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Assessing mediation of behavioral and stress pathways in the association between neighborhood environments and obesity outcomes

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ABSTRACT

Although many studies have reported associations between characteristics of the neighborhood environment and obesity, little is understood about the pathways or mechanisms through which these associations operate. The purpose of this study was to examine possible behavioral and stress pathways hypothesized to mediate the association between neighborhood environments and obesity and whether pathways contribute to different obesity outcomes. Cross-sectional data were used from the 2012–2014 Women and Their Children's Health Study (WaTCH) in Louisiana (N = 909). Participants' neighborhoods, body mass index (BMI) and waist circumference (WC) were objectively measured. The causal inference approach to mediation analysis was used to obtain indirect estimates for self-reported measures of physical activity, low access to food, and depression. The mean BMI was 32.0 kg/m^2 and the mean WC was 98.6 cm. The (adverse) neighborhood environment was significantly associated BMI ($\beta = 0.17$ kg/m^2; 95% Confidence Interval (CI): 0.03, 0.31) and WC ($\beta = 0.64$; 95% CI: 0.34, 0.95, after adjusting for covariates. Neither depression, physical activity, nor low food access mediated those associations. Further research that investigates and uses better measures of the behavioral and stress pathways through which the neighborhood environment influences obesity is warranted.

1. Introduction

The dramatic increase in the prevalence of obesity throughout the world during the past forty years has been called a global epidemic and is one of the most significant public health threats of the 21st century (Harris, 2013). Many epidemiologic studies have focused on understanding the modifiable factors that may help prevent and control obesity. However, biological, psychological, behavioral, and social risk factors have not been able to fully explain the obesity epidemic (Booth et al., 2005; Egger and Swinburn, 1997). Consequently, the neighborhood environment has emerged as an important risk factor for the increased prevalence of obesity during the past several decades (Booth et al., 2005; Egger and Swinburn, 1997; Glass et al., 2006; Powell-Wiley et al., 2013; Flegal et al., 2012; Hu, 2008). Aspects of the neighborhood environment can be categorized as features of the physical environment or the social environment. The physical environment, encompasses aspects of a person's surroundings which are human-made or modified, such as recreational centers, parks, playgrounds, and supermarkets (Papas et al., 2007). The social environment is defined as aspects of one's external environment or surroundings that influence how individuals socialize, live, and interact with others (e.g. crime, incivilities, and neighborhood disadvantage). A plethora of empirical research has emerged to assess the possible associations between aspects of the neighborhood environment and obesity as reviewed by Booth et al., (Booth et al., 2005) Papas et al. (Papas et al., 2007), Feng et al. (Feng et al., 2010), and Sugiyama et al. (Sugiyama et al., 2014). Despite the cache of research in this sphere of inquiry; however, little is understood about the pathways or mechanisms through which the neighborhood environment may influence obesity (Booth et al., 2005; Glass et al., 2006; Powell-Wiley et al., 2013; Papas et al., 2007; Mujahid et al., 2008). Competing theoretical frameworks propose either a behavioral pathway or a stress response pathway.

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The behavioral pathway posits that the physical and social environment can influence obesity through determinants of behaviors that influence energy consumption (e.g., diet) and energy expenditure (e.g., physical activity) which in turn influence obesity (Papas et al., 2007; Hill and Peters, 1998; Popkin et al., 2005). For example, some studies have shown that characteristics of the physical environment such as accessibility to parks and recreational centers as well as proximity to fast-food restaurants and food stores are associated with adiposity, and these associations are hypothesized to operate through physical activity and dietary behaviors (Mujahid et al., 2008; Sallis et al., 2006; Sallis and Glanz, 2009; Yang et al., 2012; Black et al., 2010; Michimi and Wimberly, 2012; Michimi and Wimberly, 2010). Adverse or unsafe characteristics of the social environment (e.g., crime, disorder, incivilities, social disadvantage, and psychosocial hazards) have been suggested to influence obesity by deterring physical activity (Yang et al., 2012; Burdette et al., 2006; Christian et al., 2011; Fish et al., 2010). The stress pathway, posits that adverse neighborhood environments characterized by social and economic disadvantage and neighborhood disorder can act as chronic stressors that influence obesity through activation and dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis (Glass et al., 2006; Powell-Wiley et al., 2013; Burdette and Hill, 2008). During chronic exposure to stress, the HPA axis can be overactivated thereby increasing cortisol and subsequently adiposity and abdominal obesity (Bjorntorp, 2001; Foss and Dyrstad, 2011; Lucassen and Cizza, 2012; Pasquali, 2012; Vicennati et al., 2009). Importantly, HPA axis perturbations lead to the centralization of body fat accentuated in visceral adipose tissue which can be estimated using measures such as waist circumference, and has been suggested to be a reasonable obesity measure of long-term stress activation of the HPA axis in women (Bjorntorp, 2001; Remigio-Baker et al., 2014).

