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Neighborhood characteristics and lifestyle intervention outcomes: Results from the Special Diabetes Program for Indians

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A B S T R A C T

Growing evidence reveals various neighborhood conditions are associated with the risk of developing type 2 diabetes. It is unknown, however, whether the effectiveness of diabetes prevention interventions is also influenced by neighborhood characteristics. The purpose of the current study is to examine the impact of neighborhood characteristics on the outcomes of a lifestyle intervention to prevent diabetes in American Indians and Alaska Natives (AI/ANs). Year 2000 US Census Tract data were linked with those from the Special Diabetes Program for Indians Diabetes Prevention Program (SDPI-DP), an evidence-based lifestyle intervention implemented in 36 AI/AN grantee sites across the US. A total of 3394 participants started the intervention between 01/01/2006 and 07/31/2009 and were followed by 07/31/2016. In 2016–2017, data analyses were conducted to evaluate the relationships of neighborhood characteristics with intervention outcomes, controlling for individual level socioeconomic status. AI/ANs from sites located in neighborhoods with higher median household income had 38% lower risk of developing diabetes than those from sites with lower neighborhood income (adjusted hazard ratio = 0.65, 95% CI: 0.47–0.90). Further, those from sites with higher neighborhood concentrations of AI/ANs achieved less BMI reduction and physical activity increase. Meanwhile, participants from sites with higher neighborhood level of vehicle occupancy made more improvement in BMI and diet. Lifestyle intervention effectiveness was not optimal when the intervention was implemented at sites with disadvantaged neighborhood characteristics. Meaningful improvements in socioeconomic and other neighborhood dis- advantages of vulnerable populations could be important in stemming the global epidemic of diabetes.

1. Introduction

It is well known that type 2 diabetes, a serious public health problem in the US, is highly prevalent among many racial/ethnic minority populations (CDC, 2017). The socioeconomic gradient in the risk of type 2 diabetes among developed countries has also been extensively documented (Agardh et al., 2011), which may account for a large proportion of the race/ethnic disparities observed domestically (Link and McKinlay, 2009; Signorello et al., 2007). Ongoing work seeks to elucidate the causal pathways for socioeconomic disparities in diabetes. It has been proposed that an individual's socioeconomic status may affect her/his risk of developing type 2 diabetes through multiple mechanisms, including adverse fetal and early life exposures (X. Jiang et al., 2013), obesity (Stringhini et al., 2012; Wikstrom et al., 2011), lifestyle behaviors (Stringhini et al., 2012; Wikstrom et al., 2011), psychological stress (Jiang et al., 2008; Kumari et al., 2004), and chronic inflammation (Stringhini et al., 2013).

In addition to socioeconomic disparities at the individual level, racial/ethnic minorities often reside in socio-economically disadvantaged neighborhoods. Growing evidence reveals that neighborhood conditions are associated with the risk of type 2 diabetes independent of characteristics of the individual (Auchincloss et al., 2009; Christine et al., 2015; Krishnan et al., 2010; Schootman et al., 2007). Low neighborhood socioeconomic status, high neighborhood concentrations of racial minorities, and adverse neighborhood physical and social environments have been linked to increased risk of cardiometabolic disorders (Auchincloss et al., 2009; Barber et al., 2016; Christine et al., 2015; Kershaw et al., 2015; Krishnan et al., 2010; Schootman et al., 2007). Similarly, neighborhood environment can influence the risk of diabetes through multiple pathways, such as the availability of healthy foods (Morland et al., 2002), exercise facilities (Auchincloss et al., 2009; Christine et al., 2015), and educational resources (Krishnan et al., 2010).

In order to reduce the dramatic diabetes disparities borne by racial/ ethnic minorities, it is imperative to develop successful prevention strategies that can be implemented effectively among these populations. Over the past few decades, lifestyle interventions consisting of exercise and diet behavioral modifications have proven to be efficacious in preventing type 2 diabetes (Knowler et al., 2002). Yet our previous findings have shown that lifestyle intervention is less successful among participants with lower socioeconomic status (Jiang et al., 2015). It is unknown, however, whether the effectiveness of lifestyle interventions is also influenced by the characteristics of the neighborhood wherein the participants reside. The success of behavioral changes promoted by lifestyle interventions is likely to be affected by neighborhood factors. For example, increasing physical activity usually needs safe space and/or accessible exercise facilities. Thus, we hypothesize that individuals living in more disadvantaged neighborhoods would have fewer environmental resources to achieve the needed behavioral changes and, therefore, would benefit less from lifestyle interventions.

