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Neighborhood Social and Physical Environments and Type 2 Diabetes Mellitus in African Americans: The Jackson Heart Study

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Abstract

Using data from Jackson Heart Study, we investigated the associations of neighborhood social and physical environments with prevalence and incidence of type 2 diabetes mellitus (T2DM) in African Americans (AA). Among non-diabetic participants at baseline (n=3670), 521 (14.2%) developed T2DM during a median follow-up of 7.3 years. Measures of neighborhood social environments, and food and physical activity resources were derived using surveys-and GIS-based methods. Prevalence ratios (PR) and Hazard ratios (HR) were estimated using generalized estimating equations and Cox proportional hazards models. Higher neighborhood social cohesion

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G.Y.S and A.V.D-R conceived the study concept, and wrote the manuscript. G.Y.S performed the statistical analysis of the data. G.S.Y, A.V.D-R, D.A.H, M.S, S.B.W, S.K.D, and A.C critically revised the manuscript for important intellectual content. A.V.D-R and S.K.D provided funding, administrative, technical and material support. A.V.D-R supervised the study. G.Y.S had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

was associated with a 22% lower incidence of T2DM while higher density of unfavorable food stores was associated with a 34% higher incidence of T2DM after adjusting for individual-level risk factors (HR= 0.78 [95% CI:0.62, 0.99] and HR = 1.34 [1.12, 1.61], respectively). In addition, neighborhood problems was also associated with prevalence of T2DM (PR=1.14 [1.05, 1.24]) independent of individual-level risk factors and GIS-based measures. Our findings suggest that efforts to strengthen community ties or to attract healthy food retail outlets might be important strategies to consider for prevention of T2DM in AA.

Keywords

African Americans; type 2 diabetes mellitus; neighborhood measures; social environments; food stores; physical activity resources; prevention; longitudinal analysis

Introduction

Type 2 diabetes mellitus (T2DM) is a major public health problem in the US. In addition to the high burden of morbidity, T2DM results in substantial health-care expenditures, with an estimated $245 billion in direct and indirect costs in 2012 (American Diabetes Association, 2013).The burden of T2DM is particularly high among African Americans (Centers for Disease Control and Prevention, 2014). Moreover, African Americans are more likely than Whites to suffer complications from T2DM, such as heart disease, stroke, end-stage renal disease, eye problems and lower extremity amputations (Egede and Dagogo-Jack, 2005).

Although individual-level risk factors, such as obesity, poor diet, sedentary behaviors, lower socioeconomic status (SES) and the presence of family history of diabetes, are important contributors to T2DM (Toobert et al., 2000, Brown et al., 2004), there is a growing recognition that environmental factors, including features of neighborhood environments, may also affect T2DM outcomes (Diez Roux and Mair, 2010). Neighborhood environments may contribute to the development of T2DM through the effects of limited availability of healthy foods, physical activity resources, and other built environment characteristics related to the diet and physical activity of residents (Morland et al., 2006, Moore et al., 2009, Popkin et al., 2005). In addition, aspects of neighborhood social environments, such as neighborhood social cohesion, neighborhood problems and neighborhood violence, may contribute to T2DM through stress, transmission of negative health behaviors, and lack of social support (Diez Roux and Mair, 2010, Gary et al., 2008).

Previous studies have found associations between neighborhood environments and T2DM (Gary et al., 2008, Diez Roux et al., 2002, Schootman et al., 2007, Krishnan et al., 2010). However, the majority of these studies relied on cross-sectional analysis or used neighborhood-level SES (e.g. US census-based deprivation indices) as indirect proxy for neighborhood characteristics or both. Although useful, these studies are limited in their ability to draw causal inferences and to identify specific neighborhood environments that might be relevant to the development of T2DM (Diez Roux and Mair, 2010). To date only few studies have investigated more specific features of neighborhood environments in relation to T2DM (Auchincloss et al., 2008, Auchincloss et al., 2009, Christine et al., 2015, Sundquist et al., 2015). For example, studies by Multiethnic Study of Atherosclerosis

(MESA) reported that better access to neighborhood physical activity and healthy foods resources (survey-based measures) were associated with lower levels of insulin resistance (Auchincloss et al., 2008) and lower incidence of T2DM (Auchincloss et al., 2009, Christine et al., 2015). Sundquist *et al.* also reported negative association between objectively measured neighborhood walkability and incidence of T2DM in a large sample of Swedish adults aged 18 years and older (Sundquist et al., 2015).

As a result of residential segregation by race and SES, African Americans are exposed to more adverse neighborhood environments than Whites, including worse access to healthy foods and physical activity resources and greater exposures to neighborhood stressors. However, little is known about how specific neighborhood attributes affect the risk of T2DM in African American populations. We used unique data from a population-based cohort, the Jackson Heart Study (JHS), to investigate the associations of neighborhood social and physical environments with prevalence and incidence of T2DM. Understanding the associations between neighborhood social and physical environments and T2DM may be help guide in the development of policies or place-based interventions that promote healthier environments to reduce the high rates of T2DM in African Americans, in particular among those living in Jackson, MS (Dankwa-Mullan and Pérez-Stable, 2016). We hypothesized that better neighborhood environments (more social cohesion, and more availability of favorable food stores and physical activity resources) would be associated with a decreased risk of T2DM whereas worse neighborhood environments (more neighborhood violence, neighborhood problems and availability of unfavorable food stores) would be associated with an increased risk of T2DM in African Americans independent of potential confounders (age, sex, SES, family history of diabetes, smoking status, and alcohol consumption). We further hypothesized that these associations would be mediated by individual-level physical activity, diet and body mass index (BMI).

Material and Methods

Population study

JHS is a population-based longitudinal cohort study designed to investigate predictors of cardiovascular disease (CVD) in African Americans (Fuqua et al., 2005, Taylor et al., 2005). Briefly, between March 2000 and September 2004, JHS recruited 5,301 men and women, aged 21 to 94 years, from the City of Jackson and the surrounding tri-county area (Hinds, Rankin, and Madison Counties). We used data from the baseline examination (2000 to 2004), and exams 2 (2005–2008) and 3 (2009–2013). All JHS residential addresses for the baseline exam 1and exam 2 were geocoded using TeleAtlas EZLocate web-based geocoding software. Addresses were included if geocoding accuracy was at the street or zipcode+4 level. Institutional Review Boards from all of the participating institutions approved the study and participants provided written informed consent.

Of 5,301 participants enrolled at baseline (2000–2004), 61 participants were excluded because they had no information about T2DM at baseline, and 11 participants due to missing of neighborhood environments. An additional 536 participants were excluded due to missing information of covariates, leaving a total of 4693 participants for the cross-sectional analysis (prevalence of T2DM). Of these, 1023 (22%) participants had T2DM at baseline. For the longitudinal analysis (incidence of T2DM), we restricted to 3670 participants without T2DM at baseline.