A few studies have attempted to investigate these potential pathways, and they have done so by comparing coefficient estimates between a model not including the mediator(s) and a model adjusting for the potential mediator(s) (Glass et al., 2006; Mujahid et al., 2008; Poortinga, 2006). Poortinga (2006) found that adding three different measures of physical activity to his models did not attenuate the association between perceptions of the neighborhood environment and obesity, concluding there was no evidence of mediation. Glass et al. (2006), observed that after adjusting for physical activity and diet, adults living in more adverse neighborhood environments with greater psychosocial hazards still had significantly higher odds of obesity with only a small attention of the odds ratios proposing that beyond the behavioral pathways examined, living in psychotically hazardous neighborhood may increase body weight through a stress inducing pathway. Mujahid et al. (2008), reported that physical activity and diet appeared to mediate the association between a contextual measure of the physical environment and BMI after adjusting for these variables and comparing the mean change in BMI. Importantly, none of the aforementioned studies used a formal mediation analysis to investigate potential pathways between the neighborhood environment and obesity. To our knowledge, only one previous study examined behavioral and stress processes linking neighborhood characteristics and obesity using a formal mediation analysis (Burdette and Hill, 2008). Specifically, Burdette and Hill (2008) found that perceived neighborhood disorder was associated with increased odds of obesity, which was entirely mediated by psychological distress. The association between psychological distress and obesity was fully mediated by physiological distress and poor self-rated diet quality and only partially mediated by irregular exercise (Burdette and Hill, 2008). Importantly, psychological distress was examined as a lynchpin mechanism linking perceived neighborhood disorder with obesity.

In this study, we utilized the causal inference approach for mediation analysis to investigate possible behavioral and stress pathways (specifically including self-reported measures of physical activity, low access to food, and depression) that may mediate the relationship between the neighborhood environment, and multiple obesity outcomes. Our study is unique from the previous aforementioned studies in four important ways. First, we used direct observer rating of the neighborhood environment using trained auditors. Second, we used an objective measure of BMI and further included waist circumference as a measure of central adiposity and possible phenotype of HPA axis perturbations. Also, while Burdette and Hill (2008) used a formal mediation analysis, they proposed and tested a different theoretical model linking neighborhood disorder with obesity and used the product of coefficients and Sobel test to assess mediation. Alternatively, we used the causal inference approach to mediation analysis which allows for effect decomposition of direct and indirect effects in the case of non-linearities (for binary mediators and outcome) and interactions (Valeri and VanderWeele, 2013). Investigating these potential mediators would help to estimate how much of the association between the environment and obesity is explained through each pathway and whether pathways may illuminate different processes on obesity phenotypes (e.g., stress pathway with greater abdominal obesity). Results from mediation analyses could help elucidate underlying mechanisms that may influence obesity in hopes of identifying possible mechanisms for intervention to bridge the gap between research and population health initiatives.

2. Methods

2.1. Study design and population

The Women and Their Children's Health (WaTCH) Study is a prospective cohort study established to explore the long-term health effects among women exposed to the Deepwater Horizon oil spill. The target population was women aged 18–80 years who resided in Southeastern Louisiana parishes (Orleans, St. Bernard, Jefferson, Plaquemines, Lafourche, Terrebonne, and St. Mary) before the date of the oil spill (April 20, 2010). An addressed based sampling frame was used to enumerate the target population, and women were recruited by randomly calling household telephone numbers. Baseline data, including information on individual and household characteristics, mental and social health, and health behaviors were collected using a telephone questionnaire for 2852 women between July 2012 and August 2014. Data were collected and managed using REDCap (Research Electronic Data Capture), a secure, web-based application designed to support data capture for research studies, providing: 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources (Harris et al., 2009). Medical research assistants collected anthropometric measurements and neighborhood audits on a sub-sample of women who participated in the home visit portion of the study (N = 1233). P-values for differences between women who participated in the WaTCH telephone questionnaire and women who participated in the home visit portion of the study are presented in Supplementary Table 1. Women who participated in the home visit portion of the study were more likely to be African American (P = 0.0064), have lower household income (P = 0.0002), report greater depressive symptoms ≥16 (0.0072), were more likely to report low food access (P < 0.0001), and report greater oil spill exposure (P = 0.0494). The WaTCH study was approved by the Louisiana State University Health Sciences Center Institutional Review Board and was granted a Waiver of Documentation of Informed consent for the telephone interview for which women gave verbal consent. Women who participated in the home visit portion of the study further provided written informed consent. More detailed information on the WaTCH study has been described elsewhere (Peres et al., 2016; Rung et al., 2016).