This study extended our previous research by investigating the impact of neighborhood characteristics on diabetes incidence and related behavioral outcomes of a lifestyle intervention project implemented among a diverse array of American Indian and Alaska Native (AI/AN) communities, namely the Special Diabetes Program for Indians Diabetes Prevention (SDPI-DP) demonstration project (L. Jiang et al., 2013). The SDPI-DP was funded by the US Congress to translate evidence-based diabetes prevention intervention in 36 AI/AN grantee sites across the nation. Linking each SDPI-DP grantee site to year 2000 US Census data provided us a unique opportunity to examine the association of neighborhood factors with lifestyle intervention outcomes.

2. Methods

The details of SDPI-DP are described elsewhere (L. Jiang et al., 2013). Briefly, 36 health care programs serving 80 tribes in 18 states and 11 Indian Health Service (IHS) administrative areas participated in the SDPI-DP. The participating programs implemented the 16-session Lifestyle Balance Curriculum adapted from the Diabetes Prevention Program (2002) and evaluated the effectiveness of the prevention activities. After a baseline assessment, participants attended the lifestyle curriculum consisting of diet, exercise, and behavior modification sessions to help reach and maintain a goal of 7% weight loss. The curriculum was delivered in group settings 16–24 weeks after baseline and was typically taught by a program dietitian and/or health educator.

Participants were recruited locally by each grant program. Eligibility criteria included being AI/AN, at least 18 years of age, and having pre-diabetes. Pre-diabetes was diagnosed as having either im- paired fasting glucose (IFG, i.e., a FBG level of 100–125 mg/dl and an oral glucose-tolerance test (OGTT) result < 200 mg/dl) and/or impaired glucose tolerance (IGT, i.e., an OGTT result of 140–199 mg/dl 2 h after a 75 g oral glucose load and a FBG level < 126 mg/dl). Patients were excluded if previously diagnosed with diabetes, pregnant, receiving dialysis for end-stage renal disease, or suffered from any other condition that would prohibit successful participation. Enrollment began in January 2006 and centralized data submission ended on July 31, 2016. This study included 3394 SDPI-DP participants who completed the baseline assessments and started the intervention by 07/31/ 2009.

2.1. Measures

At baseline, within a month of completing the last lifestyle class (usually 4–6 months after baseline, hereafter called the post-curriculum assessment), and annually after baseline, participants underwent a comprehensive clinical assessment to evaluate diabetes risk and incidence. At the same time, each participant completed a questionnaire encompassing sociodemographic information, health-related behaviors, and a range of psychosocial factors. The current study includes the following measures.

2.1.1. Lifestyle intervention outcomes

2.1.1.1. Diabetes incidence. The primary outcome was incident diabetes, diagnosed by an annual or semiannual glycemic measurement conducted in local or regional laboratories. An A1c ≥ 6.5%, a fasting blood glucose ≥126 mg/dl or a two-hour test result ≥200 mg/dl after a 75-g oral glucose load required confirmation by a second test, preferably within 6 weeks of the first test, established the diagnosis of diabetes. Participants were censored at diagnosis of type 2 diabetes, loss to follow-up, or end of follow-up (July 31, 2016), whichever occurred first.

2.1.1.2. Body mass index (BMI). BMI was calculated using each participant's weight and height (shoeless, in light clothing), assessed by program staff at each assessment.

2.1.1.3. Physical activity. The Rapid Assessment of Physical Activity (RAPA) is a 9-item self-report instrument with yes/no responses to questions covering a range of weekly physical activity levels (Topolski et al., 2006). Participant's activity level was categorized into five levels: 1 = sedentary, 2 = underactive, 3 = regular underactive (light activities), 4 = regular underactive, 5 = regular active.

2.1.1.4. Diet. Details about the dietary choice variables are described elsewhere (Teufel-

Shone et al., 2015). Briefly, participants were asked to recall the intake of 27 different types of foods over the last 30 days. These food types were categorized as 'healthy', 'unhealthy', or 'undetermined' based on a survey of program staff members who were involved in nutrition education. The healthy food score was constructed by averaging the intake frequency of 6 healthy foods (e.g., whole grain bread, fruit), while the unhealthy food score was the mean intake frequency of 12 unhealthy foods (e.g., processed meats, sugared soft drinks).

