIS) techniques. The NHANES was a repeated cross-sectional, multistage probability sample of the US civilian, non-institutionalized population (Centers for Disease Control and Prevention, 2006). Depending on the specific age group and specific survey wave, the 2003–2008 NHANES had response rates ranging from 70% to 80%. Detailed descriptions of the survey methods, including weight and height measurement techniques, are available on-line (http://www.cdc.gov/nchs/nhanes.htm). The present study focused on a sample of respondents aged 20–64 excluding pregnant women and those needing aid for walking or with a BMI greater than 60 or smaller than 15.

Obesity was indicated by BMI of 30 or greater based on objectively measured weight and height (kg/m^2). Race–ethnicity was self-reported, including non-Hispanic whites (referred to as ‘whites’ hereafter), non-Hispanic blacks (referred to as ‘blacks’ hereafter), Hispanics, and others. Age and age-squared,[1] gender (male versus female), immigrant status (US-born versus foreign-born), marital status (currently married vs. others), education (college, high school graduates versus below high school),[2] poverty income ratio (PIR; continuously measured), and current smoking status (current smokers versus others) were additional individual variables controlled in the analyses. Missing PIR data were imputed by predicted values of ordinary least square (OLS) regression on age, gender, education, race–ethnicity, and marital status.[3]

As the smallest geographic level of aggregation identified in the NHANES, census tract was used to define neighborhood. Three *neighborhood SES*[4] variables were derived from the 2000 census including percent households with annual income at $75,000 or more (i.e., concentrated affluence), percent residents living in poverty (i.e., concentrated poverty), and percent college-educated residents (i.e., aggregate education). A composite scale of neighborhood SES was constructed based on the three SES indicators and has acceptable reliability (alpha=0.85). Racial–ethnic composition was captured by an *ethnic heterogeneity*[4] index defined as $1-\sum p_i^2$, where p_i is the fraction of the population in a given group (Sampson and Groves, 1989). The index takes into account both the relative size and number of groups in the populations, with a score approaching one reflecting maximum heterogeneity, and a score of zero reflecting the presence of only one racial/ethnic group in the Census tract. The calculation of the index was based on proportions of Whites, Blacks, Asians/Pacific Islander, Hispanics, American Indians/Alaska Natives, and others in a census tract.

The built environment was measured by five variables. Three of them were from the 2000 census, including population density (i.e., number of residents per square mile), median age of neighborhood buildings, and percentage of residents walking to work. The three variables have been used as indicators of neighborhood design particularly as to walkability (Smith et al., 2008). In addition, two GIS-based measures were constructed including street connectivity and distance to parks.

As a proxy direct indicator of neighborhood walkability, street connectivity was defined as the number of intersections per square kilometer in an area; for this study, this area was the census tract (Frank et al., 2006). Spatial data including census tracts and road networks were constructed from the data CD-ROMs distributed with ArcGIS 9.3 by the Environmental System Research Institute (ESRI). The road network data were from the StreetMap USA file (a TIGER 2000-based streets data set enhanced by ESRI and Tele Atlas). Based on these data, an index of street connectivity was constructed for each census tract in the United States.

A measure of park accessibility was constructed from the 2006 park GIS layer in ESRI ArcGIS 9.3 Data DVD (ESRI). It was created in 2008 with 35,436 public park or forest units in the 50 states and DC. The park dataset includes national, state, and local parks and forests. Park size and within-park geometric centroids were generated in ArcGIS. Both large national parks (i.e., mainly comprised of natural spaces) and local parks (i.e., outdoor areas

[1] Age-squared was included to adjust for the curvilinear association between age and obesity risks.

[2] This measurement of education was based on previous findings that educational effects on obesity appear nonlinear and stepwise with college credential as a possible threshold (Schoenborn et al., 2002; Truong and Sturm, 2005). Different operationalization of education (i.e., different categorization or treating it continuously) did not change the results.

[3] Sensitivity analyses were performed to compare results excluding missing income values versus imputing missing income values. No qualitative differences were found.