T2DM Outcome

T2DM was defined using the American Diabetes Association 2010 criteria, i.e. a fasting plasma glucose ≥126 mm/dl or hemoglobin A1c (hbA1c) ≥6.5%, or self-reported history of diagnosis of T2DM or anti-diabetic medication use in the 2 weeks preceding assessment. Prevalence of T2DM was assessed at baseline. Incidence of T2DM was investigated in participants who did not have T2DM at baseline but developed T2DM at Exam 2 (2005–2008) or Exam 3 (2009–2013).

Neighborhood Environments

Neighborhood environments were assessed using survey-and Geographic Information System (GIS) –based measures of neighborhood physical and social environments. Survey-based measures of neighborhood social environments were assessed using valid scales during the third annual follow-up of participants between 2004 and 2008. The survey data across the 5 years were pooled to obtain more reliable estimates of survey-based neighborhood measures at census tract level.

The survey questions were grouped into three scales of neighborhood social cohesion, violence and problems based on principal component analysis with Promax oblique rotation, consistent with previous work (Mujahid et al., 2007). The social cohesion scale comprised 5 items relating to trust in neighbors, shared values with neighbors, willingness to help neighbors, and extent to which neighbors get along, with a score ranging from 1 (strongly disagree) to 4 (strongly agree). The violence scale included 5 items about occurrences of neighborhood fight, violent argument, gang fights, sexual assault or rape and robbery, with a score ranging from 1 (never) to 4 (often). The neighborhood problems scale included 6 items about neighborhood noise, heavy traffic and speeding cars, lack of access to adequate food/or shopping, parks trash and litter, with a score ranging from 1 (not really a problem) to 4 (very serious problem). The internal consistencies for the three scales were acceptably high, with Cronbach’s alpha 0.77, 0.80, and 0.76 for neighborhood social cohesion, violence and problems, respectively. For each scale, questionnaire responses for all participants within a given tract were aggregated to census tract level using unconditional empirical Bayes estimation adjusting for age and sex (Mujahid et al., 2007). JHS participants whose data were used in this study resided in 112 tracts with a median of 19 participants per tract.

GIS-based densities of food stores and physical activity resources were derived from commercially available business listings through the National Establishment Time-Series (NETS) database developed by Walls & Associate for the years 2000 through 2010, which were linked to JHS baseline exam 1 and exam 2 due to availability of geocoded addresses. In addition to food stores from NETS, additional supermarkets data were also purchased from Nielsen/ TDLinx Service Supermarket Retail Category Database (Nielsen Company, 2008) to enhance supermarket chains that were underrepresented in the NETS database (e.g. ALDI, Frys Food, Save A Lot, Smart & Final, SuperTarget, WalMart Supercenter, and Trader Joe’s). Geographic location and name matching algorithms were used to merge the supermarkets data from NETS and Nielsen/TDLinx databases while guarding against measurement errors, such as removing duplicates, eliminating headquarters that do not provide services to the public, spelling irregularities as described in detail elsewhere (Auchincloss et al., 2012). The information obtained on each establishment included name, address, SIC code, number of annual employees, annual sales volume, approximate square footage, and type of business (branch, single location, franchised, headquarters, etc.). Addresses for the all establishments were geocoded using TeleAtlas EZ-Locate web-based geocoding software. Standard Industrial Classification (SIC) codes were used to assign each establishment into favorable food stores, unfavorable food stores, and physical activity resources based on prior work (Auchincloss et al., 2012, Gordon-Larsen et al., 2006, Powell et al., 2007). A summary measure of “favorable” food store density was created by summing the densities for groceries, supermarket chains and non-chain stores (SIC 54110000, 54110100, 54110101–54110105 54119900, 54119901, 54119904, or 54119905) and fruit and vegetable markets (SIC 54319900, 54310000, 54319901, or 54319902). We also summed the densities of convenience stores (SIC 54110200, 54110201, or 54110202), bakeries, candy/nut shops, ice cream stores (SIC 54410000–54419905, 54610000–54619908, 58120200, 58120202, 58120203, 58120204), liquor stores (SIC 59210000, 59210100, 59210101, 59210102, 59219900, or 59219901), alcoholic drinking places (SIC 58130000, 58130100, 58130101–58130106, 58130200, 58130201–58130203), and fast food stores (SIC 581203) to create a summary measure of “unfavorable” food store density. For physical activity resources, a total of 114 SIC codes were selected related to indoor conditioning, dance, bowling, golf, biking, hiking, team and racquet sports, swimming, physical activity instruction, and water activities and summed to create density of physical activity resources. The densities of favorable food stores, unfavorable food stores and physical activity resources (number per square mile) were calculated for 1-mile buffer around each JHS’s residential address using ArcGIS software (ESRI, Redlands, CA) and the data were linked to each participant’s baseline exam1 and exam 2.

Covariates

Demographic variables at baseline include age [years], sex (male/female), self-reported family history of diabetes, income, and education were obtained using standard questionnaires administered by trained JHS clinic staff during the home induction interview (Taylor et al., 2005). Annual household income was self-reported in 11 categories ranging from under $5,000 to $100,000 or more and collapsed into 4 groups as poor, lower-middle, upper-middle, and affluent based on family size, US Census poverty levels, and year of baseline clinic visit. A fifth income category was created for participants who did not know their income or refused to respond and was entered as a dummy variable in the analysis. Education was self-reported as the highest level of schooling completed and classified into 4 categories: less than high school, high school graduate/GED, vocational training up to associate’s degree and bachelor’s degree and above. Current cigarette smokers were defined as having smoked at least 400 cigarettes in one’s lifetime and self-report of currently smoking. Alcohol use was defined as consumption of alcoholic beverages within the past 12 months. Both smoking status and alcohol consumption were collected at baseline and exam 3. Potential mediators included physical activity, diet and BMI. A summary score of total physical activity based on duration, frequency and intensity of physical activity in four different domains (active living, work, home and garden, and sport and exercise) was calculated from a 30-item questionnaire modified from the Baecke questionnaire used in the ARIC study (Dubbert et al., 2005). Physical activity was measured at the baseline and exam 3. Diet score was calculated according to the American Heart Association (AHA) guidelines (Lloyd-Jones et al., 2010) from a 158-item Delta Nutrition Intervention Research Initiative Food Frequency questionnaire (FFQ), which was validated for use in adults in the Mississippi Area (Carithers et al., 2005, Tucker et al., 2005). Participants were given one point for each of 5 dietary goals, with a total score ranging from 0 to 5, including fruits and vegetables of 4.5 cups/d or more, fish of two 3.5-oz servings or more per week (nonfried), fiber-rich whole grains of three 1-oz-equivalent servings/d or more, sodium less than 1500 mg/d, and sugar-sweetened beverages of 450 kcal/wk or less (36 oz). Participants were then classified as ideal (four or five of the five metrics), intermediate (two or three of the five metrics), or poor (none or one of the five metrics). Diet was assessed only at baseline exam. Standing height and weight were measured in light weight clothing without shoes at each clinic visit (baseline, exam 2, and exam 3) and BMI was calculated as weight in kilograms (kg) divided by height in meters squared (m^2). Population density was measured as persons per square mile within a 1-mile buffer of the participant’s address and calculated based on block-level US Census population. Distance to the nearest bus stop for each participant’s address in meters was calculated using ArcGIS software (ESRI, Redlands, CA) based on Jatran bus stops and routes obtained through the city of Jackson, MS.

