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Article

Associations between obesity and neighborhood socioeconomic status: Variations by gender and family income status

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ABSTRACT

Objectives: To analyze if the association between obesity and neighborhood socioeconomic status (SES) was moderated by gender and family income.

Methods: Data from 19,448 individuals 18 and older from the 2001–2008 National Health and Nutrition Examination Survey (NHANES) were geo-matched with social and built environment characteristics from the 2000 Census and other data sources. Objective height and weight measures were used to create body mass index (BMI) and obese status (BMI≥30). Tracts were divided into four quartiles using a composite factor score capturing neighborhood SES. Individuals were divided into four income groups by the income-to-poverty ratio (I/P). Multilevel regression analyses were performed.

Results: The association between neighborhood SES and obesity/BMI was more consistently significant among higher-income women than lower-income women. The same association was not found for men. Neighborhood built environment factors did not mediate the relationship between neighborhood SES and individual weight outcome.

Conclusions: Neighborhood SES had stronger and more consistent associations with obesity and BMI for women than men, and for higher-income women than lower-income women.

Introduction

Neighborhood socioeconomic status (SES) has been consistently linked to individual health outcomes with individuals living in higher-SES neighborhoods having better health than individuals living in lower-SES neighborhoods, over and beyond individual SES (Diez Roux & Mair, 2010; Suglia et al., 2016). Obesity is no exception (U.S. Department of Health and Human Services, 2001). Research has established that individuals living in lower-SES neighborhoods experience higher odds of obesity compared with individuals living in higher-SES neighborhoods, holding factors such as family income, education, age, gender and race/ethnicity constant (Black & Macinko, 2008). While it is often recognized that the health effects of neighborhood contexts may vary depending on individual-level characteristics such as gender and economic status, empirical studies testing these moderating effects have been limited (Diez Roux & Mair, 2010; Green et al., 2015). Yet, understanding if and how the relationship between neighborhood SES and obesity varies by gender and family economic status has important implications for intervention efforts and policy strategies to reduce obesity-related health disparities for specific groups, because what works for men may not work for women, and what works for higher-income individuals may not work for their lower-income counterparts. There are increasing interest and consensus among researchers and policymakers in better understanding exposure effect moderation because such understanding would allow us to identify high-risk subgroups that are particularly vulnerable to the exposure and pay more targeted attention to the most impacted population (Inglis et al., 2018; Sharkey & Faber, 2014). This emerging literature is also motivated by the concern that some interventions or policies may disproportionately benefit the already advantaged groups in society thereby inadvertently increasing health inequalities, an effect termed "intervention generated inequalities" (Lorenc, Petticrew, Welch, & Tugwell, 2013).

There are conceptual reasons to expect the relationship between neighborhood SES and individual health outcome to differ by individual factors. Black and Macinko (2008) proposed that individuals with different genetics, culture, and demographics may utilize neighborhood

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resources differently. This study focused on the moderating effect of gender and family income on the relationship between neighborhood SES and individual obesity/BMI. Gender differences in individual risk factors of obesity have been well documented, with the negative association between individual SES and obesity stronger for women than men (Wang & Beydoun, 2007; Zhang & Wang, 2004). As far as we know, only a few studies investigated gender differences in the association between neighborhood SES and obesity. Neighborhood deprivation was found to be associated with higher BMI for women but lower BMI for men in Canada (Matheson, Moineddin, & Glazier, 2008). Such relationship was also found to be stronger for women than for men in Australia (Feng & Wilson, 2015; Rachele et al., 2019). Neighborhood education level was associated with weight outcomes for women but not men in a Brazilian study (Boing & Subramanian, 2015). Conceptually, neighborhood effects might be stronger for women than for men because women are more likely to stay at home and in the proximate area than men due to their lower labor market participation rate and greater involvement in child care responsibilities (Boing & Subramanian, 2015; Stafford, Cummins, Macintyre, Ellaway, & Marmot, 2005). In addition, men and women have been found to differ in susceptibility to environmental (Institute of Medicine Committee on Gender Differences in Susceptibility to Environmental Factors, 1998) or lifestyle factors (Vari et al., 2016). For example, women experience more cycles of fat gain and loss due to natural phenomena such as pregnancy and may thus be more vulnerable to living in obesogenic environments in terms of weight gains (Institute of Medicine Committee on Gender Differences in Susceptibility to Environmental Factors, 1998). Presumably, with more exposure to obesogenic environments associated with neighborhood SES, the relationship between neighborhood SES and individual obesity should be stronger for women than men.

