Psychological and Biological Pathways Linking Perceived Neighborhood Characteristics and Body Mass Index

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Published online: 15 December 2018

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Abstract

Background Perceived neighborhood characteristics are linked to obesity, however, the mechanisms linking these two factors remain unknown.

Purpose This study aimed to examine associations between perceived neighborhood characteristics and body mass index (BMI), establish whether indirect pathways through psychological distress and inflammation are important, and determine whether these associations vary by race/ethnicity.

Methods Participants were 1,112 adults enrolled in the Texas City Stress and Health Study. Perceived neighborhood characteristics were measured using the Perceived Neighborhood Scale. Psychological distress was measured with the Center for Epidemiological Studies Depression Scale, Perceived Stress Scale and mental health subscale of the Short Form Health Survey-36. Markers of inflammation included C-reactive protein, interleukin-6, and tumor necrosis factor receptor-1. Associations were examined with Structural Equation Modeling.

Results A model linking neighborhood characteristics with BMI through direct and indirect (i.e., psychological

distress and inflammation) paths demonstrated good fit with the data. Less favorable perceived neighborhood characteristics were associated with greater psychological distress ($B = -0.87, \beta = -0.31, p < .001$) and inflammation ($B = -0.02, \beta = -0.10, p = .035$). Psychological distress and inflammation were also significantly associated with BMI ($B_{\text{distress}} = 0.06, \beta = 0.08, p = .006$; $B_{\text{inflammation}} = 4.65, \beta = 0.41, p < .001$). Indirect paths from neighborhood characteristics to BMI via psychological distress ($B = -0.05, \beta = -0.03, p = .004$) and inflammation ($B = -0.08, \beta = -0.04, p = .045$) were significant. In multiple group analysis, a model with parameters constrained equal across race/ethnicity showed adequate fit suggesting associations were comparable across groups.

Conclusion Our study extends the literature by demonstrating the importance of neighborhood perceptions as correlates of BMI across race/ethnicity, and highlights the role of psychological and physiological pathways.

Keywords Obesity • Inflammation • Neighborhood factors • Stress • Depression • Ethnic minorities • Indirect effects • Structural equation modeling

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Introduction

Obesity is a growing epidemic and public health concern both in the USA and globally. In spite of prevention efforts, national estimates demonstrate that the prevalence of obesity continues to increase [1]. In fact, for the years 2013–2014, the prevalence of obesity in the USA was 35.2% among men and 40.5% among women and significantly varied by race/ethnicity, with ethnic minorities being disproportionately affected by this condition. Therefore, identifying social, behavioral, and physiological determinants of obesity, particularly among ethnic minorities, is an important step towards developing effective interventions aimed

at ameliorating health disparities and controlling the obesity epidemic.

Neighborhood characteristics are important correlates of obesity. Characteristics of the neighborhood environment encompass aspects of the person's man-made surroundings (built environment), such as recreational centers, parks, playgrounds, and supermarkets [2]. A significant amount of research to date has been devoted to examining the association between the built environment and obesity [3]. The extent of opportunities for calorie intake and calorie expenditure, or a lack thereof, in one's built environment appears to be an important determinant of obesity. Neighborhoods with access to different types of restaurants may impact individual's dietary behavior, and therefore, have an impact on obesity. For example, neighborhoods with access to different restaurants, including healthy options such as a salad bar, may promote the consumption of vegetables and a more balanced, low-calorie diet. On the other hand, some neighborhoods may be limited in access to only fast-food restaurants, which may promote the consumption of high-fat foods. Similarly, levels of physical activity may be determined by whether there is access to recreational or sports facilities. Easy access to parks or gyms, for example, may promote physical activity, and therefore, reduce obesity risk. In fact, various reports show that physical activity is an important mediator linking neighborhood environment and obesity [4–6]. Based on these characteristics, researchers have defined certain environments as being more “obesogenic” than others [7–9].

While the association between the built environment and obesity is well established, fewer studies have investigated community and social characteristics as they relate to obesity. These factors include, for example, perceptions of neighborhood safety or crime, as well as characteristics of the social networks in the neighborhood such as sense of community and social embeddedness [10]. A growing body of literature indicates that these perceived neighborhood characteristics may also relate to obesity risk [11–14]. For example, social neighborhood characteristics are important correlates of obesity risk in children, young, and older adults [11–15]. However, little is known about the pathways linking community and social characteristics with obesity. Mechanistic hypotheses to date suggest neighborhood characteristics are associated with obesity through both psychological and biological pathways [16].

Neighborhood Characteristics, Psychological Distress, and Obesity

An important pathway that may account for the association between neighborhood characteristics and obesity is psychological distress. For the purpose of the current study, we refer to psychological distress as unpleasant

feelings or emotions that may impact individuals' functioning (e.g., depressive symptoms, perceived stress). Psychological distress is associated with obesity risk in both cross-sectional and longitudinal designs [17]. A meta-analysis of 15 studies including over 50,700 adults demonstrated that depression prospectively increased the odds of developing obesity by 58% [17]. Perceptions of less favorable neighborhood characteristics, in turn, have a strong effect on psychological distress [18]. For example, in a review of 45 studies, 37 out of 45 studies found a strong effect of neighborhood characteristic on psychological distress [18].