2.2. Obesity measures

Body height, weight, and waist circumference were objectively measured using standardized procedures by trained medical research

assistants. Each measurement was repeated three times and the average of these measurements were used to minimize systematic measurement error. Body mass index (BMI; weight kg/height m^2) and waist circumference (WC; cm) were each independently investigated as outcome measures.

2.3. Neighborhood environment

The neighborhood environment around each participant's home was assessed using an audit tool adapted from Andresen et al. (2013; 2008). Data collectors were trained in direct observation procedures to conduct an assessment of the immediate block area surrounding participants' homes, resulting in a neighborhood measurement at the individual-level. The Neighborhood Audit included 25 items rating the block face and street of each participants' residence. Nine items did not contribute to scores and were used only as descriptors (e.g., type of land use and condition of land use). Ranked categories and all item ratings were scored using Likert-type scales or were rated as yes/no (Andresen et al., 2013; Andresen et al., 2008). A composite score of the sixteen neighborhood items was created by summing the responses, with higher scores indicating more adverse neighborhood conditions.

2.4. Confounders

Confounders were included based on *a priori* theory. Age was assessed as a categorical variable: 19–30 years, 31–40, 41–50, 51–60, 61–70, and 71–80 years of age. Participants' race and ethnicity were coded as: Non-Hispanic White, Non-Hispanic African American, and Other (Hispanic, Asian/Pacific Islander, American Indian/Native American, Other, or Multi). Annual household income was categorized as: $0–$20,000, $20,001–$40,000, $40,001–$60,000, and ≥$60,001. Oil spill exposure was measured using nine (self-reported) items: participated in oil spill clean-up activities, had physical contact with the oil from the spill or clean-up, incurred damage to commercial fishing areas, whether their recreational hunting, fishing, or other activities were affected, incurred lost or damaged property, frequency and severity of oil smell, income loss, the influence on their household's current financial situation, and whether participants were affected by the oil spill more than others in their community. Items were dichotomized and summed so that higher scores indicated greater oil spill exposure. Additionally, smoking status (never, former, current) and post-menopausal status were investigated as potential confounders. However, since the changes in the estimates between the crude and adjusted models were not >10%, neither smoking status or post-menopausal status were considered true confounders in the relationship between neighborhood environments and obesity outcomes and were omitted from the statistical models.

2.5. Potential mediators

Depression was investigated as a mediator to test the hypothesis that the neighborhood environment influences obesity through a stress response pathway. Prior studies have demonstrated an association between neighborhood characteristics and depression (as a measure of the physiologic stress response) (Echeverria et al., 2008; Latkin and Curry, 2003; Galea et al., 2005; Kim, 2010; Ross, 2000). Depression was measured using the Center for Epidemiologic Studies' Depression Scale (CES-D), a 20-item self-reported questionnaire administered during the phone interview which measures current depressive symptomology using a four-point Likert scale (Radloff, 1977). Items were summed and scores ≥16 indicated depression (Radloff, 1977). Using this cut-off, the CES-D has been shown to have a sensitivity of 70.6% and a specificity of 88% for major depression in the past year (Beekman et al., 1997). The scale has also been shown to have high validity and reliability (Radloff, 1977), and has been comparable across ethnic groups including European Americans, African Americans, and Mexican-Americans (Roberts, 1980).