Statistical analysis

Descriptive statistics (mean ± SD and percentage) were used to compare the distribution of individual-level characteristics in participants with and without prevalent and incident T2DM. Prevalence rates and incidence rates of T2DM adjusted to the mean age and sex composition of the sample were calculated by tertile of the neighborhood environments using logistic and Poisson regression, respectively. Tests for trend were evaluated by entering the tertile of the neighborhood scores as ordinal variables in the regression models.

Generalized estimating equations (GEEs) models were used to examine the cross-sectional associations between neighborhood environments and prevalence of T2DM. We examined the associations of neighborhood environments with incidence of T2DM using Cox proportional hazards models, with a robust sandwich estimator for standard error to account for clustering of participants within tracts (Wei et al., 1989). Since the occurrence of T2DM was only assessed at each exam, the date of incident T2DM was assigned to the midpoint between the last T2DM-free exam and the first T2DM diagnosis exam. Participants who did not develop T2DM were censored at the date of their last exam. Each neighborhood characteristics was modeled as continuous variable because there was no evidence of nonlinear relationships between neighborhood environments and T2DM. To compare associations for neighborhood characteristics that have different units, estimates were calculated corresponding to differences between the 90th and 10th percentiles of the neighborhood environment score. To evaluate the potential mediation effects of physical activity, diet, and BMI on the associations between neighborhood environments and T2DM, models were adjusted in a sequential manner and estimates were compared before and after adjustment for these variables. Model 1 adjusted for age and family history of diabetes.

Model 2 adjusted for all variables in model 1 and SES (income and education). Model 3 adjusted for all variables in model 2 and smoking and alcohol consumption. Model 4 adjusted for all variables in model 3 and physical activity and diet. Model 5 adjusted for all variables in model 4 and BMI. Because of strong correlations among the neighborhood measures (supplementary Table 1), each neighborhood measure was investigated separately in the models to avoid problems of multi-collinearity. However, we also jointly adjusted for those neighborhood measures that were statistically significant to investigate their independent associations with T2DM.

Since there was no evidence of significant interaction between sex and neighborhood environments for prevalence and incidence of T2DM (p for all interaction tests > 0.1), pooled results were shown for all subsequent analyses. We also performed additional sensitively analysis to investigate the robustness of our findings. First, we adjusted the models for time-varying covariates (age, education, current smokers, alcohol intake, physical activity and BMI) and produced similar associations between neighborhood environments and incidence of T2DM. Additionally, we also assessed GIS-based measures in relation to incidence of T2DM as time-varying predictors in the Cox regression models. Second, since prior work has shown that population density and bus stop are independently related to health behaviors (Rundle et al., 2009, Boone-Heinonen et al., 2013), we also controlled for population density and distance to bus stop to assess whether the relationships between GIS-based measures and T2DM were affected by these confounders. Third, we also explored alternative 3-mile buffer for GIS-based measures. Schoenfeld residuals indicated that the proportional hazard assumption was not violated for each neighborhood measure. All analyses were conducted using SAS 9.3 (SAS Institute, Cary, NC).

Results

Overall, 1023 of 4693 (22%) participants had prevalence of T2DM at baseline and 521 of 3670 participants developed T2DM during a median follow-up time of 7.3 years. Table 1 presents baseline characteristics of the study participants by prevalence and incidence of T2DM. Persons with T2DM at baseline tended to be older, women, less educated, less physically active, had lower income levels, higher family history of diabetes and mean BMI, and were less likely to smoke and consume alcohol compared to those without T2DM at baseline. In addition, they were more likely to reside in neighborhoods with lower social cohesion, but with higher problems, violence, favorable and unfavorable food stores, and physical activity resources. Persons who developed T2DM were more likely to be older, had higher family history of diabetes and mean BMI, but lower mean physical activity compared to those who did not develop T2DM. Similarly those who developed T2DM tended to live in neighborhoods with significantly lower social cohesion, but higher favorable and unfavorable food stores. There were no significant changes in densities of favorable and unfavorable food stores between baseline and exam 2, but there was a significant change in the density of physical activity resources among those who developed T2DM.

Neighborhood characteristics by baseline person-level characteristics are presented in Table 2. There was significant patterning of neighborhood environments by socio-demographic factors. Older people tended to live in neighborhoods with lower social cohesion, but with higher violence, problems, unfavorable and favorable food stores, and physical activity resources than younger participants. Women lived in neighborhoods with higher violence and problems, but higher favorable food stores than men. On average, persons with lower income and education were more likely to reside in a neighborhood with lower social cohesion, favorable food stores and physical activity resources, but with higher violence, problems, and unfavorable food stores (p trend <0.05 for all).

Table 3 shows age-and sex-adjusted prevalence and incidence rates of T2DM by tertiles of neighborhood environments. Higher neighborhood social cohesion was associated with lower age-and sex-adjusted prevalence rates of T2DM. Higher neighborhood violence and problems, and densities of favorable and unfavorable food stores were associated with higher prevalence rates of T2DM but no associations were observed for the density of physical activity resources. Additionally, higher neighborhood social cohesion and higher densities of favorable and unfavorable food stores were also associated with higher incidence rates of T2DM.