Neighborhood Characteristics, Inflammation, and Obesity

In addition to psychological distress, production of cytokines and acute-phase proteins are commonly associated with obesity [19]. While most work demonstrates that this inflammatory state is a result of expanding adipose tissue in overweight and obese individuals [20], other reports suggest that the relationship between inflammation and obesity may be bi-directional [21]. In fact, a prospective study of healthy adults demonstrated that those with low-grade inflammation, measured by C-reactive protein (CRP), at baseline were significantly more likely to develop abdominal obesity during the 11-year follow-up, particularly when the inflammation was accompanied by depressive symptoms [21]. Other prospective studies indicate that inflammation is associated with future weight gain among middle-aged and older adults [22]. In turn, some reports, including findings from the Multi-Ethnic Study of Atherosclerosis (MESA), indicate that neighborhood characteristics such as deprivation, neighborhood problems, safety, and cohesion are important determinants of inflammation [23–25].

The Present Study

In spite of these findings, no study to date has comprehensively assessed the multiple pathways by which neighborhood characteristics impact obesity. Furthermore, these associations have rarely been studied with the use of multiethnic samples of adults. It is now well established that pronounced differences exist in body mass index (BMI) and obesity rates among ethnic minority samples, with Non-Hispanic Blacks and Hispanics having the highest rates of obesity [26] and cardio-metabolic abnormalities [27]. In addition, ethnic minority individuals have higher levels of psychological distress [28], increased barriers to health care [29] and greater number of competing psychosocial demands [30]. Furthermore, individuals living in neighborhoods with greater racial and ethnic minority composition often rate

neighborhood characteristics, such as perceived crime or satisfaction with neighborhood, in a more negative light [31].

In light of these disparities, it is likely that the associations among neighborhood characteristics, psychosocial distress, inflammation, and obesity vary significantly by race/ethnicity. Therefore, this study took advantage of a diverse sample of adults which included Non-Hispanic Whites, Non-Hispanic Black and Hispanic individuals, and aimed to [1] examine the association between perceived neighborhood characteristics and BMI [2], establish whether indirect effects from neighborhood characteristics to BMI via psychological distress and inflammation are present, and [3] determine whether these associations significantly vary by race/ethnicity.

Materials and Methods

Study Sample

This study used data from the Texas City Stress and Health Study (TCSHS), a social epidemiological study undertaken in a mid-sized city in the gulf coast of Texas to investigate the effect of contextual, environmental, psychological, and biological risk factors on the health of minority populations.

Multistage sampling methods were used to select participants. Forty-eight neighborhoods were included in the study. Neighborhood selection was implemented using the Socio-spatial Neighborhood Estimation Method (SNEM). An exhaustive list of housing units in these neighborhoods was then created. From this listing, housing units were classified as Hispanic or other (Non-Hispanic White or Non-Hispanic Black), with Hispanic and “Non-Hispanic Black” households defined as having at least one member in the household being Hispanic or Non-Hispanic Black, respectively. One in eight non-Hispanic White and non-Hispanic Black households were selected for the study, with one adult aged 25 years or older randomly selected from the household. One adult was also randomly selected (based on the Kish Method) from each Hispanic household that did not have an adult aged 65 or older. In Hispanic households with adults aged 65 years or older ($N = 91$), all Hispanic adults aged 65+ were selected for participation. Selected participants were interviewed in their homes. In addition to the survey, participants were also given the option to provide blood samples during a clinic visit. Height (self-reported) and weight (objectively measured and self-reported) information was also collected from participants during this visit. Further details about data collection have been described in prior work [32].

The interview response rate was 80% and participants in the final baseline sample included 2,706 adults ages 25 years and older. Our analytical sample included 1,112 participants. Participants were excluded due to missing data on inflammatory markers ($N = 1,305$), weight ($N = 1$), psychosocial scales ($N = 266$), or demographic characteristics ($N = 22$). The high proportion of missing data on inflammatory markers was due to the fact that participants were given the option to elect to provide blood samples during the study. Demographic comparisons of those who gave blood samples and those who did not revealed that, in the group that gave blood, there was a slightly higher percentage of women than men (55.7% vs. 52.0%, $p = .06$) and a higher percentage of Non-Hispanic Whites (57.9%) than Hispanics (46.0%) or Non-Hispanic Blacks (53.6%) ($p < .001$). In addition, people who participated by giving a blood sample were older (51.9 vs. 45.7 years, $p < .001$). Compared to participants excluded due to missing data (on either variable), participants retained in the analytical sample were comparable in terms of gender and education ($p > .05$). However, retained participants were more likely to be older (51.7 vs. 46.88 years, $p < .001$), more likely to be Non-Hispanic Whites (39.0% vs. 31.2%, $p < .001$) and more likely to be unemployed (50.5% vs. 39.9%, $p < .001$). The study protocol was approved by the University of Texas Medical Branch (UTMB) Institutional Review Board, and informed consent was obtained from all participants. Participants were compensated \$50 for their participation in this study.