Physical activity and low access to food were assessed to test the hypothesis that the neighborhood environment influences obesity through a behavioral pathway. Participants' physical activity was self-reported using the (International Physical Activity Questionnaire-Short Form (IPAQ-SF) 2005; Craig et al., 2003). The IPAQ-SF scoring protocol was used to estimate the time respondents spent each week walking, in moderate-intensity physical activity, and in vigorous-intensity physical activity (International Physical Activity Questionnaire, 2005). The validity of the IPAQ-SF against accelerometers was reported to have a mean Spearman's ρ of 0.30, yet the IPAQ-SF is considered to be as good as other established self-reported measures of physical activity and as having reasonable measurement properties for monitoring population levels of physical activity among adults in diverse settings (Craig et al., 2003). Participants were considered to have met physical activity guidelines if they reported 75 min/week of vigorous physical activity, or 150 min/week of moderate physical activity, or an equivalent combination (150 min/week) of moderate and vigorous physical activity (United States Department of Health and Human Services (HHS), 2008). Women in the WaTCH Study were also asked about whether they needed or received help for services (e.g., food, utilities, and housing) from organizations or agencies in their community. If respondents received or needed help from organizations or agencies with food (such as getting items from a food pantry, soup kitchen, or grocery gift card) during the past three months, they were considered to have low access to food.

2.6. Statistical analysis

We utilized the causal inference approach to mediation analysis adapted to give rise to counterfactual definitions of direct and indirect effects, which were formulated by Pearl (2001), Robins and Greenland (1992), and further extended by VanderWeele and Vansteelandt (2009; 2010) and Valeri and Vanderweele (2013). The counterfactual approach for mediation analysis allows for effect decomposition of a total effect into direct and indirect effects in the presence of exposure-mediator interaction and nonlinearities. Under the counterfactual approach for mediation analysis, we assume that the set of covariates for which adjustment was made suffices to control for confounding of the: 1) exposure-outcome; 2) mediator-outcome; and 3) exposure-mediator relations. We further assume that there is no effect of exposure that confounds the mediator-outcome relationship (Valeri and VanderWeele, 2013).

A simple mediation model for the data presented in this paper is provided in Fig. 1. The exposure variable, *A*, represents the neighborhood environment, and *Y* represents the outcome measures of obesity (BMI and WC), while *M* represents the potential mediators: depression, physical activity, and low access to food. Fig. 1, A), shows the total effect (*TE*) of the neighborhood environment on obesity. Fig. 1, B), shows possible indirect effects of the neighborhood environment on obesity that pass through the potential mediators. We use methods and formulas provided by Valeri and VanderWeele (2013). The direct and indirect effects of the neighborhood environment and obesity outcomes were estimated from fitting a model for the obesity outcome (*Y*), conditional on the neighborhood environment (*A*), the potential mediator (*M*), and a set of confounders (*C*):

$$E\,[Y|a,m,c] = \theta_0 + \theta_1 a + \theta_2 m + \theta_3' c \tag{1}$$

and a model for each the mediator (M), conditional on the neighborhood environment (*A*), and a set of confounders (*C*):

$$\text{logit}\{\text{P}(\text{M} = 1|\text{a},\text{c})\} = \beta_0 + \beta_1 a + \beta_2' c. \tag{2}$$

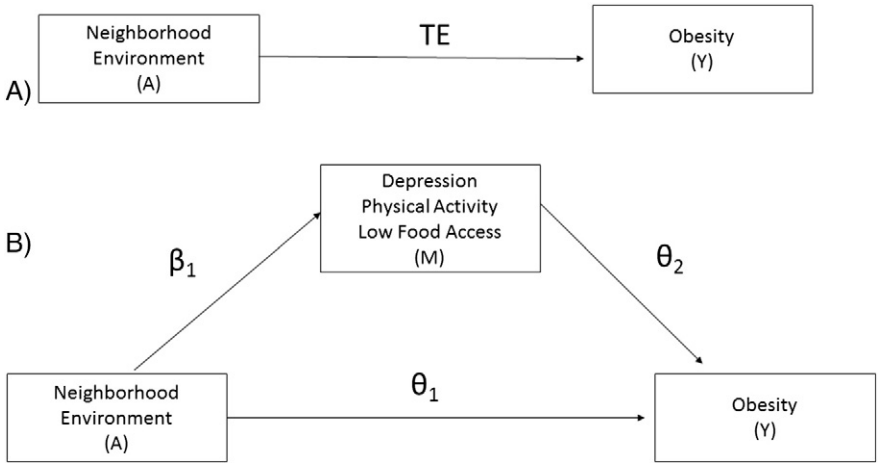

Fig. 1. Simple Mediation Model showing A) the total effect of the neighborhood environment on obesity outcomes and B) indirect effects of the neighborhood environment on obesity outcomes through each possible mediator (depression, physical activity, and low food access), WaTCH in Louisiana, 2012–2014.