Neighborhoods with better social cohesion had lower prevalence of T2DM while neighborhoods with more violence and problems had higher prevalence of T2DM after adjusting for age, sex, and family history of diabetes (Table 4 model 1). Prevalence ratios of T2DM corresponding to a difference between the 90th and 10th percentiles were 0.92, 95% confidence interval (CI), [0.86, 0.98]) for social cohesion, 1.10[1.03, 1.18] for violence, and 1.16 [1.07, 1.25] for problems. After adjustment for SES (income and education) (model 2), the associations slightly attenuated, but remained significant for neighborhood social cohesion (PR: 0.93 [0.86, 0.99]), violence (PR: 1.10[1.02, 1.18]) and problems (PR: 1.15[1.06, 1.25]). Adjusting for alcohol consumption and cigarette smoking (model 3) had no substantial effect on estimates for social cohesion, violence and problems. Associations also persisted after additional adjustment for potential mediators of physical activity and diet (model 4). Further adjustment for BMI (model 5), did not substantially alter point estimates although associations with neighborhood social cohesion and violence were no longer statistically significant (fully adjusted PR: 0.94 [0.88, 1.01]; 1.07[0.99, 1.15], and PR: 1.12[1.03, 1.21] for social cohesion, violence and problems, respectively. The association of neighborhood problems with prevalence of T2DM even persisted after controlling for GIS-based measures (PR: 1.11[1.00, 1.23]). Since the survey-based measures were highly correlated (Pearson $r > 0.73$ see supplementary Table 1), we did not examine their independent effects to avoid problems of multicollinearity. GIS-based densities of favorable and unfavorable food stores, and physical activity resources were not associated with prevalence of T2DM in any adjusted model. There was also no evidence of sex differences in the association of neighborhood environments with prevalence of T2DM (p for all interaction tests were non-significant > 0.10).Sensitivity analyses produced similar results when the GIS-based models controlled for population density and distance to bus stop (see supplementary Table 2) and when alternative 3-mile buffer was used (supplementary Table 3).

Neighborhood social cohesion and density of unfavorable food stores were significantly associated with incidence of T2DM after adjustment for age, sex, and family history of diabetes (Table 5 model 1). The adjusted hazard ratios (HR) of T2DM corresponding to a difference between the 90th and 10th percentiles were 0.74, 95% Confidence Interval (CI), [0.60–0.91] for social cohesion and 1.37[1.15–1.64] for densities of unfavorable food stores. Although the associations of neighborhood violence and problems with T2DM were in expected direction (HR for model 1: 1.16[0.95, 1.43], p=0.150, and 1.24[1.00, 1.54], p=0.051, respectively), the associations did not reach significance in any adjusted model. No associations were observed between densities of favorable food stores or physical activity resources and incidence of T2DM (Table 5).

Additional adjustment for family income and education slightly attenuated the associations of neighborhood social cohesion and density of unfavorable food stores with T2DM, but the estimates remained statistically significant (HR: 0.76[0.61, 0.95] and [HR: 1.36(1.13, 1.63], respectively). Adjusting for alcohol consumption and cigarette smoking did not modify the associations (model 3). Additional adjustment for physical activity and diet (model 4), and for BMI (model 5) did not substantially alter point estimates (HR: 0.78[0.62, 0.99] for social cohesion and HR: 1.34 [1.12, 1.60] for density of unfavorable food stores. When social cohesion and density of unfavorable food stores (Pearson correlation, $r = -0.45$ see supplementary Table 1) were simultaneously entered into the same models to examine their dependent effects (Table 6), the association between density of unfavorable food stores and incidence of T2DM remained significant in the fully adjusted model (HR: 1.28[1.03, 1.59]). However, the association between neighborhood social cohesion and T2DM was attenuated and was no longer significant independent of unfavorable food stores although the point estimate continued to suggest a protective effect (HR: 0.88[0.68, 1.15].There was no evidence that associations of neighborhood environments with incidence of T2DM differed by sex (p for all interaction tests > 0.10). Results were also robust when survey-based measures were adjusted for time-varying covariates (age, education, smoking status, alcohol intake, physical activity and BMI (supplementary Table 4). Furthermore, the results did not meaningfully change when GIS-based measures were entered into the models as time-varying predictors in addition to adjusting for time-varying covariates and controlling for population density and distance to bus stop (supplementary Table 4). Sensitivity analysis also demonstrated consistent results between GIS-Based measures and incidence of T2DM when alternative 3-mile buffer was used (supplementary Table 5).

Discussion

This study is the first to examine the associations of multiple survey- and GIS-based neighborhood social and physical environments with prevalence and incidence of T2DM in a large, economically diverse African American population in the Deep South. In cross-sectional analysis, we found evidence that lower neighborhood social cohesion, and higher neighborhood violence and neighborhood problems were associated with higher prevalence of T2DM after adjustment for all individual-level covariates except BMI. Further adjustment for BMI, only neighborhood problems remained significant. In addition, the association between neighborhood problems and prevalence of T2DM persisted after controlling for GIS-based measures. There were no significant associations between GIS-based measures of favorable and unfavorable food stores, and physical activity resources and prevalence of T2DM in any adjusted model. In the longitudinal analyses, we found persons living in a neighborhood with better social cohesion had a 22% lower risk of developing T2DM after adjusting for individual-level of risk factors and behavioral mediators. Furthermore, persons living in a neighborhood with higher density of unfavorable foods stores had a 34% higher risk of developing T2DM independent of the individual-level risk factors and behavioral mediators. However, survey-based neighborhood violence and problems, and GIS-based densities of favorable food stores and physical activity resources were not associated with incidence of T2DM in any adjusted model.

Few studies have examined neighborhood social environments in relation to T2DM. We found that higher neighborhood social cohesion was associated with lower incidence of T2DM over a median follow-up of 7.3 years independent of individual-level risk factors. However, the association was no longer statistically significant after adjusting for unfavorable food stores, but the point estimate continued to suggest a protective effect. These findings are consistent with previous longitudinal studies that reported associations between higher neighborhood social cohesion and lower incidence of myocardial infraction (Chaix et al., 2008), incidence of depression (Mair et al., 2009), stroke mortality (Kim et al., 2013), and all-cause mortality (Martikainen et al., 2003). Our findings were also consistent with several cross-sectional studies that found associations of higher neighborhood social cohesion with lower prevalence of smoking (Patterson et al., 2004), and hypertension (Mujahid et al., 2008), but higher rates of physical activity (Fisher et al., 2004), although in our study the association between neighbrhood social cohesion and prevalence of T2DM was attenuated after adjustment for BMI. The mechanisms by which neighborhood social cohesion affect T2DM have not been fully identified, but it has been posited that social cohesion may be a proxy for social support outside family and friends and act as a buffer against the adverse effects of stress (Diez Roux and Mair, 2010, Kim et al., 2013, Mair et al., 2009). Additionally, social cohesion may also play an important role in shaping behaviors and enforcing social norms for positive health behaviors (Diez Roux and Mair, 2010, Mair et al., 2009).