Measures

Perceived neighborhood characteristics

Four subscales of the Perceived Neighborhood Scale [10] were used as indicators of neighborhood characteristics, namely: (a) social embeddedness (nine items), which measures the degree of formal and informal linkages that residents in a neighborhood develop and the frequency of social interaction among neighbors; (b) sense of community (seven items), which measures feelings of membership and belongingness, trust and mutual influence, and shared socio-emotional ties with others in the neighborhood; (c) satisfaction with neighborhood (six items), which evaluates the quality of a physical environment from a cognitive-affective dimension; and (d) perceived crime (six items), which measures perceptions of threat, crime, and social disorder in a residential environment. Respondents expressed their level of agreement with items using a five-point Likert-type scale. Negatively worded items were reverse coded so that higher scores denote an increasing degree of the dimension assessed. For the perceived crime, subscale higher scores denote lower perceived crime.

Reliability coefficients (Cronbach's alpha) for the social embeddedness, sense of community, satisfaction with neighborhood, and perceived crime were 0.78, 0.84, 0.80, and 0.83, respectively. This indicates the subscales had overall good internal consistency.

BMI

The outcome of interest in our study was the participants' BMI, weight in kilograms divided by the square of height in meters – kg/m^2 . Self-reported height was used for this calculation. Weight in kilograms was recorded one time by trained clinical staff during the participant's visit to the phlebotomy clinic using a regularly calibrated digital scale. A total of 38 participants (3.42%) did not have available data on objectively measured weight. Self-reported weight in kilograms was used to calculate the BMI of these 38 participants. All data were cleaned by the data management team to ensure body size data were all biologically plausible. To this end, the values for the self-reported height and weight variables were examined and outlier detection analyses were performed before descriptive and inferential statistical analyses. The values for self-reported height ranged from 121 to 201 cm, and weight values ranged from 38 to 215 kg. These data were biologically plausible and normally distributed. Exclusion of extreme values did not alter the results presented; therefore, all data were retained. BMI was used as a continuous variable in all analyses. BMI categories are displayed as descriptive characteristics of the sample. The World Health Organization BMI categories were used for this analysis: underweight ($\text{BMI} < 18.5 \text{ kg}/\text{m}^2$), normal weight ($\text{BMI} \leq 18.5 \text{ kg}/\text{m}^2$), overweight ($\text{BMI} \leq 25 \text{ kg}/\text{m}^2$), and obese ($\text{BMI} \leq 30 \text{ kg}/\text{m}^2$) [33].

Psychological distress

Total scores for three mental health measures, the Center for Epidemiologic Studies Depression Scale-Revised (CESD-R) [34], the Perceived Stress Scale (PSS) [35], and the mental health subscale (MHS) of the Short Form (36) Health Survey (SF-36) [36] were used as indicators of psychological distress. The CESD-R is a widely used 20-item measure used to assess for symptoms of depression during the prior 2 weeks based on Diagnostic and Statistical Manual (DSM) diagnosis. Responses are provided on a scale ranging from 0 (rarely) to 3 (most or all of the time), so that higher scores denote higher depressive symptoms. The Cronbach's alpha coefficient for the CESD-R in our sample was 0.93 indicating excellent internal consistency. The PSS is a 10-item scale used to measure perceived life stress. Responses are provided on a scale ranging from 0 to 4 in which higher scores denote higher levels of perceived stress. The PSS has been previously used with diverse populations

[35] and is known to have good validity and reliability. The Cronbach's alpha coefficient for the PSS was 0.86 indicating good internal consistency. The MHS of the SF-36 [36] is self-reported measure of psychological well-being. This subscale includes five items ranging from 1 to 5; therefore, overall raw subscale scores range from 5 to 25 with higher scores denoting better mental health. The Cronbach's alpha coefficient for the CESD-R was 0.86 indicating good internal consistency.

Inflammation

Markers of inflammation included CRP, interleukin-6 (IL-6), and tumor necrosis factor receptor-1 (TNF-r1). TNF-r1 was utilized instead of tumor necrosis factor alpha (TNF- α) given that TNF- α has a short half-life of approximately 15 min, is more easily detectible than TNF- α , and has been described as a surrogate marker of TNF- α [37]. A commercially available kit was utilized to measure CRP (high sensitivity; Diagnostic Systems Laboratories, Webster, TX; limit of detection [LOD] = 0.1 mg/L; coefficient of variation [COV] < 5%). IL-6 was measured using OptEIA assay kits from BD Pharmingen (San Diego, CA; LOD = 2.2 pg/mL; COV < 10%) and TNF-r1 was measured using R&D Systems DuoSet assay kits (Minneapolis, MN; LOD = 10 pg/mL; CV < 10%). Microgen laboratories completed all assays. Further details on the validation of inflammatory markers in this multiethnic sample have been previously described [37, 38].