2.1.2. Participant characteristics

Participants self-reported their age, gender, education attainment, employment status, marital status and annual household income in the baseline questionnaire.

2.1.3. Neighborhood characteristics

Thirty-six grantee sites were linked to 2000 US census data based on the delivery address of the health care program at each site. Proxies of neighborhood characteristics were obtained from American FactFinder for the census tracts corresponding to each grantee site. Based on the results of exploratory factor analysis (Appendix 1), six census variables representing neighborhood income, wealth, education, and employment status were used to construct a summary neighborhood socio- economic score: % adults completed high school, % adults with Bachelor's or higher degree, % unemployed individuals aged 16 years and older in the civilian labor force, % below national poverty level, median household income, and median value of housing unit. We first standardized each variable. The summary neighborhood socioeconomic score was then calculated by summing the standardized version of all those six variables, with higher neighborhood socioeconomic score indicating better neighborhood socioeconomic status. Additionally, we included % AI/AN population in each census tract as a proxy for neighborhood racial residential homogeneity and % private vehicle occupancy among workers 16 years or older as a proxy for access to private transportation.

2.2. Data analysis

Dichotomous neighborhood variables were constructed using median values of the census variables so that participants from half of the sites (18 sites) were included in each of the census categories. Means and standard deviations of outcome measures at baseline and change from baseline to post-curriculum assessment were reported by dichotomous neighborhood characteristic levels. Two sample t-tests were conducted to assess whether significant differences existed in baseline or change of outcome measurements between difference levels of census variables.

Proportional hazards (Cox) regression models were used to estimate the association between neighborhood characteristics and diabetes incidence. Robust sandwich standard error estimates were used to ac- count for clustering within grantee sites. To evaluate the effects of neighborhood characteristics on behavioral outcome measurements, multilevel linear regression models were fitted, controlling for individual factors. Random intercepts at both participant and site levels were included in the models to account for repeated measures from the same participant and within-site clustering. Based on the results of our previous study (Jiang et al., 2015), all regression models included gender, age, employment status, annual household income, baseline BMI, RAPA (except the models for RAPA), and healthy diet (except the models for diet scores), as participant level covariates. Site level census variables were added to the regression model one at a time. Significant census variables were then all included in the final models. Sensitivity analyses were conducted using continuous or 3-level (divided at tertiles) neighborhood variables in the regression models. The findings were similar to those based on the binary neighborhood factors in general, but showed signs of multicollinearity in the final models. Hence, only results based on the binary neighborhood variables are presented here.

Participant socioeconomic variables had missing rates ranging from 12% to 25%. To avoid potential bias caused by missing data, a multiple imputation method was used to impute missing baseline participant socioeconomic data. The multiple imputation procedure was performed using IVEware (Raghunathan et al., 2009). Twenty imputed datasets were generated. The results of each imputed dataset were then combined using SAS MIANALYZE procedure. Sensitivity analyses were performed to assess the influence of missing data on the results, which were only slightly different. Hence, the results using imputed data are reported here.

All the analyses were performed on SAS 9.4 (SAS Institute Inc. Cary, NC). Results are considered to be statistically significant if the P value is < .05.

3. Results

As shown in Table 1, a majority of the 3394 SDPI-DP participants included in this study were female (74.1%) and younger than 50 years old (58.9%). Compared to the sites with summary neighborhood socioeconomic scores lower than the median, those sites with higher neighborhood socioeconomic scores recruited older and more retired participants. They also had higher household income and were less likely to be never married.

Table 2 presents the distributions of diabetes incidence and baseline behavioral variables by neighborhood categories. In year 2000, among the 36 census tracts where the SDPI-DP intervention was delivered, 22.5% to 94.7% of the residents completed high school education, with a median value of 78.8%. Yet, only 2.0–48.0% of the residents from those census tracts obtained a Bachelor or higher degree. Of those 36 tracts, the median unemployment rate was 4.7%; the median % living below poverty level was 24.0%; the median household income was $31,581; the median value of housing unit was $68,750. A total of 388 incident diabetes occurred during a mean follow-up time of 4.1 years (range: 0.5–10.5 years). Participants from sites with more neighbor- hood residents living below federal poverty threshold, with lower median household income and lower median value of housing unit had significantly higher diabetes incidence rate.