The interaction between family income and neighborhood SES has several possibilities. On the one hand, compared with higher-income individuals, lower-income individuals may be more affected by neighborhood SES because they may benefit more from public goods offered by higher-SES neighborhoods to compensate for limited individual resources while experiencing intensified unhealthy consequences of living in lower-SES neighborhoods due to limited public goods (Wen & Christakis, 2005). This "deprivation amplification," a process whereby neighborhood conditions amplify individual disadvantages resulting in detrimental health consequences, has rarely been tested on obesity outcomes with the exception of a recent Australian study (Rachele et al., 2019). The more affluent residents may also provide role models for mainstream social norms, maintain social cohesion (Child et al., 2019), and uphold neighborhood institutions, and therefore increase the well-being of the poor (Wilson, 1987, 1996). On the other hand, lower-income individuals may be less affected by neighborhood SES because lower individual income is often associated with a lower sense of self-control and self-efficacy (Bandura, 1986; Boardman & Robert, 2000; Gurin, Gurin, & Morrison, 1978; Hughes & Demo, 1989), which may lead to lower motivations for behavioral change benefiting less from favorable environmental contexts as they may not utilize neighborhood resources even when such resources are available. Lower-income individuals living in higher-SES neighborhoods may also suffer more stress from relative deprivation than higher-income individuals living in lower-SES neighborhoods. Limited empirical study found built environment characteristics to be less consistently associated with BMI among disadvantages groups than their more-affluent counterparts (Lovasi, Neckerman, Quinn, Weiss, & Rundle, 2009). If neighborhood SES and obesity followed a similar pattern, then one would expect the negative neighborhood SES and obesity association to be stronger for higher-income than lower-income individuals.

Important confounders for the association between neighborhood SES and obesity include individual sociodemographic characteristics such as age, race/ethnicity, education (Wang & Beydoun, 2007), and neighborhood built environment factors such as population density, pedestrian-friendly design, and land use diversity (Cervero & Kockelman, 1997). This study sought to investigate if and how the association between neighborhood SES and obesity/BMI may be moderated by gender and family income after controlling for differences in individual characteristics and neighborhood built environment characteristics. Based on the conceptual arguments and the limited empirical literature, we hypothesized that (1) the association between neighborhood SES and obesity/BMI was stronger for women than men; and (2) the association between neighborhood SES and obesity/BMI was stronger for higher-income than lower-income individuals.

Methods

The main data source was the National Health and Nutrition Examination Survey (NHANES) administered by the National Center for Health Statistics (NCHS) (Centers for Disease Control and Prevention, 2001–2008). NHANES is a program of studies designed to assess the health and nutritional status of the civilian, noninstitutionalized US population, with approximately 5,000 persons interviewed and examined each year. NHANES 2001–2008 were pooled to achieve adequate sample sizes for conducting statistical tests by individual income and neighborhood SES combinations, and to allow for a large geographical representation. A total of 23,388 adults 18 and older were in NHANES 2001–2008. After excluding pregnant women ($n = 1,037$), those with missing BMI information ($n = 1,772$), $BMI < 18.5$ ($n = 420$), $BMI > 60$ ($n = 29$), missing family income ($n = 667$), and missing tract information ($n = 15$), the final sample consisted of 19,448 individuals 18 and older, including 9,525 women and 9,923 men.

Tract-level and county-level data were obtained from the 2000 Census (U.S. Bureau of the Census, 2000) and other sources and were geo-linked to NHANES by staff at the Centers for Disease Control and Prevention (CDC) Research Data Center. These included tract food desert status from USDA (U.S. Department of Agriculture, 2009), tract population density (1000 per square mile) and median housing age from the 2000 Census (U.S. Bureau of the Census, 2000), street connectivity (number of intersections for streets with $\leq$25 miles per hour speed limits per square kilometer in the tact) corresponding to the 2005 road network (Wang, Wen, & Xu, 2013) and distance to the closest park from the 2006 ESRI ArcGIS data (Environmental Systems Research Institute, 2010), green canopy coverage (average of the percentages of tree canopy coverage within the tract) derived from the tree canopy dataset in the 2001 National Land Cover Database that provided tree canopy density at a spatial resolution of 30 m (Homer et al., 2007), county crime rate (number of crime per 100,000 persons, both Part I (e.g., murder, rape, robbery) and Part II (e.g., vandalism, weapons violations, gender offenses, drug and alcohol abuse violations) offenses from the 1998–2008 Uniform Crime Reporting Program data from the National Archive of Criminal Justice Data (National Archive of Criminal Justice Data, 1998–2008), and county EPA air quality nonattainment status from the Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency, 2006).

Two outcome measures were used to capture weight status: (1) a dichotomous variable indicating obesity ($BMI \geq 30$), and (2) a continuous BMI measure. Both variables were clinically measured in the NHANES.