Covariates

Age, gender, race/ethnicity, and education information were collected via clinical questionnaires and were included in regression models as covariates. Age and education (years of education) were used as continuous variables, whereas categorical variables included gender, and race/ethnicity. Gender (1 = women, 0 = men) was dichotomized for regression analysis. Race/ethnicity categories, Non-Hispanic White, Non-Hispanic Black and Hispanic, were used in multiple group analyses.

Statistical Analysis

Preliminary statistical analyses included descriptive statistics and assessment of normality distributions. Inflammatory markers, CRP, IL-6, and TNF-r1 were log-transformed due to having non-normal distributions. Data for continuous variables are presented as means and standard deviations and were compared between groups using independent *t*-tests or nonparametric tests, as appropriate. Categorical variables are presented as percentages and were compared with the chi-squared test.

Structural equation modeling (SEM) was used to examine associations among variables and indirect

effects. All analyses accounted for clustering by neighborhood (48 clusters). Measurement models were fitted first to examine fit with the data. Several indicators including the comparative fit index (CFI), root mean squared error of approximation (RMSEA), and the average of the standardized residuals (SRMR) were used to evaluate model fit. The chi-square tests were not used as it has been shown to be sensitive to sample size [39]. Structural regression models, which included both direct and indirect paths, were fitted next and assessed for model fit. Once a final model was established, it was reassessed using multiple group comparisons to examine racial/ethnic differences. Within this approach, the model was estimated for Non-Hispanic Whites, Non-Hispanic Blacks and Hispanics separately but simultaneously. Factor loadings, factor covariances and regression paths were constrained to be equal across groups and model fit was once again assessed. Mplus version 7.0 was used for all SEM analyses.

Results

Descriptive Statistics

Our sample comprised 1,112 individuals, 655 women (58.90%) and 457 men (41.10%). Approximately 50.60% of adults identified as Hispanic, 39.00% identified as Non-Hispanic White, and 10.30% identified as Non-Hispanic Black. Mean age was 51.73 ($SD = 15.76$). Adults had on average 11.66 ($SD = 3.26$) years of education. Furthermore, mean BMI was 30.78 kg/m^2 ($SD = 7.28$) and 31.50% and 47.90% of the sample fell in the overweight and obese category, respectively. BMI values ranged from 12.95 kg/m^2 to 60.00 kg/m^2 . There were significant differences in various demographic, contextual, psychological, and biological factors by race/ethnicity. Detailed characteristics of the study sample by ethnicity are described in Table 1.

Measurement Models

Measurement models were first fitted separately for the Perceived Neighborhood Characteristics, the Psychological Distress, and the Inflammation latent factors. The Perceived Neighborhood Characteristics measurement model showed excellent fit with the data, as evidenced by the following indexes: CFI = 1.00, RMSEA = 0.00, SRMR = 0.00. Factor loadings were significant ($p < .001$) for all four indicators: Sense of Community (unstandardized = 1.00; standardized = 0.56), Satisfaction with Neighborhood (1.52; 0.95), Perceived Crime (1.25; 0.75), and Social Embeddedness (0.60; 0.35). Correlated residuals

were specified between the Sense of Community and the Social Embeddedness indicators. In the case of both the Psychological Distress and the Inflammation factors, model fit was not assessed given the model was *just identified* due to having only three indicators each. However, factor loadings for all indicators were significant for both the Psychological Distress: Depression (unstandardized = 1.00; standardized = 0.85), Perceived Stress (0.56; 0.73), Mental Health (−0.38; −0.90), and the Inflammation factors: CRP (1.00; 0.32), IL-6 (3.70; 0.60), and TNF- α (0.62; 0.55). A measurement model was also fitted to assess all three latent factors simultaneously. This model showed excellent fit with the data: CFI = 0.99, RMSEA = 0.04, SRMR = 0.04.

Structural Models

An initial structural model looking at the association between the Perceived Neighborhood Characteristics factor and BMI was first examined for model fit. The model controlled for age, gender and education. The model showed good fit with the data: CFI = 0.97, RMSEA = 0.07, SRMR = 0.03. The Perceived Neighborhood Characteristics factor was significantly associated with BMI ($B = -0.14$, $\beta = -0.07$, $p = .026$) after adjusting for age, gender, and education. Age and gender were also significantly associated with BMI ($B_{\text{age}} = -0.04$, $\beta = -0.08$, $p = .014$; $B_{\text{gender}} = 1.03$; $\beta = -0.07$, $p = .023$). Education was not significantly associated with BMI.