We also found that neighborhood problems was associated with higher prevalence of T2DM even after adjustment for individual-level risk factors and GIS-based measures, but the association with incidence T2DM was not significant although it was in the expected direction. Our findings are consistent with one study that reported a positive association between neighborhood problems and T2DM among low-income rural Latinos in California (Moreno et al., 2014). Another study also reported neighborhood problems are positively associated with depression and negative health behaviors (Echeverria et al., 2008). The specific mechanisms through which neighborhood problems affect T2DM are not fully understood, however, problematic neighborhoods may negatively influence T2DM through stress related mechanisms that could affect T2DM directly or lead residents to engage in negative health behaviors (Echeverria et al., 2008, Gary et al., 2008, Gary-Webb et al., 2013). In our study, the associations between neighborhood problems and prevalence of T2DM persisted after adjustment for physical activity, diet, and BMI. It is possible that other mechanisms may be involved. For example, neighborhood problems can be a direct source of stress in individuals, which may contribute to T2DM through the activation of the sympathetic nervous system and hypothalamic-pituitary-adrenal axis or visceral fat accumulation (Gary-Webb et al., 2013). However, our ability to examine these factors as mediators was limited by the measures available and their timing. Additional research is needed to corroborate our findings and understand the specific mechanisms that are involved in linking neighborhood social cohesion and neighborhood problems with T2DM.

Our study also demonstrated a significant and independent association between GIS-based density of unfavorable food stores and incidence of T2DM. Greater density of unfavorable food stores (e.g. fast foods, convenience stores, liquor stores) was associated with higher incidence of T2DM after adjusting for individual-level risk factors. This association also persisted even after adjusting for neighborhood social cohesion. Our findings are generally consistent with prior work that reported significant associations between availability of fast-food stores and poor diet quality intake and higher BMI (Boone-Heinonen et al., 2011, Hickson et al., 2011, Reitzel et al., 2014). For example, Hickson *et al.* reported greater fast food restaurants availability was associated with higher energy intake in the same cohort (Hickson et al., 2011). We are aware of only one study in UK that investigated that association between density of fast-food stores and T2DM and found significant positive association between the number of fast-food outlets in individual's neighborhood and prevalence of T2DM (Bodicoat et al., 2015). However, this study was cross-sectional and used less comprehensive measure of unfavorable food stores compared to our study.To the best of our knowledge, this study is the first to report an association between density of unfavorable food stores and incidence of T2DM in a large sample of African Americans. Our findings therefore have potentially important public health implications that policies or intervention strategies (e.g. zoning regulations) that limit the proliferation of unfavorable food stores may reduce the burden of T2DM and related risk factors in African Americans. This is particularly important given that unfavorable food stores tend to be concentrated in African American and low-income communities (Block et al., 2004, Galvez et al., 2008, Larson et al., 2009, Morland et al., 2002, Zick et al., 2009).

The mechanisms by which unfavorable food stores affect T2DM remain unclear. However, it has been suggested that the availability of greater density of unfavorable food stores promote greater consumption of fast-food and sugar-sweetened beverages, which in turn can lead to a higher T2DM in African Americans (Boone-Heinonen et al., 2011). We adjusted for diet, physical activity, and BMI, but these variables did not explain the association although adjustment for BMI slightly attenuated the association between unfavorable food stores and T2DM. However, our ability to investigate mediation might be prone to the measurement errors such as recall bias of food frequency questionnaire and lack of availability of measures at each follow up-visit. Furthermore, teasing apart the meditating pathways are inherently challenging using standard regression analyses (Blakely, 2002). More research is needed using time-varying mediators and appropriate mediation methods to better identify the intermediaries and understand the specific mechanisms through which density of unfavorable food stores increase the risk of T2DM.

Contrary to our hypothesis, GIS-based densities of favorable food stores and physical activity resources were not associated with T2DM in our study. These findings are not surprising since previous studies have also found no association between GIS-based measures of favorable food stores and physical activity resources and T2DM and related risk factors (Auchincloss et al., 2009, Christine et al., 2015, Boone-Heinonen et al., 2011). For example, a MESA study found no association between GIS-measures of favorable food stores and physical activity resources and incidence of T2DM (Christine et al., 2015). However, other studies found strong association between survey-based measures of availability of healthy foods and walkability with incidence of T2DM (Auchincloss et al., 2009). This suggests that GIS-based measures of favorable food stores and physical activity might be less relevant to T2DM and related behaviors compared to survey-based measures given that they simply measure the presence or absence of resources and provide limited information about access, quality, affordability, and utilization of resources (Block et al., 2011, Moore et al., 2008). Future research will need to enhance or develop more comprehensive neighborhood measures of food and physical activity environments that strongly related to T2DM and related behaviors in African Americans.

Limitations and Strengths

This study has several limitations that we would like to highlight. First, our findings were based on African American population that came from a single site of Jackson, MS and might not be generalizable to other geographic areas. Second, it is possible that our results could be affected by residual confounding and unmeasured time-varying factors although we adjusted for all known potential confounders (Handy et al., 2005). Third, our measures of physical activity and diet relied on self-reported retrospective recalls and are susceptible to recall bias and measurement errors. In addition, diet was measured only at baseline and changes in diet may occur over the study period, but we were not able to adjust fully for time-varying diet in our study. Fourth, the use of self-reported survey-based neighborhood measures could be subject to the same-source bias although this is tempered by the fact that summary measures were created using empirical Bayes estimates by pooling information from several respondents of the same neighborhood. This process has been shown to reduce some of the measurement errors in individual responses and yield a more valid measure of neighborhood construct of interest (Mujahid et al., 2007). Additionally, time-varying survey-based measures were not available thus we were unable to investigate how changes in survey-based measures may influence incidence of T2DM over the course of the study period. Fifth, GIS-based measures were only assessed for baseline and exam 2 and may not accurately reflect long-term exposures relevant to the development of T2DM over the course of the follow-up period. Sixth, our GIS-based measures were based on the presence and absence of commercial listings of food and physical activity establishments from secondary database and did not account for the quality, accessibility, cost and utilization of the resources. In addition, commercial database of food stores and physical activity resources are subject to measurement errors, such as misclassification, missing, undercount and geospatial inaccuracies (Powell et al., 2007, Boone et al., 2008) and these errors may potentially bias the associations between GIS-based measures and T2DM. Finally, missing data are another potential limitation that could affect the association between neighborhood measures and T2DM. However, it is unlikely that the missing data would substantially affect our results given a large sample size and the fact that the missingness was not dependent on outcome.