The main explanatory variables were neighborhood SES and respondents' family income status. Neighborhood SES was measured by a tract-level factor score created based on four socioeconomic variables including: percent households with annual income at $75,000 or more (i.e., concentrated affluence as operationalized in previous work (Sampson, Morenoff, & Earls, 1999; Wen, Lauderdale, & Kandula, 2009)), percent residents living in poverty (i.e., concentrated poverty), percent college-educated residents (i.e., aggregate education), and percent owned houses (homeownership rate). These four area-based socioeconomic variables were conceptually and empirically clustered with factor loadings ranging from 0.67 (homeownership) to −0.87 (poverty rate) and a Cronbach alpha coefficient of 0.77. The factor score was created for all 64,791 tracts with non-zero population using 2000 Census data. All tracts were assigned one of the four quartiles: (1) low-SES tracts (bottom quartile), (2) midlow-SES tracts (25%–50% quartile), (3) midhigh-SES tracts (50%–75% quartile), and (4) high-SES tracts (top quartile).

Respondents' family income status was measured by family income-to-poverty threshold ratio (I/P), and divided into four mutually exclusive categories: (1) I/P < 1, (2) $1 \leq$ I/P < 2, (3) $2 \leq$ I/P < 3, and (4) I/P ≥ 3. Family income-to-poverty ratio was defined by family income divided by the US poverty thresholds, which was published by the US Bureau of the Census and varied by family size and number of children (US Bureau of the Census, 2001–2008). I/P is a better measure of family economic status than family income because it takes into account economies of scale (US Department of Health and Human Services, 2001–2016).

For descriptive statistics, SAS Proc Surveymeans with MEC weights (provided by NHANES) was used to account for NHANES's complex sample design. For multivariate analyses, random intercept multilevel models using Proc Glimmix were estimated, allowing intercepts to vary by tracts (Carle, 2009). Log likelihood ratio tests were used to test the significance of the moderating effects of gender and family income status. Multilevel regression analyses on weight status were conducted first in the whole sample finding significant effects of contextual SES net of a range of sociodemographic controls, including individual-level SES. Next, multilevel regression analyses were performed by gender regardless of individual income (Böckerman, Johansson, Helakorpi, & Uutela, 2009; Chen & Crawford, 2012; Robert & Reither, 2004), followed by separate analyses by family I/P status, first without controls, then with individual controls, and then with additional neighborhood controls. Analyses were conducted remotely using SAS 9.2 on the secured server at the Research Data Center at CDC.

Results

Table 1 shows that, overall, the prevalence of obesity was higher for lower-income women (40% and 39% for the two lower-income groups) than for higher-income women (35% and 31% for the two higher-income groups). However, men in the poorest group had the lowest prevalence of obesity (26%), followed by men with I/P between 1 and 2 (30%) (Table 2). The highest prevalence of obesity for men was 32% for those with I/P between 2 and 3. BMI followed the same pattern.

On average, lower-income individuals were younger and less educated, more likely to be Black or Hispanic, and more likely to be foreign-born. They were more likely to live in tracts with higher population density, older housing, and better street connectivity, all indicators of more walkable urban neighborhoods. Lower-income individuals were also more likely to live in tracts with a longer distance to the nearest park and to live in food deserts, although that was likely an artifact of the USDA food desert definition as only low-income neighborhoods were qualified to be designated as food deserts (U.S. Department of Agriculture, 2009).

Tables 1 and 2 also show a strong pattern of residential segregation by income, in that individuals tended to live in tracts where the tract SES was similar to their own income status. Tables 3 and 4 present descriptive and multilevel regression estimates for the association between tract SES and obesity/BMI for women and men, respectively. The first column shows estimates for obese prevalence and mean BMI by tract SES status, followed by estimates from three sets of models. Model 1 only had the tract SES variables. Model 2 added all individual controls. Model 3 further added neighborhood built-environment controls. For the tract SES variables, midhigh-SES tract was used as the reference category because individuals living in midnight-SES tracts had weighted obesity rate/mean BMI similar to those for the entire sample and could

Table 1
Descriptive statistics for BMI, obesity, and explanatory variables by family income to poverty ratio for **women**: 2001–2008 National Health and Nutrition Examination Survey (NHANES).