Using the models provided above for a dichotomous mediator and continuous outcome, we can estimate the natural indirect effect as:

$$NIE = \theta_2 \frac{\{\exp(\beta_0 + \beta_1 a + \beta_2' c)\}}{\{1 + \exp(\beta_0 + \beta_1 a + \beta_2' c)\}} - \frac{\{\exp(\beta_0 + \beta_1 a^* + \beta_2' c)\}}{\{1 + \exp(\beta_0 + \beta_1 a^* + \beta_2' c)\}} \quad (3)$$

where $\beta_1 a$ and $\beta_1 a^*$ represent the different exposure levels being compared. Regressions, standard errors using the delta method, and confidence intervals for each indirect effect were obtained using a mediation macro developed by Valeri and VanderWeele (2013). The mediation macro also allows the user to test for exposure-mediator interactions. The above models exclude the interaction terms originally provided by Valeri and VanderWeele (2013) since there were not any exposure-mediator interactions. All analyses were conducted using SAS, version 9.3 (SAS Institute Inc., Cary, North Carolina).

3. Results

Of the 2852 women who participated in the WaTCH Study, analyses were restricted to home visit participants (n = 1233). Neighborhood audits were not collected for 37 participants and were removed from the analyses. After removing women who resided outside the study parishes (n = 7), and with missing geocoded addresses (n = 7), and sequentially for income (n = 51), race/ethnicity (n = 11), obesity measures (n = 117), mediator variables (n = 35), and with any missing audit scores (n = 53), 915 women remained in the analytic sample. Another 6 participants were removed due to incorrect measurement or record of height. The final sample included 909 women. Demographic characteristics are presented in Table 1. The mean age of women was 45 years and nearly half of the study participants were African American or Other race/ethnicity. Slightly over 30% of women had depression (CES-D scores ≥16), 62% met recommendations for physical activity, and 31% reported low access to food. The mean BMI was 32.0 kg/m^2 and the mean WC was 98.6 cm. Characteristics of participants' neighborhoods are presented in Table 2. The mean neighborhood score was 5.3, with a possible range between 0 and 26, and an observed range between 0 and 19. The (adverse) neighborhood environment was significantly associated BMI (β = 0.17 kg/m^2; 95% CI: 0.03, 0.31) and WC (β = 0.64; 95% CI: 0.34, 0.95), after adjusting for covariates (Table 3).

The direct and indirect effects of depression, physical activity, and low food access are shown in Tables 4 and 5 for BMI and WC, respectively. The effect estimates of the neighborhood environment on each mediator (β_1 *paths*) are the same in each table, since these are simply the associations between *A* and *M* (adjusted for confounders) and do not include the outcome, *Y*, in the regression model. For each unit increase in neighborhood environment score, the odds of depression increased 4% (OR: 1.00, 1.08; p-value: 0.0678), and the odds of low access to food also increased 4% (OR: 1.04; 95% CI: 1.00, 1.09; p-value: 0.0759), although these associations were marginally significant. None of the θ_2 paths (associations between potential mediators and BMI or WC) were statistically significant (Tables 4 and 5). Further, none of the indirect effects through the mediators were significant. Thus, the total effect and the direct effect estimates of the neighborhood environment on obesity outcomes were near equivalent.

Table 1
Demographic Characteristics, WaTCH in Louisiana, 2012–2014 (N = 909).

	N (%)
Total	909
Oil spill exposure (mean, SD)	1.7 (1.6)
Age (mean, SD)	45.1 (11.8)
Age categories	
19–30	93 (10.2)
31–40	225 (24.8)
41–50	373 (41.0)
51–60	115 (12.7)
61–70	69 (7.6)
71–80	34 (3.7)
Race/ethnicity	
White	467 (51.4)
African American	365 (40.2)
Other	77 (8.5)
Household income	
$0–$20,000	252 (27.7)
$20,001–$40,000	186 (20.5)
$40,001–$60,000	160 (17.6)
>$60,000	311 (34.2)
Body mass index, kg/m^2 (mean, SD)	32.0 (8.1)
Waist circumference, cm (mean, SD)	98.6 (17.5)
Depression	
CES-D < 16	629 (69.2)
CES-D ≥ 16	280 (30.8)
Met Recommendations for physical activity	
No	347 (38.2)
Yes	562 (61.8)
Low food access	
No	632 (69.5)
Yes	277 (30.5)

Abbreviations: SD, standard deviation; WaTCH, Women and Their Children's Health Study.