[4] To make sure our results are robust to different operationalization of neighborhood socio-demographic contexts, sensitivity analyses were performed using neighborhood SES and ethnic heterogeneity scales constructed from the 2005–2009 American Community Survey data (ACS) using the same methods. We then fit all the models using the ACS-based neighborhood SES or ethnic heterogeneity scales and the results remained largely unchanged. We thus chose to present the results based on the 2000 census because the ACS data were aggregated from a small percentage of the population thus arguably less reliable than the census data. Another advantage of using the 2000 census data to characterize neighborhood socio-demographic contexts is that this approach would allow a temporal sequence, from neighborhood exposure to risk of obesity, which is consistent with our hypothesized causal order, namely neighborhood contexts affecting obesity risk.

set aside for recreation) were included. Very small parks of less than 4000 square feet (or 0.1 acre) were not available in this data set and were not included in this study. We adopted an innovative method to calculate census tract park accessibility. Specifically, we identified seven parks closest to a census block centroid and calculated average distances from the census block centroid to each of these seven parks weighted on population and park sizes. We then aggregated the census-block level distance to parks to the census tract level. A key advantage of this new method of measuring park access is that it takes into account the uneven population distributions across areas and different park sizes. It allows the comparison of park spatial accessibility across various geographic scales. We chose to use *seven* parks based on the theory and evidence from psychology that seven is a key threshold number of pieces of information for human brains to process; beyond this threshold, additional information cannot be handled effectively due to the natural limitations on our brain capacity (Miller, 1956). Details of this method have been published elsewhere (Zhang et al., 2011).

3.2. Analytical strategy

GIS techniques were employed to construct neighborhood street connectivity and access to parks. Factor principal component analyses were performed to construct the neighborhood SES scale. Multilevel random-intercept logistic regression models taking study design and weights into account were fit to test the hypotheses. All neighborhood variables were standardized before they were included in the analytical models. MPlus 6.0 was used to perform the analyses.

Four gender-specific models were fit to test our hypotheses. The baseline model included blacks (versus whites), Hispanics (versus whites), others (versus whites), age and age-squared, immigrant status (US-born versus foreign-born), marital status (currently married versus others), educational attainment (high school graduates, college versus below high school), poverty income ratio (treated as a continuous variable), current smoking status (smokers versus nonsmokers), and survey years. Because the group of others is too heterogeneous to make meaningful comparisons, our focus of comparison is between black and whites and between Hispanics and whites. Model 2 added neighborhood SES and ethnic heterogeneity; Model 3 added the built environment factors; and Model 4 was the final model including all significant covariates shown in previous models and remained significant in the last round of multivariate modeling. To explore whether the built environment is a mediator of racial–ethnic disparities in obesity risk, odds ratios of blacks and Hispanics from Models 2 and 4 can be compared. If the odds ratios decrease with the addition of the built environment variable, then evidence is supportive of the mediating hypothesis. By contrast, increasing odds ratios would signal a suppressing effect of the built environment.

Variance of residuals, intra-clustering correlations (ICC), and Akaike Information Criterion (AIC) were presented along with the regression results. AIC is a measure of the relative rather than absolute goodness of fit of a statistical model grounded in the concept of information entropy (Akaike, 1974). As AIC not only rewards goodness of fit, but also includes a penalty that is an increasing function of the number of estimated parameters, the preferred model among a set of candidate models for the data is the one with the minimum AIC value.

Table 1
Sample statistics.
Source: 2003–2008 National Health and Nutrition Examination Survey merged with a number of place-based data sets including the 2000 census and GIS-based data.