Variable	Women I/P < 1	Women I/P 1-2	Women I/P 2-3	Women I/P ≥ 3	Statistical significance for group differences
	n = 1926	n = 2454	n = 1776	n = 3369	
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	
Obese	39.7% (1.6%)	38.6% (1.3%)	35.4% (1.4%)	30.6% (0.9%)	***
BMI	29.35 (0.25)	29.15 (0.17)	28.69 (0.21)	27.87 (0.15)	***
Age	40.74 (0.62)	48.21 (0.65)	48.87 (0.50)	46.70 (0.33)	***
Race/ethnicity:					
White	49.8% (3.5%)	63.1% (2.5%)	72.1% (2.2%)	81.5% (1.3%)	***
Black	21.3% (2.1%)	15.2% (1.4%)	11.9% (1.1%)	7.7% (0.9%)	***
Hispanic	23.6% (2.8%)	16.9% (1.6%)	10.2% (1.2%)	5.7% (0.5%)	***
Other race	5.3% (0.8%)	4.9% (0.8%)	5.8% (0.9%)	5.1% (0.4%)	
Foreign-born	22.8% (2.0%)	16.9% (1.5%)	13.1% (1.6%)	9.8% (0.7%)	***
Education:					
< High school	40.5% (2.0%)	29.4% (1.8%)	16.9% (0.9%)	7.0% (0.6%)	***
High school	26.6% (1.7%)	30.7% (1.4%)	31.7% (1.4%)	20.1% (0.9%)	***
Some college	26.8% (1.7%)	29.7% (1.6%)	35.1% (1.5%)	34.1% (1.1%)	***
College or more	5.4% (0.8%)	9.8% (1.0%)	15.9% (1.1%)	38.7% (1.3%)	***
I/P	0.59 (0.01)	1.47 (0.01)	2.51 (0.01)	4.44 (0.02)	***
Tract SES status:					
Low-SES tract	44.1% (2.8%)	29.7% (2.3%)	17.4% (1.7%)	8.3% (1.0%)	***
Midlow-SES tract	28.4% (2.8%)	30.7% (2.4%)	28.4% (2.9%)	20.0% (2.4%)	***
Midhigh-SES tract	20.2% (1.9%)	28.9% (2.3%)	33.2% (2.2%)	33.8% (2.3%)	***
High-SES tract	7.3% (1.3%)	10.8% (1.4%)	20.9% (2.4%)	37.9% (3.1%)	***
Tract built environment:					
Tract population density	6.13 (0.92)	4.73 (0.64)	4.12 (0.56)	3.22 (0.31)	**
Tract housing age	34.54 (0.79)	31.87 (0.94)	30.64 (0.73)	28.26 (0.79)	***
Tract street connectivity	97.11 (11.63)	78.50 (5.66)	76.33 (5.13)	73.87 (5.00)	***
Tract greenness	20.00 (2.11)	21.29 (2.11)	22.08 (1.66)	22.94 (1.59)	*
Distance to closest park	5.34 (0.83)	5.45 (0.74)	4.50 (0.56)	4.20 (0.56)	***
Tract food desert	15.0% (2.0%)	12.6% (1.7%)	7.2% (1.1%)	4.0% (0.7%)	***
County poor air quality	54.7% (4.4%)	53.1% (4.4%)	56.6% (4.9%)	59.6% (5.0%)	
County crime rate	4243.14 (182.26)	4086.05 (183.85)	4018.49 (183.34)	3979.15 (198.92)	

Note: BMI = body mass index. SES = socioeconomic status. I/P = income-to-poverty ratio.
*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$ for overall group differences based on logliklihood ratio tests for categorical variables and F-tests for continuous variables.

Table 2
Descriptive statistics for BMI, obesity, and explanatory variables by family income to poverty ratio for **men**: 2001–2008 National Health and Nutrition Examination Survey (NHANES).