Average baseline BMI was significantly higher among participants from sites with fewer neighborhood residents achieving a Bachelor or higher degree and those sites with lower median household income. Mean physical activity level was lower for participants from sites with fewer neighborhood residents achieving a Bachelor or higher degree. With few exceptions, those from sites with more neighborhood socio-economic advantages ate healthy foods more frequently and unhealthy foods less frequently than their counterparts from sites with fewer neighborhood socioeconomic advantages. Further, participants from sites located in neighborhoods with higher proportions of AI/ANs

Table 1
Distribution of baseline characteristics stratified by summary neighborhood socio-economic score among the Special Diabetes Program for Indians Diabetes Prevention Program participants recruited between 01/01/2006 to 07/31/2009 from 36 grantee sites across the United States.

Participants' characteristics	Total	Summary neighborhood socioeconomic score		Chi square test *P*-value[a]
	N = 3394	Below or equal to median	Above median	
	n (%)	n (%)	n (%)	
Gender				NS
Female	2516 (74.1)	1263 (75.4)	1253 (72.9)	
Male	878 (25.9)	412 (24.6)	466 (27.1)	
Baseline age in years				< 0.0001
18 to < 40	1011 (29.8)	616 (36.8)	395 (23.0)	
40 to < 50	989 (29.1)	503 (30.0)	486 (28.3)	
50 to < 60	860 (25.3)	387 (23.1)	473 (27.5)	
60 +	534 (15.7)	169 (10.1)	365 (21.2)	
Education status				0.0128
< High school	449 (15.2)	221 (15.7)	228 (14.7)	
High school	641 (21.7)	278 (19.8)	363 (23.4)	
Some college	1329 (44.9)	667 (47.5)	662 (42.7)	
College graduate	538 (18.2)	239 (17.0)	299 (19.3)	
Employment status				< 0.0001
Employed	2090 (71.2)	1059 (75.4)	1031 (67.3)	
Retired	205 (7.0)	49 (3.5)	156 (10.2)	
Unemployed or student	642 (21.9)	296 (21.1)	346 (22.6)	
Annual household income				< 0.0001
0–$14,999	539 (21.4)	280 (23.0)	259 (19.9)	
$15,000–$29,999	551 (21.9)	261 (21.5)	290 (22.3)	
$30,000–$49,999	721 (28.7)	386 (31.8)	335 (25.7)	
$50,000 +	705 (28.0)	288 (23.7)	417 (32.1)	
Marital status				< 0.0001
Married or living together	1531 (57.8)	737 (58.5)	794 (57.3)	
Separated/divorced or widowed	666 (25.2)	264 (20.9)	402 (29.0)	
Never married	450 (17.0)	260 (20.6)	190 (13.7)	

Abbreviations: BMI, body mass index; RAPA, Rapid Assessment of Physical Activity; AIAN, American Indian and Alaska Native; NS, not statistically significant.
a Chi square test for association between participant's baseline characteristic and summary neighborhood socioeconomic score category.