Table 2
Neighborhood Characteristics Obtained from Neighborhood Audit: Items, Ratings, and Frequencies, WaTCH in Louisiana, 2012–2014 (N = 909).

Variable and items rating	N (%)
Volume of traffic	
None (0)	246 (27.1)
Light (1)	416 (45.8)
Moderate (2)	153 (16.8)
Heavy (3)	94 (10.3)
Condition of street	
Very good (0)	360 (39.6)
Moderate (1)	266 (29.3)
Fair (2)	213 (23.4)
Poor (3)	70 (7.7)
Amount of noise	
Very quiet (0)	479 (52.7)
Fairly quiet (1)	300 (33.0)
Somewhat noisy (2)	123 (13.5)
Very noisy (3)	7 (0.8)
Smells	
None (0)	883 (97.1)
Any (1)	26 (2.9)
Dirt or dust	
None (0)	898 (98.8)
Any (1)	11 (1.2)
Abandoned car	
None(0)	752 (82.7)
Any (1)	157 (17.3)
Beer, liquor bottles	
None(0)	822 (90.4)
Any (1)	87 (9.6)
Cigarette, tobacco litter	
None(0)	694 (76.4)
Any (1)	215 (23.7)
Garbage, litter, broken glass	
None (0)	479 (52.7)
Light (1)	351 (38.6)
Moderate (2)	52 (5.7)
Heavy (3)	27 (3.0)
Condition of residential homes	
Very well kept (0)	418 (46.1)
Moderately kept (1)	301 (33.1)
Fair (2)	157 (17.3)
Poor/badly deteriorated (3)	33 (3.6)
Bars/gates on doors or windows	
None(0)	646 (71.1)
Any (1)	263 (28.9)
Condition of recreational facilities (if present)?	
Very well kept/good condition(0)	32 (57.1)
Moderately well-kept condition (1)	18 (32.1)
Fair condition (2)	5 (8.9)
Poor/badly deteriorated condition (3)	1 (1.8)
Graffiti	
None(0)	882 (97.0)
Any (1)	27 (3.0)
Tobacco advertisements	
None(0)	893 (98.2)
Any (1)	16 (1.8)
Alcohol advertisements	
None(0)	889 (97.8)
Any (1)	20 (2.2)
Home “for sale” signs	
None(0)	670 (73.7)
Any (1)	239 (26.3)
Neighborhood audit observed scores	
Mean	5.3
SD	3.9
Minimum	0
Maximum	19

Abbreviations: SD, standard deviation; WaTCH, Women and Their Children's Health Study.

Table 3
Total Effects of the Neighborhood Environment Predicting Relative Change in Body Mass Index and Waist Circumference, WaTCH (N = 909) in Louisiana, 2012–2014.

	Model 1: change in body mass index (kg/m^2)		Model 2: change in waist circumference (cm)	
	β	95% CI	β	95% CI
Intercept (β_0)	28.93[a]	26.68, 31.18	88.91[a]	84.12, 93.71
Neighborhood audit score	0.17[b]	0.03, 0.31	0.64[a]	0.34, 0.95
Oil spill exposure	0.08	−0.24, 0.40	0.19	−0.50, 0.87
Age categories				
19–30	Reference		Reference	
31–40	1.30	−0.61, 3.20	5.87[b]	1.81, 9.94
41–50	2.40[b]	0.60, 4.21	8.96[a]	5.12, 12.80
51–60	2.66[b]	0.52, 4.81	11.18[a]	6.60, 15.75
61–70	1.14	−1.31, 3.58	8.96[b]	3.74, 14.19
71–80	1.14	−1.98, 4.27	6.44	−0.22, 13.11
Race/ethnicity				
White	Reference		Reference	
African American	2.21[b]	1.02, 3.41	3.28[b]	0.73, 5.82
Other	0.39	−1.53, 2.31	0.20	−3.90, 4.29
Household income				
$0–$20,000	Reference		Reference	
$20,001–$40,000	0.98	−0.54, 2.50	0.14	−3.10, 3.38
$40,001–$60,000	−0.71	−2.35, 0.94	−3.60[b]	−7.12, −0.08
≥$60,001	−2.21[b]	−3.72, −0.70	−6.49[a]	−9.71, −3.27

Abbreviations: CI, confidence interval; WaTCH, Women and Their Children's Health Study.
[a] $P < 0.0001$.
[b] $P < 0.05$.