Variable	Men I/P < 1	Men I/P 1-2	Men I/P ≥ 3	Men I/P ≥ 3	Statistical significance for group differences
	n = 1731	n = 2444	n = 1897	n = 3851	
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	
Obese	25.8% (1.3%)	29.7% (1.2%)	32.3% (1.5%)	31.1% (0.9%)	***
BMI	27.33 (0.19)	28.05 (0.16)	28.41 (0.19)	28.43 (0.10)	***
Age	38.15 (0.53)	44.02 (0.58)	45.50 (0.62)	45.57 (0.33)	***
Race/ethnicity:					
White	47.9% (3.5%)	59.0% (2.7%)	69.9% (2.0%)	82.0% (1.2%)	***
Black	17.2% (1.6%)	13.7% (1.3%)	11.3% (1.1%)	7.3% (0.7%)	***
Hispanic	28.8% (3.0%)	21.8% (1.9%)	13.9% (1.3%)	5.8% (0.6%)	***
Other race	6.1% (1.1%)	5.5% (0.9%)	4.9% (0.6%)	4.9% (0.5%)	
Foreign-born	29.9% (2.8%)	23.5% (1.8%)	16.8% (1.7%)	9.9% (0.8%)	***
Education:	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	0.0% (0.0%)	
< High school	43.6% (1.7%)	35.6% (1.4%)	18.2% (1.3%)	8.7% (0.7%)	***
High school	26.5% (1.9%)	30.3% (1.4%)	33.3% (1.4%)	23.0% (0.9%)	***
Some college	21.9% (1.4%)	24.7% (1.5%)	30.9% (1.3%)	30.4% (0.9%)	***
College or more	7.2% (1.0%)	8.7% (0.9%)	16.8% (1.4%)	37.8% (1.4%)	***
I/P	0.61 (0.01)	1.49 (0.01)	2.53 (0.01)	4.46 (0.01)	***
Tract SES status:					
Low-SES tract	45.0% (3.3%)	31.6% (2.6%)	18.9% (1.8%)	8.6% (1.0%)	***
Midlow-SES tract	26.3% (2.5%)	30.4% (2.5%)	29.2% (2.9%)	20.7% (2.4%)	***
Midhigh-SES tract	21.7% (2.0%)	27.1% (2.3%)	32.0% (2.1%)	33.7% (2.4%)	***
High-SES tract	7.0% (1.1%)	11.0% (1.4%)	19.8% (2.3%)	37.0% (3.0%)	***
Tract built environment:					
Tract population density	6.51 (1.11)	5.27 (0.80)	4.55 (0.73)	3.45 (0.35)	**
Tract housing age	33.97 (0.78)	32.07 (1.02)	30.79 (0.85)	28.71 (0.77)	***
Tract street connectivity	92.85 (9.22)	78.61 (5.78)	78.40 (5.52)	75.06 (4.99)	*
Tract greenness	19.51 (2.04)	21.50 (2.05)	21.97 (1.74)	22.01 (1.45)	
Distance to closest park	5.11 (0.75)	5.69 (0.75)	4.74 (0.62)	4.07 (0.53)	***
Tract food desert	13.2% (2.4%)	12.5% (1.9%)	8.3% (1.3%)	4.4% (0.7%)	***
County poor air quality	55.0% (4.4%)	52.0% (4.4%)	58.6% (5.0%)	60.0% (4.9%)	***
County crime rate	4258.79 (174.65)	4022.36 (179.07)	4119.13 (199.02)	4010.31 (197.69)	*

Note: BMI = body mass index. SES = socioeconomic status. I/P = income-to-poverty ratio.
*p < 0.1, **p < 0.05, ***p < 0.01 for overall group differences based on logliklihood ratio tests for categorical variables and F-tests for continuous variables.

thus be roughly seen as the "national average".

Descriptive statistics show a clear pattern of negative association between obesity/BMI and tract SES for women. The estimated obesity prevalence was 41.7%, 38.8%, 32.8%, and 26.4% for women living in low-, midlow-, midhigh- and high-SES tracts, while the estimated mean BMI was 29.72, 29.02, 28.39, and 27.15, respectively. These differences were statistically significant (Model 1) and remained significant after controlling for individual (Model 2) and built-environment variables (Model 3) for the obesity model, while losing statistical significance for the midlow-SES tracts only for the BMI model. When the four income groups were examined separately, the association between tract SES and obesity/BMI was statistically insignificant for women below poverty. For the three groups of women with income above poverty, higher tract-SES status was mostly significantly associated with lower rate of obesity without controls (Model 1). After individual factors were controlled for (Model 2), compared with women in midhigh-SES tracts, living in low-SES tracts was associated with 25%, 37%, and 25% higher odds of being obese for women with $1 \leq I/P < 2$, $2 \leq I/P < 3$ and $I/P \geq 3$, respectively, while living in high-SES tracts was associated with 22% and 27% lower odds of being obese for women with $2 \leq I/P < 3$ and $I/P \geq 3$ only. Further controlling for built-environment variables (Model 3) rendered none of the tract SES variables significant for women with $1 \leq I/P < 2$. For women with $2 \leq I/P < 3$, living in low-SES tracts was associated with 33% higher odds of being obese than those living in midhigh-SES tracts, while for women with $I/P \geq 3$, living in low-SES tracts was associated with 29% higher odds of being obese but living in high-SES tracts was associated with 25% lower odds of being obese, both compared with midhigh-SES tracts. The BMI models show similar patterns as the obesity models but with a smaller number of significant associations. The association between tract SES and BMI was statistically insignificant for women in the two lower income groups after controlling for individual factors. For the two higher-income groups, only living in high-SES tracts was significantly associated with lower BMI in all three models, compared with living in midhigh-SES tracts.

For men as a whole (Table 4), most of the relationship between tract-SES and obesity/BMI was statistically insignificant at the descriptive level, with the only exception being men in high-SES tracts, who had 18% lower odds of being obese compared with men in midhigh-SES tracts (Model 1). That was reduced to 13% lower odds when individual and built-environment variables were controlled for (Model 3). When individual factors (Model 2) and built-environment factors were controlled for (Model 3), midlow-SES tracts showed statistically significant 14% and 15% higher odds of being obese, compared with midhigh-SES tracts for all men. When the four income groups were examined separately, the association between tract SES and obesity/BMI was statistically insignificant for the lowest- ($I/P < 1$) and highest-income ($I/P \geq 3$) men in the models with controls (Models 2 and 3). For the two middle-income groups, after both sets of controls, men living in midlow-SES tracts had 28% higher odds of being obese than men living in midhigh-SES tracts, where there were no significant differences among individuals living in the other three SES tracts. The BMI models showed a similar pattern, in that the midlow-SES tracts was associated with elevated BMI for Men with $2 \leq I/P < 3$.