Next, the structural model depicted in Fig. 1 was evaluated for model fit. In addition to a direct path from Perceived Neighborhood Characteristics to BMI, paths were also specified from Perceived Neighborhood Characteristics to Psychological Distress and Inflammation, as well as from Psychological Distress and Inflammation to BMI. Furthermore, an indirect path was specified from Perceived Neighborhood Characteristics to BMI through Psychological Distress and through Inflammation. Age, gender, and education were also added to the model as control variables. The structural model demonstrated good fit with the data evidenced by the following fit indexes: CFI = 0.95, RMSEA = 0.06, SRMR = 0.04. The Perceived Neighborhood Characteristics factor was significantly associated with both Psychological Distress ($B = -0.87$, $\beta = -0.31$, $p < .001$) and Inflammation ($B = -0.02$, $\beta = -0.10$, $p = .035$). Psychological Distress and Inflammation were also significantly associated with BMI ($B_{\text{distress}} = 0.06$, $\beta = 0.08$, $p = .006$; $B_{\text{inflammation}} = 4.65$, $\beta = 0.41$, $p < .001$). After the inclusion of potential indirect pathways, the direct path from Perceived Neighborhood Characteristics to BMI was no longer

Table 1 Descriptive characteristics of the study sample

	Overall (<i>n</i> = 1,112)	NH Whites (<i>n</i> = 434)	NH Blacks (<i>n</i> = 115)	Hispanics (<i>n</i> = 563)	<i>p</i> -value*
	<i>M</i> (<i>SD</i>)/ <i>IQR</i>	<i>M</i> (<i>SD</i>)/ <i>IQR</i>	<i>M</i> (<i>SD</i>)/ <i>IQR</i>	<i>M</i> (<i>SD</i>)/ <i>IQR</i>	
Demographic Characteristics					
Age, years	51.73 (15.76)	55.09 (15.94)	51.51 (15.10)	49.19 (15.28)	<.001
Gender, % female	58.90	54.60	66.10	60.70	.038
Education, years	11.66 (3.26)	12.85 (2.49)	11.77 (3.18)	10.73 (3.49)	<.001
Contextual Factors					
Sense of Community	26.64 (6.46)	27.64 (5.94)	25.54 (6.95)	26.09 (6.65)	<.001
Satisfaction	22.83 (5.81)	23.12 (5.5)	20.53 (6.50)	23.08 (5.79)	<.001
Perceived Crime	23.59 (5.98)	23.93 (5.62)	21.53 (6.64)	23.75 (6.04)	<.001
Social Embeddedness	31.70 (6.24)	32.36 (5.81)	30.87 (7.07)	31.35 (6.34)	.013
Psychosocial Factors					
CES-D, Total Score	9.15 (11.19)	9.41 (10.73)	12.43 (12.72)	8.27 (11.09)	.001
PSS, Total Score	13.28 (7.22)	13.19 (7.34)	14.79 (7.2)	13.04 (7.1)	.057
SF36 Mental Health Subscale, Raw Score	20.20 (4.00)	20.07 (3.91)	19.00 (4.50)	20.55 (3.92)	<.001
SF36 Mental Health Subscale, Transformed Scale Score	76.01 (20.01)	75.34 (19.53)	70.00 (22.50)	77.76 (19.60)	<.001
Biological Outcomes					
CRP, mg/dL [†]	7.98 (3.06–19.03)	7.80 (3.00–18.29)	11.20 (4.67–22.13)	7.53 (2.88–18.02)	.015
Interleukin-6, pg/mL [†]	0.63 (0.01–2.03)	0.53 (0.01–1.80)	1.18 (0.01–2.73)	0.60 (0.01–2.04)	.013
TNF receptor-1, pg/mL [†]	1543.27 (1190.88–2028.68)	1635.98 (1218.61–2267.21)	1535.28 (1158.54–1968.2)	1474.09 (1169.95–1918.05)	.001
BMI, kg/m ²	30.78 (7.28)	30.24 (7.49)	33.30 (8.55)	30.69 (6.72)	<.001
BMI Category, %					.016
Normal Weight	20.30	24.90	13.90	18.70	
Overweight	31.50	29.70	27.80	33.60	
Obese	47.90	45.40	58.30	47.80	

**p*-value based on χ^2 (categorical), and ANOVA or Kruskal–Wallis test (continuous), comparing racial/ethnic differences for individual variables, [†]results are shown as median and interquartile range

BMI, Body mass index; *CRP*, C-reactive protein; *IQR*, Interquartile range; *M*, Mean; *SD*, Standard deviation; *TNF*, Tumor necrosis factor.

significant ($B = -0.02$, $\beta = -0.01$, $p = .805$). Assessment of indirect paths demonstrated that the indirect path from Perceived Neighborhood Characteristics to BMI via Psychological distress was significant ($B = -0.05$, $\beta = -0.03$, $p = .004$). Similarly, the indirect path from Perceived Neighborhood Characteristics to BMI via Inflammation was also significant ($B = -0.08$, $\beta = -0.04$, $p = .045$). A detailed description of parameter estimates in the model is presented in [Table 2](#).