4. Discussion

We used a formal mediation analysis to investigate behavioral and stress pathways as potential mechanisms between the neighborhood environment and obesity. We found that the (adverse) neighborhood environment was significantly associated with BMI and WC. However, neither depression, physical activity, nor low food access mediated those associations.

Important considerations must be acknowledged when interpreting the findings in this study. First, although the associations between the neighborhood environment and BMI and WC were statistically significant, the size of the estimates or change in the dependent variables that result from one-unit increase in the neighborhood environment score are small substantial effects in magnitude. Given the small magnitude of the total effects of the neighborhood environment and obesity outcomes and insignificant contributing pathways, we would not expect to find significant mediation in this study.

Another important point of discussion about the null findings in this study and the failure to find significant mediation do not conclude that the pathways do not exist. Measurement error and bias that may affect the precision and accuracy of the mediators used in this study can contribute to attenuated results towards the null hypothesis of no association. Specifically, dietary behaviors and food intake were not assessed among women in the WaTCH Study. Some studies that have investigated the validity of the IPAQ-SF against objective measures (such as accelerometers) of physical activity levels concluded that the IPAQ-SF may overestimate physical activity levels (Craig et al., 2003; Macfarlane et al., 2007; Mader et al., 2006). An overestimation (if non-differential) of physical activity may result in an association that is biased towards the null. Although prior studies have demonstrated an association between neighborhood characteristics and depression (as a measure of the physiologic stress response) (Echeverria et al., 2008; Latkin and Curry, 2003; Galea et al., 2005; Kim, 2010; Ross, 2000), other measures of HPA axis dysregulation and possible inclusion of biomarkers of the physiologic stress process such as C-reactive protein or cortisol may be better measures of the stress pathway. Latkin and Curry (2003) reported that a measure of depression may be a more appropriate measure of the psychological stress response of adverse neighborhood characteristics that may act as chronic stressors. This assumption was based on prior findings by Turner and Lloyd (1995) who reported that chronic stressors have a stronger association with depression compared to stressors of shorter duration. Exposures to chronic stressors over time can precipitate feelings of anxiousness, restlessness, and hopelessness, ultimately leading to depression (Hill et al., 2005).

Table 4
Indirect and Direct Effects of the Neighborhood Environment on Body Mass Index, WaTCH (N = 909) in Louisiana, 2012–2014[a].

	Path β_1[b]		Path θ_2[c]		Indirect effect[d]		Direct effect[e]	
	OR	95% CI	β	95% CI	β	95% CI	β	95% CI
Mediators								
Depression	1.04	1.00, 1.08	0.10	−1.06, 1.27	0.001	−0.01, 0.01	0.17[f]	0.03, 0.31
Physical activity	1.01	0.97, 1.05	−0.05	−1.11, 1.01	−0.0001	−0.002, 0.002	0.17[f]	0.03, 0.31
Low Access to Food	1.04	1.00, 1.09	−0.24	−1.54, 1.06	−0.002	−0.01, 0.01	0.17[f]	0.03, 0.32

Abbreviations: CI, confidence interval; OR, odds ratio; WaTCH, Women and Their Children's Health Study.
[a] Estimates are adjusted for oil spill exposure, age categories, race/ethnicity, and household income.
[b] Association between neighborhood environment and potential mediators.
[c] Association between potential mediators and obesity measures.
[d] Association between neighborhood environment and obesity measures, through each potential mediator.
[e] Association between neighborhood environment and obesity measures, adjusted for each mediator.
[f] $P < 0.05$.

Thus, the perpetual and chronic stress of living in an adverse neighborhood environment may have a more pronounced mental health impact expressed through depression that is differentiated from other stressors of shorter duration such as daily life hassles. Also, how the neighborhood environment is measured and defined can affect possible associations between mediators and obesity outcomes.