For control variables (results not presented in tables but available upon request), the two most consistent individual factors associated with obesity/BMI were age and being foreign-born, with older age associated with higher BMI and higher odds of obesity and being foreign-born associated with lower BMI and lower odds of obesity. In addition, with the exception of men in the two lower-income groups, Blacks and Hispanics had higher BMI and higher odds of obesity than Whites; and college education was associated with lower BMI and lower odds of obesity. Family I/P and obesity/BMI had opposite associations

Table 3
Association between odds of obesity and BMI with tract SES by family income-to-poverty ratio for **women**: 2001–2008 National Health and Nutrition Examination Survey (NHANES).

Variable	Obese	Regression results: Odds Ratio for obese = 1			BMI	Regression results: Coefficient for BMI		
	Percent (SE)	Model 1	Model 2	Model 3	Mean (SE)	Model 1	Model 2	Model 3
All women:								
Low-SES tract	41.7% (1.5%)	1.46 ***	1.21 ***	1.21 **	29.72 (0.22)	1.33 ***	0.48 **	0.49 **
Midlow-SES tract	38.8% (1.1%)	1.29 ***	1.16 **	1.16 **	29.02 (0.17)	0.63 ***	0.17	0.14
Midhigh-SES tract	32.8% (1.2%)	Ref.	Ref.	Ref.	28.39 (0.19)	Ref.	Ref.	Ref.
High-SES tract	26.4% (1.0%)	0.73 ***	0.78 ***	0.79 ***	27.15 (0.16)	−1.23 ***	−0.88 ***	−0.84 ***
Women I/P < 1:								
Low-SES tract	42.1% (2.4%)	1.24	1.04	1.09	29.93 (0.34)	1.09	0.40	0.73
Midlow-SES tract	40.3% (2.2%)	1.14	1.01	1.01	29.24 (0.34)	0.39	−0.19	−0.08
Midhigh-SES tract	37.0% (3.7%)	Ref.	Ref.	Ref.	28.85 (0.55)	Ref.	Ref.	Ref.
High-SES tract	30.6% (5.4%)	0.75	0.73	0.71	27.71 (0.82)	−1.13	−0.44	−0.50
Women I/P 1–2:								
Low-SES tract	42.3% (2.6%)	1.42 **	1.25 *	1.20	29.91 (0.39)	1.25 **	0.31	0.12
Midlow-SES tract	41.5% (2.1%)	1.37 **	1.22	1.20	29.31 (0.33)	0.64	−0.03	−0.18
Midhigh-SES tract	34.1% (2.2%)	Ref.	Ref.	Ref.	28.67 (0.29)	Ref.	Ref.	Ref.
High-SES tract	32.4% (4.0%)	0.92	1.04	1.04	27.92 (0.59)	−0.75	−0.29	−0.19
Women I/P 2–3:								
Low-SES tract	40.9% (2.4%)	1.38 ***	1.37 **	1.33 *	29.51 (0.39)	0.82 *	0.57	0.49
Midlow-SES tract	39.7% (2.8%)	1.31 *	1.14	1.15	29.20 (0.43)	0.51	0.16	0.11
Midhigh-SES tract	33.4% (2.2%)	Ref.	Ref.	Ref.	28.69 (0.33)	Ref.	Ref.	Ref.
High-SES tract	28.2% (2.7%)	0.78 *	0.73 *	0.79	27.32 (0.33)	−1.36 ***	−1.19 **	−0.99 **
Women I/P ≥ 3:								
Low-SES tract	40.6% (3.0%)	1.49 ***	1.25 *	1.29 *	29.24 (0.40)	1.16 **	0.61	0.67
Midlow-SES tract	35.7% (2.1%)	1.21	1.16	1.21	28.63 (0.24)	0.55	0.48	0.55
Midhigh-SES tract	31.4% (1.8%)	Ref.	Ref.	Ref.	28.08 (0.30)	Ref.	Ref.	Ref.
High-SES tract	25.0% (1.3%)	0.73 ***	0.77 ***	0.75 ***	26.99 (0.22)	−1.09 ***	−0.84 ***	−0.90 ***

Note: BMI = body mass index. SES = socioeconomic status. I/P = income-to-poverty ratio.
Note: Reference group is "low SES tract". Model 1 did not have controls. Model 2 added the following individual level controls: age, age squared, race/ethnicity (white as reference group, black, Hispanic, and other race), foreign-born, education (less than high school, high school as reference group, some college, and college), and family income-to-poverty ratio. Model 3 further added these tract-level built environment controls: population density, median housing age, street connectivity, green canopy coverage, distance to the closest park, USDS food desert status, county crime rate, and county EPA air quality status.
$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

for women and men, with higher family I/P generally associated with lower BMI and lower odds of obesity for women but higher BMI and higher odds of obesity for men.