Despite these limitations, this study has several important strengths, including the use of a large and socioeconomically diverse African American samples, prospective design with long-term follow-up of T2DM, the ability to investigate multiple dimensions of neighborhood social and physical environments related to T2DM in high-risk and under-studied population. To the best of our knowledge, the present study is the first to examine both survey- and GIS-based measures of neighborhood environments in relation to T2DM in African Americans. Our findings can help inform future policies and place-based interventions aimed at creating healthier-environments that support healthy eating and activing living to reduce the high rates of T2DM in African Americans living in the Jackson, MS metropolitan statistical area (Dankwa-Mullan and Pérez-Stable, 2016).

In conclusion, our findings provide longitudinal evidence that neighborhoods with greater density of unfavorable food stores may increase the risk of developing T2DM among African Americans independent of individual-level risk factors and neighborhood social cohesion. Our findings also showed neighborhoods with better social cohesion may be protective of future development of T2DM independent of individual-level risk factors. In addition, we found strong association between neighborhood problems and prevalence of T2DM independent of individual-level risk factors and GIS-based measures. Additional research is needed to corroborate our findings using rigorous longitudinal studies or natural experiments or randomized trials. If corroborated by future studies, these findings suggest that modification of neighborhood environments might be an important strategy to consider for the prevention of T2DM in African Americans.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations and Acronyms

CI	Confidence Interval
CVD	Cardiovascular disease
GIS	Geographic Information Systems
JHS	Jackson Heart Study
HR	Hazard ratio
PR	Prevalence ratio

PY	Person-years
T2DM	Type 2 diabetes mellitus

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Highlights

- African Americans experience high rates of type 2 diabetes of mellitus (T2DM).
- They also tend to live in adverse neighborhood social and physical environments.
- We examined the impact of these neighborhood features on T2DM in African Americans.
- Higher neighborhood social cohesion was associated with lower incidence of T2DM.
- Higher density of unfavorable food stores was associated with higher incidence of T2DM.
- Improving community ties or attracting healthy food stores may reduce T2DM.

Table 1

Selected baseline characteristics [*] of participants with prevalent and incident type 2 diabetes mellitus (T2DM), the Jackson Heart Study (2000–2004).

	Prevalent T2DM			Incident T2DM		
No. of participants	**No (N=3670)**	**Yes (N=1023)**	**P value**	**No (N=3149)**	**Yes (N=521)**	**P value**
Demographic characteristics						
Age, y, mean(SD)	53.6 (13.0)	60.4 (10.6)	<0.001	53.4 (13.2)	54.8 (11.1)	0.014
Men	37.5	33.9	0.037	37.6	36.9	0.755
Family history of diabetes	2.0	72.1	<0.001	1.6	4.8	<0.001
Socioeconomic status						
Income			<0.001			0.808
Low income	13.9	18.8		13.9	13.8	
Lower middle	22.8	28.5		22.8	23.8	
Upper middle	30.5	29.0		30.7	28.8	
Affluent	32.8	23.7		32.5	34.6	
Education			<0.001			0.602
<High school	17.2	28.7		16.9	19.2	
High school/GED	18.4	18.1		18.4	18.4	
Voc/Some college/AA degree	29.7	26.3		29.8	29.4	
College graduate	34.6	26.9		34.9	33.0	
Risk factors/health behaviors						
Current smokers	13.5	10.7	0.016	13.9	11.5	0.150
Alcohol drinking	49.2	33.6	<0.001	49.7	46.1	0.124
Physical activity , mean (SD)	8.6 (2.6)	7.5(2.6)	<0.001	8.6 (2.6)	8.4(2.5)	0.061
[†]Ideal AHA dietary intake	0.64	0.40	0.004	0.74	0.08	0.509
BMI, mean (SD)	31.1 (7.2)	34.2(7.2)	<0.001	30.7(7.1)	33.7(7.1)	<0.001
Type 2 diabetes	78.2	21.8	-	85.8	14.2	-
[‡]**Survey-based neighborhood**						
Social cohesion	3.03 (2.93–3.12)	3.01 (2.93–3.09)	<0.001	3.03 (2.93–3.12)	3.01 (2.93–3.09)	0.021
Violence	1.26 (1.15–1.32)	1.28 (1.18–1.33)	<0.001	1.26 (1.15–1.32)	1.26 (1.15–1.33)	0.196
Neighborhood problems	1.56 (1.37–1.71)	1.61 (1.44–1.73)	<0.001	1.56 (1.37–1.71)	1.58 (1.41–1.72)	0.064

	Prevalent T2DM			Incident T2DM		
No. of participants	**No (N=3670)**	**Yes (N=1023)**	**P value**	**No (N=3149)**	**Yes (N=521)**	**P value**
[§]**GIS-based neighborhood**						
Favorable food stores	0.00(0.00–0.53)	0.05(0.00–0.62)	<0.001	0.00(0.00–0.51)	0.02(0.00–0.64)	0.007
[//]Change in favorable food stores				0.00 (0.00–0.00)	0.00(−0.01–0.4)	0.567
Unfavorable food stores	2.15(0.51–4.59)	2.91(1.12–5.09)	<0.001	2.10(0.50–4.52)	2.49(0.61–5.26)	0.017
Change in unfavorable food stores				0.05(−0.12–1.07)	0.21(−0.17–1.26)	0.125
Physical activity resources	0.03(0.00–0.54)	0.11(0.00–0.60)	0.042	0.14(0.00–0.66)	0.17(0.00–0.66)	0.249
Change in physical activity resources				0.00(0.00–0.57)	0.02(0.00–0.66)	0.036

Abbreviation: BMI: body mass index, SD: standard deviation, IQR: inter-quartile range, GIS: geographic information systems, JHS: Jackson Heart Study.

[*] Data are given as the percentage of participants unless otherwise indicated

[†] Ideal dietary intake was defined according to American Heart Association (AHA) 2020 guidelines if participant met four to five of five of the following recommendations: fruits and vegetables of 4.5 cups/d or more; fish of two 3.5-oz servings per week or more (preferably oily fish); fiber-rich whole grains of three 1-oz-equivalent servings per day or more; sodium less than 1500 mg/d or more; and sugar-sweetened beverages of 450 kcal (36 oz)/wk or less.

[‡] Survey-based neighborhood environments were collected from JHS participants and aggregated to census tracts using empirical Bayes estimation. Item responses had a possible range of 1 to 4; higher scores indicate better social cohesion, higher violence, and problems.

[§] GIS-based densities of favorable and unfavorable food stores and physical activity resources were derived using standard industrial classification codes from commercial listings of establishments obtained from National Establishment Time-Series database from Walls & Associates. The densities were calculated for a 1-mile buffer around each of JHS participant’s residential address.

[//] Change in densities between exam1 (2000–2004) and exam 2 (2005–2008).