In ancillary analysis, a model that included indirect paths from Perceived Neighborhood Characteristics to Inflammation through Psychological Distress and BMI was tested. Assessment of indirect paths demonstrated that the indirect path from Perceived Neighborhood Characteristics to Inflammation via BMI was significant ($B = -0.01$, $\beta = -0.03$, $p = .028$). The indirect path from Perceived Neighborhood Characteristics to

Inflammation via Psychological distress was not significant. Other parameter estimates in this model are presented in [Supplementary Table 2](#). Furthermore, in exploratory analysis, a structural model using depressive symptoms (CES-D scores) as a marker of psychological distress (instead of the latent variable approach) was tested. Results were unchanged. The indirect path from Perceived Neighborhood Characteristics to BMI via depressive symptoms was significant ($B = -0.04$, $\beta = -0.02$, $p = .005$).

Differences Across Ethnicity

Multiple group analyses were performed to compare the structural model across individuals of different ethnicities. The model with parameters (loadings and regression paths) constrained equal across

Fig. 1. Structural regression model linking neighborhood characteristics to body mass index. * $p < .05$. CES-D, Center for Epidemiological Studies Depression Scale; CRP, C-reactive protein; IL-6, Interleukin-6; PSS, Perceived Stress Scale; TNF- α , Tumor Necrosis Alpha Receptor-1.

ethnicities showed adequate fit to the data: CFI = 0.95, RMSEA = 0.04, SRMR = 0.06 suggesting the presence of comparable associations across Non-Hispanic White, Non-Hispanic Black and Hispanic adults. We conducted additional analyses using the χ^2 difference test to compare a fully constrained model to nested models where specific individual paths of interest were unconstrained. Results indicated that when compared to a fully constrained model, a model where the path from Perceived Neighborhood Characteristics to Psychological Distress was allowed to freely vary across groups did not fit the data significantly better ($\chi^2 \Delta = 0.008$, $df = 2$, $p > .05$). Similar results were observed for the path from Psychological Distress to BMI ($\chi^2 \Delta = 2.184$, $df = 2$, $p > .05$), Perceived Neighborhood Characteristics to Inflammation ($\chi^2 \Delta = 5.741$, $df = 2$, $p > .05$), and Inflammation to BMI ($\chi^2 \Delta = 2.079$, $df = 2$, $p > .05$). Therefore, the fully constrained model was retained indicating that associations of interest do not significantly vary across race/ethnicity. Furthermore, we conducted ancillary analysis testing the final structural model (depicted in Fig. 1) with race/ethnicity included as a *control* variable (in addition to age, gender, and education), and results were unchanged. In addition, multiple group analyses were conducted to compare the structural model across genders. The model with parameters (loadings and regression paths) constrained equal across genders showed adequate fit to the data: CFI = 0.95, RMSEA = 0.05, SRMR = 0.06 suggesting the presence of comparable associations across gender.

Discussion

In this paper, we used a diverse sample of adults to simultaneously examine, for the first time, potential psychological and biological pathways linking perceived neighborhood characteristics and BMI. Our results indicate that less favorable perceived neighborhood characteristics are associated with greater BMI. Indirect paths from perceived neighborhood characteristics to BMI via psychological distress and inflammation were significant. In addition, we provide novel data by demonstrating that these associations are comparable among three major race/ethnicities: Non-Hispanic White, Non-Hispanic Black, and Hispanic individuals.

Few reports have rigorously examined the role of psychological distress as a pathway linking neighborhood characteristics and BMI with only one study to date examining potential mediating pathways in this relationship [16]. In contrast with our findings, this study showed that depression did not mediate the association between neighborhood and obesity. Differences in the results are not attributable to differences in the assessment of psychological distress. Depressive symptoms, measured using the CES-D only, were used to examine potential mediation in the study by Sullivan et al. While our study used a latent variable approach to measure the theoretical construct of psychological distress which included the CES-D, the PSS, and the MHS of the SF-36 as indicators, we conducted ancillary analyses to determine whether indirect effects via CES-D scores (only) were significant. These analyses indicated

Table 2 Unstandardized, standardized, and significance level for paths in structural model

Parameter Estimate	B	β	95% CI
Direct Effects			
Neighborhood Characteristics ^a on			
Age ^c	0.04	0.17	0.11 to 0.24*
Gender ^c	−0.92	−0.12	−0.16 to −0.08*
Education ^c	0.08	0.06	0.01 to 0.14*
Psychological Distress ^a on			
Neighborhood Characteristics ^b	−0.87	−0.31	−0.37 to −0.25*
Age ^c	−0.05	−0.08	−0.13 to −0.03*
Gender ^c	3.55	0.17	0.13 to 0.21*
Education ^c	−0.02	0.01	−0.05 to 0.04
Body Mass Index ^a on			
Neighborhood Characteristics ^b	−0.02	−0.10	−0.17 to −0.02*
Age ^c	0.02	0.38	0.32 to 0.44*
Gender ^c	−0.02	−0.02	−0.09 to 0.06
Education ^c	−0.01	−0.06	−0.12 to 0.01
Inflammation ^a on			
Neighborhood Characteristics ^b	−0.02	−0.01	−0.07 to 0.05
Psychological Distress ^b	0.06	0.08	0.03 to 0.13*
Body Mass Index ^b	4.65	0.41	0.32 to 0.49*
Age ^c	−0.10	−0.22	−0.27 to −0.18*
Gender ^c	0.91	0.06	0.01 to 0.12*
Education ^c	0.10	0.04	−0.00 to 0.08
Indirect Effects			
Neighborhood → Stress → BMI	−0.05	−0.03	−0.04 to −0.01*
Neighborhood → Inflammation → BMI	−0.08	−0.04	−0.07 to −0.01*