Neighborhood built environment variables were largely statistically insignificant in both the obesity and BMI models with a few exceptions. For women, newer neighborhoods and lower street connectivity were associated with higher BMI and/or higher odds of obesity for women in the lowest and highest income groups, but with lower BMI and/or higher odds of obesity for two middle-income groups. For all men regardless of family income, statistically significant neighborhood factors associated with lower BMI and/or higher odds of obesity included: high tract population density, high street connectivity, high crime rate, and poor air quality. With separate models by family income status, population density only mattered for men in the two higher income groups, whereas neighborhood housing age only mattered for the second-lowest income group. No neighborhood built environment variables were statistically significant for the lowest income men.

Discussion

We analyzed US nationally representative data and found some evidence of associations between tract SES and obesity/BMI, net of a variety of individual and tract-level built environment characteristics. Consistent with our first hypothesis, we found that neighborhood SES association with weight status to be more consistent for women than men. Furthermore, the direction of the association showed a clear gradient pattern, with women living in higher SES tracts have healthier body weight than women living in lower SES tracts. When we investigated this association separately by women's family income status, we found that, consistent with our second hypothesis, this association was more likely to be present for higher-income women than for lower-income women. Indeed, for women in the two lower-income categories, after individual and built-environment factors were controlled for, there was no clear evidence of such an association.

For men, even at the descriptive level, a neighborhood SES health gradient with respect to obesity was not found. In fact, the highest obesity prevalence was among men living in midlow-SES tracts, not those living in low-SES tracts. Separate analyses by men's family income status show that this finding was mostly driven by men in the two middle-income groups. No other tract-SES and weight outcome association were found once individual and built-environment differences were controlled for.

The findings pertaining to women were consistent with our expectation that relationship between tract SES and weight status in the full sample was largely driven by the association among those with higher family income, which were consistent with findings by Lovasi et al. (Lovasi, Hutson, Guerra, & Neckerman, 2009) regarding the relationship between neighborhood built environment and BMI. The finding supports the idea that lower-income individuals may be less affected by neighborhood SES because lower individual income is often associated with a lower sense of self-control and self-efficacy (Bandura, 1986; Boardman & Robert, 2000; Gurin et al., 1978; Hughes & Demo, 1989), which may lead to lower motivations to take advantage of neighborhood resources for behavioral change. Lower-income individuals living in higher SES neighborhoods may also suffer more from stress related to relative deprivation than higher-income individuals living in lower-SES neighborhoods. Unfortunately, we did not have direct measures of these psychological concepts. Thus, these mechanisms remain as hypotheses that need further testing.

The finding that the association between neighborhood SES and obesity/BMI was statistically insignificant for men regardless of individual income was not consistent with findings by Matheson et al. (Matheson et al., 2008), who found that men living in affluent neighborhoods had higher BMI compared with men living in deprived

Table 4
Association between odds of obesity and BMI with tract SES by family income-to-poverty ratio for **men**: 2001–2008 National Health and Nutrition Examination Survey (NHANES).