P value (*t*-test or Wilcoxon-Mann-Whitney test for continuous variables and $\chi 2$ and fisher exact tests for categorical variables).

Table 2

Mean (SD) score of neighborhood environments[*] by socio-demographic characteristics of participants without type 2 diabetes mellitus (T2DM) at baseline (2000–2004).

		†Survey-based neighborhood social environments			‡GIS-based neighborhood physical environments		
	N	**Social cohesion**	**Violence**	**Problems**	**Favorable food stores**	**Unfavorable food stores**	**Physical activity resources**
Overall	3670	3.01(0.12)	1.26(0.13)	1.55(0.19)	0.29(0.44)	3.09(3.22)	0.33(0.53)
Age							
<60	2420	3.02(0.12)	1.24(0.13)	1.53(0.19)	0.27(0.42)	2.71(3.08)	0.32(0.56)
60+	1250	3.00(0.12)	1.29(0.12)	1.61(0.17)	0.34(0.46)	3.82(3.34)	0.35(0.49)
§P value		<.001	<.001	<.001	<.001	<.001	0.079
Gender							
Women	2295	3.01(0.12)	1.26(0.12)	1.56(0.19)	0.30(0.44)	3.15(3.16)	0.33(0.52)
Men	1375	3.02(0.12)	1.25(0.13)	1.54(0.19)	0.27(0.43)	2.98(3.30)	0.33(0.56)
P value		0.069	0.042	0.004	0.024	0.122	0.701
Income							
Low income	432	2.97(0.13)	1.30(0.13)	1.62(0.18)	0.33(0.45)	3.39(2.94)	0.36(0.55)
Lower middle	710	2.98(0.12)	1.30(1.13)	1.62(0.18)	0.36(0.49)	3.92(3.36)	0.38(0.53)
Upper middle	947	3.02(0.12)	1.24(0.12)	1.54(0.18)	0.29(0.42)	2.97(3.14)	0.32(0.50)
Affluent	1021	3.05(0.11)	1.21(0.11)	1.48(0.17)	0.25(0.41)	2.67(3.31)	0.30(0.58)
P for trend		<.001	<.001	<.001	<.001	<.001	0.011
Education							
<High school	632	2.97(0.13)	1.31(0.13)	1.63 (0.17)	0.33(0.46)	3.92(3.29)	0.39(0.53)
High school/GED	676	2.99(0.12)	1.28(0.12)	1.59(0.18)	0.33(0.47)	3.42(3.22)	0.33(0.48)
Voc./some college/AA	1091	3.02(0.12)	1.25(0.12)	1.54(0.18)	0.27(0.42)	2.77(2.97)	0.30(0.52)
College graduate	1271	3.04(0.11)	1.23(0.12)	1.50(0.18)	0.26(0.42)	2.77(3.29)	0.32(0.57)
P for trend		<.001	<.001	<.001	<.001	<.001	0.005

Abbreviation: SD: standard deviation, GIS: geographic information systems, JHS: Jackson Heart Study.

[*] Data are given as the mean (SD) of the neighborhood measures.

[†] Survey-based neighborhood environments were collected from JHS participants and aggregated to census tracts using empirical Bayes estimation. Item responses had a possible range of 1 to 4; higher scores indicate better neighborhood social cohesion, and higher neighborhood violence and problems.

[‡] GIS-based densities of favorable and unfavorable food stores and physical activity resources were derived using standard industrial classification codes from commercial listings of establishments obtained from National Establishment Time-Series database from Walls & Associates. The densities were calculated for a one-mile buffer around each of JHS participant’s residential address.

[§] P value using ANOVA and P for trend for neighborhood scores entered as ordinal variables in ANOVA model.

Table 3

Age-and-sex adjusted prevalence and incidence rates[*] of type 2 diabetes mellitus (T2DM) by tertiles of neighborhood environments.

	Age-and sex-adjusted prevalence rates (%)[*]			
Neighborhood environments	**Low**	**Medium**	**High**	**[§]P for trend**
[†]Survey-based social environments				
Social cohesion	22.4	21.6	18.9	0.017
Violence	19.1	20.0	23.8	0.002
Problems	18.6	20.8	23.4	0.001
[‡]GIS-based physical environments				
Favorable food stores	19.4	21.6	22.9	0.011
Unfavorable food stores	17.9	23.0	21.9	0.010
Physical activity resources	19.3	21.9	21.8	0.089

	Age-and-sex-adjusted incidence rates per 1000 Person Years [*]			
Neighborhood environments	Low	Medium	High	[§]P for trend
[†]Survey-based social environments				
Social cohesion	27. 5	24.8	20.8	0.010
Violence	21.6	26.4	25.0	0.187
Problems	23.1	23.1	26.6	0.190
[‡]GIS-based physical environments				
Favorable food stores	21.7	24.5	28.2	0.008
Unfavorable food stores	21.1	23.8	28.4	0.007
Physical activity resources	21.6	25.2	26.0	0.086

Abbreviation: GIS: geographic information systems.

[*] Logistic regression was used to estimate age-and sex-adjusted prevalence rates of T2DM and Poisson regression was used to estimate age-and sex-adjusted incidence rates of T2DM (sum of events/person-years) according to neighborhood scores; person-years were approximated by using midpoints between clinic visits.

[†] Survey-based neighborhood environments were collected from JHS participants and aggregated to census tracts using empirical Bayes estimation. Item responses had a possible range of 1 to 4; higher scores indicate better social cohesion, and higher violence and problems.

[‡] GIS-based densities of favorable and unfavorable food stores and physical activity resources were derived using standard industrial classification codes from commercial listings of establishments obtained from National Establishment Time-Series database from Walls & Associates. The densities were calculated for a 1-mile buffer around each of JHS participant's residential address.

[§] P for trend for neighborhood scores entered as ordinal variables in logistic regression or Poisson model.

Table 4

Adjusted prevalence ratios[*] for type 2 diabetes mellitus (T2DM) prevalence corresponding to a difference between the 90th and 10th percentiles in neighborhood environments, 2000–2004.