	Full sample	Whites	Blacks	Hispanics	Others
Individual characteristics					
Sample size	9739	6708	1137	1309	585
Measured obesity (BMI $\geq$ 30)	33.18%	32.37%	43.48%	35.20%	22.06%
Non-Hispanic whites	68.86%	NA	NA	NA	NA
Non-Hispanic blacks	11.68%	NA	NA	NA	NA
Hispanics	13.45%	NA	NA	NA	NA
Others	6.01%	NA	NA	NA	NA
Age (mean)	40.89	41.84	39.56	37.15	40.99
Male	50.53%	50.54%	47.14%	53.24%	51.11%
US-born	89.96%	97.42%	95.91%	52.72%	76.22%
Married or cohabitating	66.25%	69.42%	47.39%	65.76%	67.63%
High school graduates	24.59%	25.45%	25.45%	21.95%	18.98%
College degree or above	26.65%	30.64%	17.55%	9.61%	36.81%
Poverty income ratio[a] (mean)	3.15	3.46	2.57	2.15	3.02
Current smokers	26.90%	28.47%	26.53%	21.37%	22.01%
Neighborhood characteristics					
Sample size	1790	989	443	342	16
Percent affluent households[b]	20.85%	24.96%	15.79%	15.60%	19.18%
Percent residents in poverty[b]	14.95%	10.51%	20.47%	20.42%	19.13%
Percent college educated residents[b]	31.55%	29.23%	29.28%	27.66%	37.91%
Ethnic heterogeneity[c]	0.36	0.32	0.38	0.43	0.52
Population density[d]	7186.59	4963.17	9517.37	10,112.4	17,548.52
Street connectivity[e]	102.63	91.04	123.39	106.75	155.38
Neighborhood age (years)	33.17	31.56	37.22	32.46	35.81
Percent residents walking to work	2.92%	2.91%	2.86%	2.81%	7.87%
Distance to parks (mile)	7.42	5.25	1.77	3.21	1.63

[a] Poverty income ratio (PIR) is a ratio in which the numerator is a family's household income and the denominator is the appropriate poverty threshold given the family's size and composition.
[b] A composite scale of neighborhood SES was constructed based on percent affluent households, percent residents in poverty and percent college educated residents.
[c] An index of ethnic heterogeneity is calculated as $1-\sum p_i^2$ where p_i is the fraction of the population in a given group (Sampson and Groves, 1989).
[d] Population density is measured by number of residents per square miles.
[e] Street connectivity is measured by number of intersections per square miles.

4. Results

Table 1 shows the descriptive statistics of the full sample and the subgroup samples. The objectively measured prevalence of obesity in the full sample is 33.18%, lowest in whites (32.37%), followed by Hispanics (35.20%), and highest in blacks (43.48%). The vast majority of whites and blacks are US-born, whereas 52.72% of Hispanics are foreign-born. Considering SES, whites have the highest proportion of respondents with college or graduate degrees, followed by blacks and then by Hispanics. Whites also enjoy higher household income as indexed by poverty income ratio compared to blacks and Hispanics. Meanwhile, whites have the highest prevalence of current smokers compared to the other two groups.

Neighborhood SES follows a similar pattern with whites being the most advantaged. Especially in terms of economic resources Whites' neighborhoods also tend to be less racial-ethnically integrated than those for blacks and Hispanics. As to the built environment, the picture is considerably different. Whites' neighborhoods are the youngest and have the lowest population density and street connectivity probably because whites are more likely to live in newer, less walkable but socioeconomically advantaged suburban areas. Whites also on average have the longest distance or least spatial access to local parks. On the other hand, whites tend to live in neighborhoods with higher percentage of residents walking to work. Blacks have the best access to local parks, probably due to their residential concentration in urban areas. Population density, street connectivity, neighborhood age, and percentage of residents walking to work are often viewed as markers of walkability and/or mixed land use. Access to parks is arguably a built environment attribute that is likely to invite increased physical activity. Therefore, a clear-cut picture of white privilege in built environment attributes is not observed in this nationwide sample.

Table 2 presents odds ratios of weighted multilevel logistic models for obesity risk based on objectively measured BMI for men. Controlling for socio-demographic factors and smoking status, blacks and Hispanics are at greater risk of obesity as compared to whites (Model 1). Older age, being US-born, being married, and having higher income are positively associated with obesity risk, whereas college education and smoking are negative covariates (Model 1). There is a temporal trend towards higher obesity risks across the survey years. Net of individual controls, both neighborhood SES and ethnic heterogeneity are negatively associated with obesity risk (Model 2). Among the built environment factors, population density, street connectivity, and percentage of residents walking to work are all negatively associated with obesity risk while distance to parks is a positive covariate (Model 3). The final model shows that neighborhood SES (OR=0.845; $p<0.001$), ethnic heterogeneity (OR=0.918; $p<0.001$), population density (OR=0.890; $p<0.001$), street connectivity (OR=0.953; $p<0.001$), and percentage of residents walking to work (OR=0.848; $p<0.001$) are significant and positive covariates of obesity risk, whereas distance to parks is a negative one (OR=1.100; $p<0.01$). For example, for men, a one standard deviation (SD) increase in the measure of percentage of residents walking to work corresponds to an 18% reduction in obesity risk, whereas a one SD increase in the measure of distance to parks is associated with a 10% increase in obesity risk. As to the hypothesized mediating effect of the built environment, the results do not lend support to the hypothesis. The odds ratios of blacks and Hispanics did not decrease but slightly increased from Models 2 to 4 (from 1.292 in Model 2 to 1.389 in Model 4 for blacks and from 1.463 in Model 2 to 1.520 in Model 4 for Hispanics; Table 2), showing the role of the built environment is not to explain obesity disparities for men but to suppress it to some extent. The intra-clustering correlations (ICCs) are about 12% across the models. Based on the AIC values, Model 4 is preferred.