^adenotes variable is an outcome of interest, ^bdenotes variable is a predictor of interest, ^cdenotes variable is a control variable, * $p < .05$.

BMI, Body mass index; CI, Confidence intervals.

there was a significant indirect effect from perceived neighborhood characteristics to BMI through depressive symptoms.

Our results are consistent with the previous studies that have separately examined the association between neighborhood characteristics and psychological distress [40, 41], and the relationship between psychological distress and BMI [42]. These studies demonstrated that perception of less favorable neighborhood characteristics significantly predicts greater depressive symptoms [43] and overall psychological distress [41]. Similarly, our results are in line with previous findings showing a longitudinal association between psychological distress and obesity [42].

Psychological distress can impact obesity risk via multiple behavioral and biological pathways. Psychological distress, for instance, is associated with unhealthy behaviors, such as increased fat intake and decreased physical activity [44, 45] that are known to promote weight gain. Greater psychological distress and history of past depression are associated with metabolic

responses to high-fat meals [46]. In fact, a recent study demonstrated that greater daily stressors were associated with decreased postmeal energy expenditure, lower fat oxidation, and higher insulin production [47], all of which promotes weight gain.

We found that inflammation served as an indirect pathway in the association between neighborhood characteristics and BMI. Previously, the links between neighborhood characteristics, inflammation, and BMI have only been studied in isolation. For instance, in a study of adult men and women, neighborhood stressors were associated with increased levels of CRP [48]. Similarly, in a study of middle- and older-aged adults, neighborhood level deprivation was associated with increased inflammation and cardio-metabolic risk [24]. It is possible that these associations are explained by actual physical conditions of disadvantaged neighborhoods that may raise the risk of systemic inflammation. For example, long-term exposure to air pollution in disadvantaged urban neighborhoods prospectively predicted increases in CRP of almost 2.4 $\mu\text{g/ml}$ after 5 years in a cohort of

over 5,000 adults [49]. This study adds to the literature by being the first to assess these factors simultaneously to test a comprehensive, theoretically driven model.

Inflammation, in turn, was shown to prospectively predict weight gain in various reports [21, 22]. Indeed, inflammation predicted weight gain over a 3-year period in a cohort of 13,017 men and women. Individuals who were in the highest quartile in terms of inflammation showed increased weight gain of a half-pound a year compared with those in the lowest quartile. Other work has demonstrated similar findings [50]. The mechanisms by which inflammation promotes weight gain are not completely clear. However, inflammatory processes, in the presence of sedentary lifestyles and ample food availability likely promote weight gain [51]. This association may also be attributable to the physiological inter-relationships between inflammation and metabolism. For example, the proinflammatory cytokine TNF- α has been shown to alter several aspects of lipid metabolism [52] and promotes insulin resistance [53]. In addition, this cytokine regulates and is regulated by peroxisome proliferator-activated receptor gamma, a nuclear factor that is involved in adipocyte growth, differentiation and function [54]. Furthermore, glucocorticoids, generated in response to the inflammation of chronic, low-grade insults, could impact weight gain [55]. Future work should assess cortisol, as well as inflammation as pathways linking neighborhood characteristics and obesity.

The association between inflammation and BMI is clearly bi-directional [56]. One major limitation of SEM is that the temporal ordering of variables cannot be determined when using cross-sectional data. It is worth noting that a model that included an indirect effect from neighborhood characteristics to inflammation via BMI was also tested in ancillary analysis. Associations between inflammation and BMI were present and there was evidence of an indirect path from Perceived Neighborhood Characteristics to Inflammation via BMI, however, the coefficient for the indirect path was very small. It is possible that the effects were so small because the effect of BMI on inflammation unfolds in a different time frame than the one we captured. The use of cross-sectional data implies that the effects are instantaneous. Choosing the period, or time of interest, as well as the lag, or the amount of time that elapses between measurements is crucial to understanding causal pathways [57]. Future fine grained longitudinal work is needed to clearly understand causal pathways.

Despite the differences in competing psychosocial demands [30], access to healthcare [29], mental health [28], and cardiovascular health profiles [58] across members of different races/ethnicities, the strength of associations in our study were not moderated by race/ethnicity. In

the MESA study, investigators studied the impact of race/ethnicity in the association between neighborhood racial/ethnic composition and depressive symptoms [43]. While small differences in associations were found among African-American, Hispanic, and Chinese men and women, these differences did not reach statistical significance. It is possible that differences exist in the level of endorsement of less favorable neighborhood characteristics and psychological distress, as well as in the prevalence of obesity and systemic inflammation. However, *mean* differences do not necessarily impact the strength of associations among variables.