	[†]Survey-based social environments					
	Social cohesion		**Violence**		**Problems**	
Model No.	**PR(95% CI)**	**P value**	**PR(95% CI)**	**P value**	**PR(95% CI)**	**P value**
Model 1	0.92(0.86, 0.98)	0.007	1.10(1.03, 1.18)	0.006	1.16(1.07, 1.25)	<0.001
Model 2	0.93(0.86, 0.99)	0.032	1.10(1.02, 1.18)	0.013	1.15(1.06, 1.25)	0.001
Model 3	0.92(0.86, 0.99)	0.027	1.10(1.02, 1.18)	0.015	1.15(1.06, 1.25)	0.001
Model 4	0.93(0.87, 1.00)	0.041	1.09(1.01, 1.17)	0.036	1.14(1.05, 1.24)	0.002
Model 5	0.94(0.88, 1.01)	0.083	1.07(0.99, 1.15)	0.084	1.12(1.03, 1.21)	0.008

	[‡]GIS-based physical environments					
	Favorable food stores		Unfavorable food stores		Physical activity resources	
Model No.	PR(95% CI)	P value	PR(95% CI)	P value	PR(95% CI)	P value
Model 1	1.03(0.98, 1.09)	0.224	1.07(0.99,1.17)	0.087	1.03 (0.98, 1.09)	0.185
Model 2	1.03(0.98, 1.09)	0.266	1.07(0.99,1.17)	0.087	1.04 (0.98, 1.09)	0.173
Model 3	1.03(0.98, 1.09)	0.248	1.08(0.99,1.17)	0.080	1.04 (0.98, 1.09)	0.169
Model 4	1.03(0.98, 1.09)	0.230	1.07(0.99,1.16)	0.099	1.03 (0.98, 1.09)	0.203
Model 5	1.01(0.96, 1.07)	0.715	1.07(0.99,1.16)	0.083	1.04 (0.99, 1.10)	0.136

Abbreviations: BMI: body mass index, CI: confidence interval, PR: Prevalence ratio, GIS: Geographic Information Systems, JHS: Jackson Heart Study.

[*] Adjusted PRs for baseline characteristics and were estimated using Generalized Estimating Equation (GEE) accounting for nesting of participants within census tract-level.

[†] Survey-based neighborhood environments were collected from JHS participants and aggregated to census tracts using empirical Bayes estimation. Item responses had a possible range of 1 to 4; higher scores indicate better social cohesion, and higher violence and problems.

[‡] GIS-based densities of favorable and unfavorable food stores and physical activity resources were derived using standard industrial classification codes from commercial listings of establishments obtained from National Establishment Time-Series database from Walls & Associates. The densities were calculated for a 1-mile buffer around each of JHS participant's residential address.

Model 1: Age, sex, and family history of diabetes

Model 2: Model 1 + income, and educational level

Model 3: Model 2 + alcohol intake, and smoking status

Model 4: Model 3 + physical activity level, and diet

Model 5: Model 4 + BMI

Table 5

Adjusted hazard ratios* for type 2 diabetes mellitus (T2DM) incidence corresponding to a difference between the 90th and 10th percentiles in neighborhood environments, 2000–2013.

	†Survey-based social environments					
	Social cohesion		**Violence**		**Problems**	
Model No.	**HR(95% CI)**	**P value**	**HR(95% CI)**	**P value**	**HR(95% CI)**	**P value**
Model 1	0.74(0.60,0.91)	0.004	1.16(0.95,1.43)	0.15	1.24(1.00,1.54)	0.051
Model 2	0.76(0.61,0.95)	0.016	1.13(0.91,1.40)	0.284	1.20(0.95,1.52)	0.126
Model 3	0.76(0.60,0.95)	0.016	1.13(0.91,1.40)	0.284	1.20(0.95,1.52)	0.127
Model 4	0.76(0.61,0.96)	0.019	1.11(0.90,1.38)	0.329	1.19(0.94,1.50)	0.149
Model 5	0.78(0.62,0.99)	0.044	1.07(0.87,1.32)	0.515	1.15(0.92,1.44)	0.219

	‡GIS-based physical environments					
	Favorable food stores		Unfavorable food stores		Physical activity resources	
Model No.	HR(95% CI)	P value	HR(95% CI)	P value	HR(95% CI)	P value
Model 1	1.22(0.98,1.52)	0.080	1.37(1.15,1.64)	<0.001	1.10(0.98,1.25)	0.118
Model 2	1.21(0.98,1.51)	0.084	1.36(1.13,1.63)	0.001	1.10(0.97,1.25)	0.135
Model 3	1.22(0.98,1.52)	0.081	1.37(1.13,1.65)	0.001	1.10(0.97,1.25)	0.132
Model 4	1.21(0.97,1.52)	0.089	1.36(1.13,1.63)	0.001	1.09(0.97,1.24)	0.163
Model 5	1.23(0.98,1.55)	0.076	1.34(1.12,1.60)	0.001	1.11(0.97,1.26)	0.135

Abbreviations: BMI: body mass index, CI: confidence interval, HR: hazard ratio, GIS: geographic information systems, JHS: Jackson Heart Study.

[*] Adjusted HRs for baseline characteristics and were estimated using Cox hazard regression with sandwich estimator accounting for nesting of participants within census-tract level, and time to event was approximated by using midpoints between clinic visits.

[†] Survey-based neighborhood environments were collected from JHS participants and aggregated to census tracts using empirical Bayes estimation. Item responses had a possible range of 1 to 4; higher scores indicate better neighborhood social cohesion, and higher neighborhood violence and problems.

[‡] GIS-based densities of favorable and unfavorable food stores and physical activity resources were derived using standard industrial classification codes from commercial listings of establishments obtained from National Establishment Time-Series database from Walls & Associates. The densities were calculated for a 1-mile buffer around each of JHS participant’s residential address.

Model 1: Age, sex, and family history of diabetes

Model 2: Model 1 + income, and educational level

Model 3: Model 2 + alcohol intake, and smoking status

Model 4: Model 3 + physical activity level, and diet

Model 5: Model 4 + BMI

Table 6

Adjusted hazard ratios for the associations between neighborhood environments and incidence of type 2 diabetes mellitus (T2DM), with significant neighborhood environments were entered simultaneously into the same models.[*]

	Model 1	Model 2	Model 3	Model 4	Model 5
Neighborhood environments	**HR(95% CI)**	**HR(95% CI)**	**HR(95% CI)**	**HR(95% CI)**	**HR(95% CI)**
Social cohesion	0.83(0.66,1.04)	0.85(0.67,1.09)	0.86(0.67,1.10)	0.86(0.67,1.10)	0.88(0.68,1.15)
Unfavorable food stores	1.28(1.04,1.57)	1.28(1.03,1.59)	1.29(1.03,1.61)	1.28(1.03,1.59)	1.28(1.03,1.59)

Abbreviations: BMI: body mass index, CI: confidence interval, HR: hazard ratio.

[*] Neighborhood social cohesion and unfavorable food stores were entered into the models simultaneously.

Model 1: Age, sex, and family history of diabetes,

Model 2: Model 1 + income, and educational level,

Model 3: Model 2 + alcohol intake, and smoking status,

Model 4: Model 3 + physical activity level, and diet,

Model 5: Model 4 + BMI