Table 3 presents the results for women. The patterns are largely similar to those for men with a few exceptions. White advantage with respect to measured obesity is apparently greater for women. Compared to the results for men, marriage is no longer significant and household income is negatively rather than positively associated with obesity risk (Model 1). Ethnic heterogeneity is no longer significant and population density becomes a positive rather than negative neighborhood factor of obesity risk for women. The final model shows that neighborhood SES (OR=0.719; $p<0.001$), street connectivity (OR=0.935; $p<0.001$), and percentage of residents walking to work (OR=0.802; $p<0.001$) are significant and negative covariates of obesity risk, whereas population density (OR=1.020; $p<0.100$) and distance to parks (OR=1.074; $p<0.01$) are positive ones. The odds ratios of blacks and Hispanics slightly decreased from Models 2 to 4 but the magnitude of the reductions (from 1.786 in Model 2 to 1.749 in Model 4 for blacks and from 1.562 in Model 2 to 1.484 in Model 4 for Hispanics; Table 3) is very small (2% and 5%, respectively). The ICCs range from 9% to 10%. Based on the AIC values, Models 3 and 4 are the most preferred.

5. Discussion

The rising epidemic of obesity has affected all major segments of the US population (Ogden et al., 2006). While we need to address this problem across all ethnic groups, the burden of the epidemic is differentially carried across racial–ethnic groups. Thanks to advancements made to understand the etiology of obesity in recent years (Reither et al., 2009; Whitaker, 2002), it is increasingly recognized that a constellation of biological, psychological, behavioral and socio-environmental factors determine one's risk for excess weight gain. Considering that racial–ethnic concepts are not biologically grounded but socially constructed (Smaje, 2000), the observed disparities in obesity by race–ethnicity can presumably be better explained by factors that largely lie in psychosocial and environmental realms.

The present study confirms the pattern of racial–ethnic disparities in obesity. Based on objectively measured BMI using a nationally representative sample, results indicate that whites are at lower risks of obesity than blacks and Hispanics and the magnitude of disparity is greater in women than in men. These patterns are consistent with previously published prevalence studies (Baltrus et al., 2005; Flegal et al., 2002; Seo and Torabi, 2006).

The key aim of this study was to explore the role of neighborhood built environment attributes in contributing to obesity risk and explaining obesity disparities by race–ethnicity. Gender-stratified analyses were performed, producing largely similar patterns of built environment and obesity associations. Consistent for men and women, net of individual controls and neighborhood SES and ethnic composition, neighborhood street connectivity and percentage of residents walking to work are significantly and negatively associated with obesity risk, whereas distance to parks exhibiting a positive association. Street connectivity is an objective measure of walkability while percentage of residents walking to work captures both walkability and mixed land use patterns. Distance to parks represents spatial inaccessibility of parks as an important neighborhood amenity and activity-promoting destination. The significance of these variables on obesity risk lends strong support to the notion that pedestrian-friendly design and activity-promoting no-cost facilities such as parks are associated with lower BMI and obesity risk, providing national evidence on the link between the built environment and obesity. This is an important addition to our knowledge base of the neighborhood-obesity link insofar as most past studies were conducted in local settings and reliant on reported BMI producing mixed results (Durand et al., 2011; Mujahid et al., 2008; Sallis et al., 2009; Smith

Table 2
Odds ratios of multilevel logistic models for risk of obesity among men.
Source: 2003–2008 National Health and Nutrition Examination Survey.