Preferably, we would have examined BMI and WC as dichotomous outcome variables. For dichotomous outcomes in cross-sectional studies, the odds ratio is not a good approximation of the risk or prevalence ratio when the outcome is not rare (≥10%) (Valeri and VanderWeele, 2013; VanderWeele and Vansteelandt, 2010; Spiegelman and Hertzmark, 2005). Using dichotomized cut points established by National Institutes of Health (1998) for women, 52.7% of women in the WaTCH Study had a BMI ≥ 30 kg/m^2 and 71.2% had a high WC (>88 cm). The causal effect for a dichotomous outcome that is not rare can be estimated using a generalized linear model regression with a binomial distribution and a log link and the causal effects will have a risk ratio interpretation and the counterfactual formulas for mediation analysis hold exactly (Valeri and VanderWeele, 2013). Otherwise, if odds ratios are used when the outcome is not rare, non-collapsibility is a serious problem and the effect estimates lack a causal interpretation (Valeri and VanderWeele, 2013). However, many of the log-linear models failed to converge so we resorted to continuous measures of BMI and WC.

The results in this paper are similar to other studies that have attempted to understand neighborhood influences on obesity. By controlling for the potential mediator variable in their regression models and comparing effect size changes neither Poortinga (2006) or Glass et al. (2006), found evidence that behavioral factors mediate the association between measures of the neighborhood environment and obesity. However, Mujahid et al. (2008), reported that physical activity and diet appeared to mediate the association between a contextual measure of the physical environment and BMI by comparing the mean change in BMI. Burdette and Hill (2008) found that psychological distress mediated the association between neighborhood disorder and increased odds of obesity although they tested a slightly different theoretical model with the product of coefficients and Sobel test to assess mediation.

There are limitations in our study worth noting. Data are cross-sectional and the temporality between adverse neighborhood environments and obesity outcomes cannot be determined yet are the assumptions of mediation analysis. The mediation analyses make several assumptions in the data related to unmeasured confounding, as previously mentioned. However, if these assumptions are violated, then unmeasured confounding could also bias estimates. Another important issue is that of exposure-mediator interaction. However, these interactions were tested within the macro and found to be not significant and thus unlikely to bias effect estimates. Also, due to the high prevalence of obesity in this study and inclusion of only women who lived in Southeastern parishes in Louisiana, these results may not be generalizable to other population samples.

There are also several strengths. Obesity outcomes were objectively measured using trained medical research assistants. Also, this study was able to explore whether different mediating pathways may illuminate different processes on obesity phenotypes (e.g., stress pathway with greater abdominal obesity). Quality assurance procedures, study protocols, and data management tools (e.g. REDCap) to support valid data entry were implemented throughout the WaTCH study to reduce measurement and processing error.

5. Conclusions

The findings from this study suggest that the neighborhood environment is still associated with obesity outcomes; however, further research investigating and using better measures of the mechanisms

Table 5
Indirect and Direct Effects of the Neighborhood Environment on Waist Circumference, WaTCH (N = 909) in Louisiana, 2012-2014[a].

	Path β_1[b]		Path θ_2[c]		Indirect Effect[d]		Direct Effect[e]	
	OR	95% CI	β	95% CI	β	95% CI	β	95% CI
Mediators								
Depression	1.04	1.00, 1.08	2.08	−0.40, 4.57	0.01	−0.01, 0.04	0.63[f]	0.32, 0.93
Physical activity	1.01	0.97, 1.05	−0.83	−3.09, 1.43	−0.001	−0.01, 0.01	0.64[f]	0.34, 0.95
Low Access to Food	1.04	1.00, 1.09	0.97	−1.80, 3.74	0.01	−0.01, 0.03	0.64[f]	0.33, 0.94

Abbreviations: CI, confidence interval; OR, odds ratio; WaTCH, Women and Their Children's Health Study.
[a] Estimates are adjusted for oil spill exposure, age categories, race/ethnicity, and household income.
[b] Association between neighborhood environment and potential mediators.
[c] Association between potential mediators and obesity measures.
[d] Association between neighborhood environment and obesity measures, through each potential mediator.
[e] Association between neighborhood environment and obesity measures, adjusted for each mediator.
[f] $P < 0.05$.

through which this association operates is warranted. Future studies should consider: 1) different measures of the neighborhood environment; 2) greater precision of the variables used as mediators such as objective measures of physical activity and better assessment measures of the dietary pathway; 3) other measures of HPA axis dysregulation and possible inclusion of biomarkers of the physiologic stress process; and 4) whether the potential mechanisms between the neighborhood environment and obesity vary by race/ethnicity which may contribute to disparities in obesity. The null mediation analyses in this study precluded examination of more complex models and relationships. Future studies which examine neighborhood processes may need to examine more complex hypotheses and relationships between mediators incorporating other methods.

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.pmedr.2016.06.012.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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