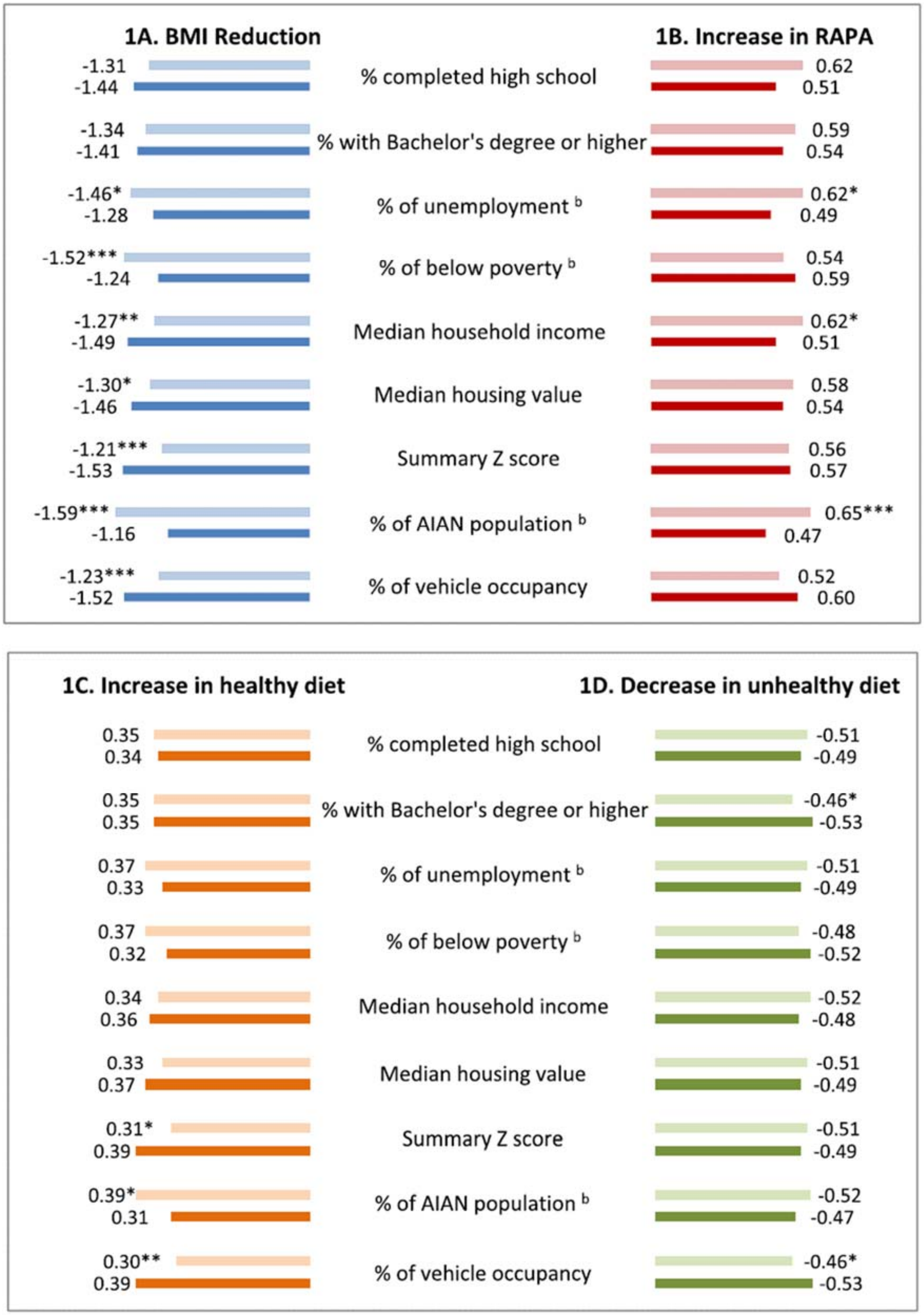
Table 2
Diabetes incidence during follow-up and baseline behavioral measures by census variables among the Special Diabetes Program for Indians Diabetes Prevention Program participants recruited between 01/01/2006 to 07/31/2009 from 36 grantee sites across the United States.