	Model 1	Model 2	Model 3	Model 4
Individual-level variables				
Non-Hispanic Whites (NHW)	*Reference*	*Reference*	*Reference*	*Reference*
Non-Hispanic Blacks (NHB)	1.247**	1.292**	1.390***	1.389***
Hispanics	1.352***	1.463***	1.523***	1.520***
Others	0.712***	0.783***	0.875***	0.874***
Age	1.048**	1.051**	1.046*	1.046*
Age-squared	1.000†	1.000†	1.000	1.000
US-born	1.897***	1.852***	1.758***	1.757***
Currently married	1.338***	1.336***	1.292***	1.290***
High school graduates	1.083	1.083	1.056	1.057
College degree or above	0.724**	0.769*	0.809*	0.810[a]
Poverty income ratio[a]	1.037†	1.059***	1.062***	1.062***
Current smoker	0.640***	0.628***	0.620***	0.621***
NHANES 2003–2004	*Reference*	*Reference*	*Reference*	*Reference*
NHANES 2005–2006	1.074†	1.111**	1.069	1.068
NHANES 2007–2008	1.083*	1.103***	1.086***	1.083***
Neighborhood-level variables				
Socioeconomic status (SES)[b]		0.874***	0.849***	0.845***
Ethnic heterogeneity[c]		0.881***	0.920***	0.918***
Population density[d]			0.887***	0.890***
Street connectivity[e]			0.948*	0.953***
Neighborhood age			1.016	
Percent residents walking to work			0.847***	0.848***
Distance to parks			1.101***	1.100**
σ_u^2	0.436	0.435	0.434	0.433
ρ (intraclass correlation)	0.117	0.117	0.117	0.116
AIC	5230.015	5218.051	5193.127	5191.240

Sample size: 4963 men living in 1603 census tracts.

† $p \leq 0.10$.
* $p \leq 0.05$.
** $p \leq 0.01$.
*** $p \leq 0.001$ (two-tailed tests).
[a] Poverty income ratio (PIR) is a ratio in which the numerator is a family's household income and the denominator is the appropriate poverty threshold given the family's size and composition.
[b] A composite scale of neighborhood SES was constructed based on percent affluent households, percent residents in poverty and percent college educated residents.
[c] An index of ethnic heterogeneity is calculated as $1-\sum p_i^2$ where p_i is the fraction of the population in a given group (Sampson and Groves, 1989).
[d] Population density is measured by number of residents per square miles.
[e] Street connectivity is measured by number of intersections per square miles.

et al., 2008). The present study confirms that the significance of the built environment for obesity is likely generalizable to a national pattern and robust to measurement of obesity.

Among the built environment attributes we examined, neighborhood median housing age was the only one not significant for either gender. This is inconsistent with findings reported from a study of adults living in Salt Lake County, Utah where housing age was found to be one of the strongest and consistent predictors of BMI (Smith et al., 2008). By contrast, the strong association between prevalence of walking to work and BMI in the Utah study is confirmed in the present national study, suggesting the effect of housing age on BMI is probably situational rather than universal whereas prevalence of walking to work seems to be a sensitive indicator of the built environment that has some good reliability and validity in the obesity and built environment research. As a neighborhood measure conveniently available in the US census, prevalence of walking to work should be more used and analyzed in future studies.

As to population density, the results are opposite for men and women. As expected, it is negatively correlated to obesity risk for men. By contrast, it is linked to women's greater obesity risk. The unexpected finding for women is consistent with the Utah study (Smith et al., 2008) which is hard to explain in either case. Higher population density may signal more walkable destinations because of the critical mass needed to encourage institutional developments such as shops, services, and schools. It is thus assumed population density is positively correlated with institutional resources available in an area (Sallis et al., 2012; Smith et al., 2008) and thus should be a preventive force against obesity. While this assumption has not been adequately evaluated, population density has been empirically linked to higher active transportation suggesting that high density neighborhoods have more destinations to travel to for the residents. That said, higher density is not always associated with lower BMI (Frank et al., 2004; Pendola and Gen, 2007; Ross et al., 2007) and as shown in the present study the density–obesity relationship can vary according to gender and likely other demographic factors as well (Frank et al., 2004). The density–obesity link needs to be further explored.