Variable	Obese	Regression results: Odds Ratio for obese = 1			BMI	Regression results: Coefficient for BMI		
	Percent (SE)	Model 1	Model 2	Model 3	Mean (SE)	Model 1	Model 2	Model 3
All men:								
Low-SES tract	30.8% (1.3%)	0.99	1.00	1.07	28.08 (0.17)	−0.15	−0.05	0.20
Midlow-SES tract	33.5% (1.3%)	1.13	1.14 *	1.15 **	28.61 (0.18)	0.37	0.39 **	0.46 ***
Midhigh-SES tract	30.9% (1.3%)	Ref.	Ref.	Ref.	28.23 (0.15)	Ref.	Ref.	Ref.
High-SES tract	26.8% (1.3%)	0.82 **	0.89	0.87 *	27.98 (0.13)	−0.25	−0.13	−0.19
Men I/P < 1:								
Low-SES tract	26.5% (1.6%)	1.25	1.01	1.07	27.32 (0.25)	0.31	0.01	0.28
Midlow-SES tract	30.1% (3.2%)	1.50 *	1.11	1.13	27.89 (0.49)	0.89	0.45	0.54
Midhigh-SES tract	22.3% (2.7%)	Ref.	Ref.	Ref.	27.00 (0.37)	Ref.	Ref.	Ref.
High-SES tract	16.3% (4.6%)	0.68	0.75	0.80	26.41 (0.59)	−0.60	−0.14	−0.32
Men I/P 1–2:								
Low-SES tract	29.9% (2.4%)	1.12	0.97	1.07	28.05 (0.29)	0.26	−0.27	−0.10
Midlow-SES tract	33.8% (2.1%)	1.34 *	1.09	1.28 *	28.48 (0.33)	0.69	0.19	0.27
Midhigh-SES tract	27.6% (2.4%)	Ref.	Ref.	Ref.	27.79 (0.29)	Ref.	Ref.	Ref.
High-SES tract	23.2% (2.9%)	0.79	0.87	0.97	27.47 (0.45)	−0.32	0.02	−0.13
Men I/P 2–3:								
Low-SES tract	30.6% (2.4%)	0.90	0.97	1.07	28.28 (0.32)	−0.08	0.15	0.52
Midlow-SES tract	36.2% (3.4%)	1.15	1.29 *	1.28 *	28.90 (0.42)	0.54	0.65 *	0.72 **
Midhigh-SES tract	33.0% (2.0%)	Ref.	Ref.	Ref.	28.36 (0.22)	Ref.	Ref.	Ref.
High-SES tract	27.0% (3.3%)	0.75	0.93	0.97	27.88 (0.43)	−0.48	0.10	0.15
Men I/P ≥ 3:								
Low-SES tract	37.0% (2.6%)	1.23	1.07	1.16	28.82 (0.34)	0.34	0.02	0.30
Midlow-SES tract	32.9% (1.9%)	1.03	1.03	1.04	28.72 (0.22)	0.24	0.18	0.27
Midhigh-SES tract	32.3% (1.7%)	Ref.	Ref.	Ref.	28.48 (0.20)	Ref.	Ref.	Ref.
High-SES tract	27.5% (1.4%)	0.79 **	0.92	0.91	28.12 (0.12)	−0.36	−0.15	−0.23

Note: BMI = body mass index. SES = socioeconomic status. I/P = income-to-poverty ratio.
Note: Reference group is "low SES tract". Model 1 did not have controls. Model 2 added the following individual level controls: age, age squared, race/ethnicity (white as reference group, black, Hispanic, and other race), foreign-born, education (less than high school, high school as reference group, some college, and college), and family income-to-poverty ratio. Model 3 further added these tract-level built environment controls: population density, median housing age, street connectivity, green canopy coverage, distance to the closest park, USDS food desert status, county crime rate, and county EPA air quality status.
*p < 0.1, **p < 0.05, ***p < 0.01.

neighborhoods using Canadian data. In addition to data from different countries as a possible reason for this difference in findings, it is likely that our more detailed classification of neighborhood SES (four categories vs their two) was able to capture the non-monotonic relationship between neighborhood SES and obesity for men. One possible explanation is that men living in low-SES neighborhoods were more likely to have manual labor jobs that increased their physical activity, but men living in midlow-SES neighborhoods, while having moved away from manual labor, had yet to establish habits of leisure-time physical activity. The finding that the midlow-SES tract effect was statistically significant only for the two middle-income groups (i.e., $1 \leq I/P < 3$) is consistent with this possible explanation.

This study is cross-sectional in nature, and as such, only association between neighborhood SES and individual weight status can be ascertained, and neighborhood self-selection bias cannot be effectively teased out. Future work should use panel data to better adjust for self-selection. Nevertheless, our findings based on a nationally representative sample are important because we address important interacting effects of individual factors and neighborhood characteristics that have not been adequately addressed in the literature. The finding that both gender and family income status are important moderators of the neighborhood SES and obesity relationship has implications for both public health policies and for researchers alike. For example, given that the prevalence of obesity is higher among women than men in the US (Centers for Disease Control and Prevention, 2019), public health policies that improve neighborhood SES are likely to benefit women more than men, therefore narrowing the gender obesity gap. For future research on neighborhood factors and individual health outcomes for women, it is important to test family income as a moderator to investigate if such interaction effect exists in other health outcomes. For men, the role of occupation as a moderator is important to explore. Future research should also directly test the mechanisms under such interaction effects to further our understanding of the relationship between neighborhood SES and individual health outcomes.

Ethical statement

The authors declare that the work described has not been published previously, nor is it under consideration for publication elsewhere. This submission is approved by all authors. If accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

Declaration of competing interest

None.

CRediT authorship contribution statement

Jessie X. Fan: Conceptualization, Methodology, Data curation, Formal analysis, Writing - original draft. **Ming Wen:** Funding acquisition, Conceptualization, Methodology, Data curation, Writing - review & editing. **Kelin Li:** Writing - review & editing.

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