		Diabetes incidence/1000 person-years		BMI (N = 3394)		RAPA (N = 3073)		Healthy diet (N = 3088)		Unhealthy diet (N = 3085)	
	Median value Range IQR	Rate (95% CI)	P^a	Mean (SD)	P^b	Mean (SD)	P^b	Mean (SD)	P^b	Mean (SD)	P^b
Grantee characteristics from census				35.82 (7.50)		3.75 (1.09)		3.40 (0.82)		2.89 (0.73)	
% of adults completed high school	78.8%		NS		NS		NS		0.0024		< 0.0001
Below or equal to median	22.5%, 94.7%	39.4 (34.4, 45.0)		36.04 (7.75)		3.72 (1.10)		3.36 (0.85)		2.96 (0.73)	
Above median	71.4%, 83.8%	34.1 (29.2, 39.7)		35.61 (7.24)		3.79 (1.08)		3.45 (0.78)		2.82 (0.72)	
% of adults with bachelor's or higher degree	14.4%		NS		0.0002		0.0036		NS		NS
Below or equal to median	2.0%, 48.0%	37.5 (32.8, 42.7)		36.35 (7.76)		3.69 (1.11)		3.40 (0.83)		2.87 (0.72)	
Above median	9.4%, 24.8%	36.2 (30.8, 42.2)		35.40 (7.25)		3.81 (1.07)		3.41 (0.81)		2.90 (0.74)	
% of unemployed[c]	4.7%		NS		NS		NS		NS		0.0008
Below or equal to median	1.5%, 11.0%	35.7 (30.8, 41.0)		35.65 (7.54)		3.74 (1.09)		3.42 (0.82)		2.85 (0.71)	
Above median	3.2%, 6.2%	38.3 (33.1, 44.1)		36.03 (7.44)		3.77 (1.09)		3.39 (0.82)		2.94 (0.75)	
% below federal poverty threshold[c]	24.0%		< 0.0001		NS		NS		< 0.0001		< 0.0001
Below or equal to median	5.7%, 49.8%	27.0 (22.6, 32.1)		35.69 (7.35)		3.76 (1.10)		3.49 (0.78)		2.77 (0.70)	
Above median	10.8%, 30.7%	45.4 (40.0, 51.3)		35.95 (7.64)		3.75 (1.09)		3.32 (0.84)		3.00 (0.74)	
Median household income	$31,581		< 0.0001		0.0001		NS		< 0.0001		< 0.0001
Below or equal to median	$14,836, $61,739	44.6 (39.3, 50.4)		36.33 (7.77)		3.73 (1.09)		3.32 (0.85)		2.98 (0.74)	
Above median	$24,033, $40,462	27.4 (22.9, 32.6)		35.33 (7.20)		3.78 (1.09)		3.48 (0.78)		2.80 (0.71)	
Median value of housing unit	$68,750		0.01		NS		NS		< 0.0001		< 0.0001
Below or equal to median	$25,600, $469,500	41.4 (36.3, 47.1)		35.71 (7.57)		3.73 (1.09)		3.31 (0.82)		2.98 (0.73)	
Above median	$50,550, $100,550	31.8 (27.0, 37.2)		35.93 (7.42)		3.78 (1.09)		3.50 (0.81)		2.80 (0.72)	
Summary neighborhood socioeconomic score	−0.25		0.005		NS		NS		< 0.0001		< 0.0001
Below or equal to median	−8.82, 9.27	42.2 (36.8, 48.0)		35.78 (7.51)		3.75 (1.10)		3.32 (0.85)		2.99 (0.74)	
Above median	−2.60, 2.37	31.5 (26.8, 36.7)		35.86 (7.49)		3.76 (1.08)		3.48 (0.78)		2.79 (0.71)	
% of AIAN population[c]	18.5%		NS		NS		NS		0.0347		NS
Below or equal to median	0.2%, 96.5%	33.8 (29.0, 39.2)		35.78 (7.53)		3.72 (1.09)		3.43 (0.82)		2.87 (0.73)	
Above median	6.6%, 73.1%	40.0 (34.8, 45.7)		35.87 (7.46)		3.79 (1.09)		3.37 (0.82)		2.91 (0.73)	
% of private vehicle occupancy	87.3%		NS		< 0.0001		0.0096		< 0.0001		NS
Below or equal to median	22.3%, 96.7%	36.5 (31.4, 42.3)		35.26 (7.23)		3.80 (1.08)		3.46 (0.81)		2.89 (0.73)	
Above median	79.5%, 90.4%	37.3 (32.4, 42.7)		36.41 (7.72)		3.70 (1.10)		3.34 (0.82)		2.88 (0.73)	

Abbreviations: IQR, interquartile range; BMI, Body Mass Index; RAPA, Rapid Assessment of Physical Activity; AIAN, American Indian and Alaska Native; CI, confidence interval; NS, not statistically significant.
[a] Poisson regression was used to estimate diabetes incidence rates and test if significant differences exist between participants in different neighborhood categories.
[b] Two-sided P value for two sample t-test comparing two categories of each census socioeconomic variable.
[c] Above median represents disadvantaged socioeconomic level.

Fig. 1. Bar chart of improvements in BMI and behavioral outcomes at post curriculum assessment by census variables among the Special Diabetes Program for Indians Diabetes Prevention Program participants recruited between 01/01/2006 to 07/31/2009 from 36 grantee sites across the United States (completers of post curriculum assessments only).
Abbreviations: BMI, Body Mass Index; RAPA, Rapid Assessment of Physical Activity; AIAN, American Indian and Alaska Native. For each census socioeconomic variables, the top bar (light color) represents the value of BMI or behavior change in below or equal to median category and the bottom bar represents the value in above median category. Two sample t tests were used to compare BMI or behavior changes in below or equal to median category versus above median category by each census socioeconomic variable: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.
[b] Above median category represents disadvantaged socioeconomic level.

reported lower frequencies of healthy foods consumption. Last, those from sites with higher level of private vehicle occupancy had higher average BMI, exercised less, and ate healthy foods less frequently at baseline.



reported lower frequencies of healthy foods consumption. Last, those from sites with higher level of private vehicle occupancy had higher average BMI, exercised less, and ate healthy foods less frequently at baseline.