As to whether built environment attributes help explain obesity disparities by race–ethnicity, results show that for men the built environment plays a small suppressing effect on racial–ethnic disparities in obesity and for women the mediating role of the built environment is minimal. By and large, despite its strong association with obesity risk, the built environment cannot explain much why racial–ethnic minorities are at higher risks of obesity than whites. Although inconsistent with our expectations, these findings are in accords with the descriptive statistics where the presumed white privilege in activity-inviting and obesity-preventive built environments is not observed; rather, blacks and Hispanics seem to have better neighborhood built environments for the purpose of maintaining healthy weight. These unexpected findings may lend support to the notion that a narrowing of weight-related disparities over

Table 3
Odds ratios of multilevel logistic models for risk of obesity among women.
Source: 2003–2008 National Health and Nutrition Examination Survey.

	Model 1	Model 2	Model 3	Model 4
Individual-level variables				
Non-Hispanic Blacks (NHB)	1.841***	1.786***	1.815***	1.749***
Hispanics	1.553***	1.562**	1.560**	1.484***
Others	0.469***	0.504***	0.514***	0.488***
Age	1.091***	1.093***	1.087***	1.087***
Age-squared	0.999***	0.999***	0.999***	0.999***
US-born	2.057***	2.091***	2.067***	2.093***
Currently married	0.976	0.973	0.947	0.947
High school graduates	1.006	1.006	1.001	1.005
College degree or above	0.586**	0.623***	0.633**	0.631**
Poverty income ratio[a]	0.867***	0.905***	0.905***	0.904***
Current smoker	0.699***	0.682***	0.691***	0.693***
NHANES 2005–2006	1.128*	1.175***	1.167***	1.151**
NHANES 2007–2008	1.108***	1.145**	1.140*	1.134**
Neighborhood-level variables				
Socioeconomic status (SES)[b]		0.803***	0.764***	0.719***
Ethnic heterogeneity[c]		0.901	0.922	
Population density[d]			1.039**	1.020*
Street connectivity[e]			0.951***	0.935***
Neighborhood age			0.967	
Percent residents walking to work			0.811***	0.802***
Distance to parks			1.071**	1.074**
σ_u^2	0.342	0.336	0.352	0.353
ρ (intraclass correlation)	0.094	0.093	0.097	0.097
AIC	5445.605	5417.367	5405.461	5405.995

Sample size: 4776 women living in 1611 census tracts.
† $p \leq 0.10$.
* $p \leq 0.05$.
** $p \leq 0.01$.
*** $p \leq 0.001$ (two-tailed tests).
[a] Poverty income ratio (PIR) is a ratio in which the numerator is a family's household income and the denominator is the appropriate poverty threshold given the family's size and composition.
[b] A composite scale of neighborhood SES was constructed based on percent affluent households, percent residents in poverty and percent college educated residents.
[c] An index of ethnic heterogeneity is calculated as $1-\sum p_i{}^2$ where p_i is the fraction of the population in a given group (Sampson and Groves, 1989).
[d] Population density is measured by number of residents per square miles.
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time is possible because whites and higher SES individuals tend to move away from central urban areas to suburban and exurban areas characterized by suburban sprawl which has been linked to higher rates of obesity (Truong and Sturm, 2005). In other words, rather than serving as a mediator of obesity disparities, the built environment may be becoming a suppressor over time because of the more obesogenic suburban areas being concentrated with more socioeconomically advantaged social groups. In this study, we did find that blacks and Hispanics on average had better access to local parks than whites and their neighborhoods tend to be more walkable compared to those of whites. That said, the built environment encompasses numerous aspects of the neighborhood design. We were not able to examine an exhaustive list of factors capturing all the physical aspects of the local space. Due to data limitation, many built environmental factors are omitted from the analyses including those much relevant to BMI such as food environment and fee-for-service exercise facilities.

A side finding from this study concerns the effects of marriage and income; both featured inconsistent associations across gender. For men, being married is a risk factor of obesity; but for women marriage is not a significant covariate. The relationship between marital status and obesity among adults can be driven by complex interactions among marital status, parenthood, gender, and time use patterns. Regardless of gender, being married may incur weight gain because married individuals are more likely to eat out (Umberson et al., 2009) and exercise less due to time pressure associated with child rearing. It is also possible that married men and women tend to feel settled without much need to attract any more on the dating market and thus become less concerned with their appearance and less engaged in positive behaviors like exercising. Meanwhile, married women are likely more engaged in energy-expending house chores compared to unmarried women and married men possibly offsetting some of the weight gain forces experienced with marriage.