These results should be interpreted in light of the strengths and limitations of this study. An important strength of this study is the large sample size and diverse population which allowed for comparison across three major ethnicities: Non-Hispanic Whites, Non-Hispanic Black and Hispanic adults. Few studies to date have extensively characterized individuals across these three major ethnicities in terms of psychological variables and biological markers of stress simultaneously. Our study assessed both behavioral and biological pathways linking neighborhood characteristics and BMI. Similarly, this study recruited individuals in the general population, therefore increasing the generalizability of our results. Furthermore, the statistical modeling of variables of interests as latent variables (neighborhood characteristics, psychological distress and inflammation) ensured that indicators are truly measuring the theoretical concepts that they are intended to measure. Latent variables represent the shared variance of their indicators, and therefore measure constructs of interest without error [39].

A limitation of our study is the use of BMI as a proxy for obesity across ethnicities. Studies show that BMI performs poorly as an indicator of obesity among ethnic minority individuals. For example, using NHANES III data, a study compared BMI with total body fat and percentage body fat (%BF) measured through bioelectrical impedance among Non-Hispanic Black and Non-Hispanic White adults [59]. They showed that, in spite of having a significantly higher BMI, Non-Hispanic Blacks had between 1.3 kg (men) and 3.2 kg (women) greater fat-free mass than Non-Hispanic Whites. In addition, a small number of participants in our sample self-reported their weight. While the proportion of subjects with self-reported weight was minimal, it is worth noting that self-reported weight may create error as it is often misrepresented. In addition, it is possible that this error (over- or under-estimation) may differ systematically across race/ethnic group. Furthermore, weight was recorded only once for the other participants, and height was self-reported for all participants. The use of self-reported height is an important limitation. Therefore, the

BMI variable was not derived from objectively measured variables, only.

This study is also limited by its cross-sectional design, thus causality and temporal inferences cannot be made. While our structural model was specified based on theoretical considerations, conclusions on causality cannot be made based on results from structural equation modeling, particularly when using cross-sectional data. In addition, given our concurrent assessment of neighborhood characteristics, psychological distress, inflammation and BMI, we are not able to determine the temporal order of variables. In fact, the association between variables might be bi-directional. For example, as outlined earlier, increased inflammation may lead to weight gain. At the same time, it has also been demonstrated that obesity leads to systemic inflammation [56] and increases the risk of inflammatory chronic conditions, such as coronary heart disease [50]. Concurrent assessment may also introduce bias, particularly when the methods of data collection are self-reported questionnaires. Due to the fact that neighborhood characteristics indicators and psychological distress indicators were collected concurrently via self-report, the significant association between these variables may have been a result of common method variance. Furthermore, a third variable, such as overall negative affectivity may have resulted in individuals reporting both lower perceived neighborhood characteristics and psychological well-being (higher psychological distress). Finally, it is important to note that while our study controlled for education as a marker of socioeconomic status (SES), other SES indicators such as income and neighborhood SES (e.g., median neighborhood income) were not accounted for. Prior research shows these variables are likely to be important social determinants of psychological distress [60, 61], inflammation [62], and obesity [61, 63]. Therefore, residual confounding related to SES may be present in these analyses.

Future studies should prospectively examine whether psychological distress and inflammation serve as longitudinal mediators of the association between neighborhood characteristics and obesity. Nevertheless, our work provides important insights on the association between neighborhood characteristics and obesity, and the biobehavioral pathways linking these two conditions.

Conclusions

In summary, our findings from a large diverse sample of adults demonstrate the importance of neighborhood perceptions as it relates to BMI, and extends the literature by identifying two potential biobehavioral pathways

linking these two conditions: psychological distress and inflammation. In addition, we determined that perceived neighborhood characteristics impact BMI via the same indirect effects among Non-Hispanic Whites, Non-Hispanic Blacks, and Hispanics. Future studies should replicate our findings with the use of prospective designs, as well as identify whether interventions targeting psychosocial distress or inflammation reduce the impact of less favorable perceived neighborhood characteristics on BMI.

Supplementary Material

Supplementary material is available at *Annals of Behavioral Medicine* online.

Acknowledgments Data collection for the present study was funded by the National Cancer Institute (P50 CA105631). Preparation of the manuscript was supported by a grant from the National Heart, Lung and Blood Institute (1R01HL127260-01).

Compliance with Ethical Standards

Disclosure of potential conflict of interests Authors have no conflict of interest to disclose.

Research Involving Human Participants or Animals The study protocol was approved by the University of Texas Medical Branch (UTMB) Institutional Review Board, and informed consent was obtained from all participants.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

This article does not contain any studies with animals performed by any of the authors.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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