As to income effect on obesity, women benefits from higher income whereas men's obesity risk is positively linked to income. This seemingly contradictory pattern is in fact consistent with the literature with mixed evidence on the income-obesity link. The observed income gradient in obesity rates has been neither deep nor always present, (Mokdad et al., 2003; Schoenborn et al., 2002) perhaps partly due to the complex interaction effects of income with gender and race–ethnicity (Zhang and Wang, 2004). The positive relationship between income and obesity risk may reflect benefits on healthy weight of more labor-demanding occupations for men of lower income. Compared to the income effect, the effect of education on obesity is found often stronger and more consistent (McLaren, 2007). This pattern is confirmed in the present study as well. In theory, higher education is linked to lower obesity risk as individuals with higher education are likely to be more aware of health-promoting information, more readily to internalize the symbolic value of a thin body that is appreciated in prestigious occupations and social circles, and thus more motivated and better equipped to follow recommended healthy lifestyles (McLaren, 2007; McLaren and Kuh, 2004; Mirowsky et al., 2000). Regardless of sources of these observed gender differences, gender-stratified analyses appear warranted in future work.

Several limitations of the present study need to be acknowledged. First and foremost, this study is cross-sectional and no causality should be assumed from the results. The study cannot address non-random selection of individuals into residential settings. Research linking community characteristics to individual outcomes must contend with the potential existence of selection bias in the interpretation of results. It might well be that families select themselves into residential opportunities that reflect pre-existing motivations and personal characteristics that might also influence risk of obesity. However, a body of research is beginning to emerge showing that non-random selection might be present in the estimation of neighborhood built environment factors on individual BMI but that causation is also present (Kowaleski-Jones et al., 2010; Sallis et al., 2009).

Second, the temporal sequencing from neighborhood variables to obesity measures was not established. For examples, although census data were from year 2000, prior to the 2003–2008 NHANES where obesity measures were obtained, park data were constructed based on a GIS database of parks in 2006. It can be argued however that neighborhood characteristics are not likely to change dramatically within a few years. Thus the varied timing of neighborhood data collection should not shake the cross-sectional nature of the present study. Third, only main effects were examined. To keep the analyses focused, we leave complex within-level or cross-level interaction effects for future research. For example, it would be interesting to test how neighborhood walkability varies by SES and/or by psychological factors such as perception of body image and self-efficacy. Fourth, inevitably, due to data limitation, the study suffered from omitted-variable problem. For example, occupation at the individual level should be controlled in the regression analyses as occupations differ considerably from one another in terms of their labor demands, which will in turn influence risk of obesity and its prevalence across gender and ethnic groups in the U.S. Unfortunately, this variable is not available in the continuous NHANES. In addition, neighborhood food environment and cultural factors should be considered in future work if data permits. Of course, the more variables included in a study, the less feasible a national analysis becomes. Researchers are always faced with making trade-off decisions accommodating conflicting demands in design considerations. Lastly, in the present study the neighborhood was defined by census tract, an administrative unit used in the US census. Although this approach takes advantage of easily accessible census data and is often adopted in the literature, the drawback of using artificially defined spatial boundaries to circumscribe socio-culturally meaningful neighborhoods is an inevitable exposure misspecification, a conservative bias commonly shared in studies of neighborhood effects on health. Future research is warranted to investigate how empirical results vary according to different neighborhood definitions.

In conclusion, this multilevel nationwide study provides evidence on the contextual associations of neighborhood built environment attributes with individual risks of obesity net of individual controls and neighborhood SES and ethnic composition. These findings suggest that neighborhood design is likely a fruitful setting to conduct interventions for maintaining healthy weight and preventing excess weight gain. That said, the built environment does not appear to be a good explainer for obesity disparities by race–ethnicity. The sources of these disparities remain elusive. Longitudinal analyses of a wide range of childhood and adulthood risk factors of obesity incorporating a rich set of contextual characteristics would be promising to offer advances in our knowledge about what factors contribute to persistent obesity disparities by race–ethnicity in the US.

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