Fig. 1 illustrates changes in BMI and behavior outcomes at post- curriculum assessment by census measures. Most of the census variables were significantly associated with BMI reduction. Greater BMI reduction was observed in participants who live in neighborhoods with more socioeconomic advantages, including lower unemployment rate, lower poverty level, higher median household income, and higher median house value. Fewer significant relationships were found for changes in exercise and diet. Specifically, a higher summary neighborhood socio- economic score was significantly associated with both greater BMI reduction and greater increase in healthy foods consumption. Higher percentage of AI/ANs was significantly associated with lower magnitude of change in all outcome measures except unhealthy food score. Meanwhile, higher rate of private vehicle occupancy was associated with larger improvements in all outcomes except physical activity.

The results of a series of regression models are displayed in Table 3. After controlling for individual socioeconomic status, higher median household income was significantly associated with lower risk of incident diabetes and higher neighborhood socioeconomic score was significantly associated with more BMI reduction (Model 1); larger percentage of AI/ANs was correlated with less BMI reduction and smaller increase in physical activity (Model 2); while higher proportion of private vehicle occupancy was associated with larger improvements in BMI and both diet scores (Model 3). Model 4 includes individual socioeconomic status, baseline BMI, RAPA, and healthy diet scores, and the three significant neighborhood variables. After controlling for other neighborhood factors, participants from sites located in neighborhoods with higher household income had 35% lower risk in diabetes incidence than those from sites with lower neighborhood income (HR = 0.65, 95% CI; 0.47–0.90). Furthermore, those from sites in neighborhoods with > 18.5% AI/ANs achieved 0.32 less BMI reduction (95% CI: 0.16–0.48) and a 0.19 lower increase (95% CI: 0.08–0.30) in RAPA than those from sites with smaller proportion of AI/ANs. Meanwhile, participants from sites in neighborhoods with higher private vehicle occupancy had 0.28 more BMI reduction (95% CI: 0.14–0.43), 0.08 higher increase in healthy diet score (95% CI: 0.02–0.15), and 0.06 more reduction in unhealthy diet score (95% CI: 0.01–0.12) than those from sites with lower level of vehicle occupancy.

Table 3
Multivariate association of neighborhood characteristics and lifestyle intervention outcomes among the Special Diabetes Program for Indians Diabetes Prevention Program participants recruited between 01/01/2006 to 07/31/2009 from 36 grantee sites across the United States.

	Incident diabetes during follow-up	BMI reduction	Increase in RAPA	Increase in healthy diet	Decrease in unhealthy diet
	(N = 3394)	(N = 3394)	(N = 3073)	(N = 3088)	(N = 3085)
	H.R (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Model 1: Participant level characteristics[a] + summary neighborhood socioeconomic score (only results for site level characteristics were listed)					
Median household income > median	0.65 (0.47, 0.89)**				
Summary neighborhood socioeconomic score > median		−0.32 (−0.47, −0.17)***	0.05 (−0.05, 0.15)	0.05 (−0.01, 0.11)	−0.003 (−0.06, 0.06)
Model 2: Participant level characteristics[a] + % of AIAN population (only results for site level characteristics were listed)					
% of AIAN population > median[b]	1.23 (0.89, 1.69)	0.44 (0.29, 0.58)***	−0.18 (−0.28, −0.08)***	−0.05 (−0.11, 0.01)	0.04 (−0.01, 0.10)
Model 3: Participant level characteristics[a] + % of private vehicle occupancy (only results for site level characteristics were listed)					
% of private vehicle occupancy > median	0.94 (0.67, 1.33)	−0.35 (−0.49, −0.20)***	0.02 (−0.08, 0.12)	0.09 (0.03, 0.15)**	−0.07 (−0.13, −0.01)*
Model 4					
Participant level characteristics:					
Female	0.72 (0.55, 0.94)*	0.29 (0.13, 0.46)***	0.26 (0.15, 0.37)***	−0.02 (−0.09, 0.05)	0.05 (−0.02, 0.11)
Age (10 year increment)	1.07 (0.97, 1.19)	−0.04 (−0.11, 0.02)	0.01 (−0.04, 0.05)	0.01 (−0.02, 0.04)	0.02 (−0.11, 0.05)
Employment status (ref: employed)					
Retired	0.88 (0.55, 1.42)	−0.31 (−0.62, 0.002)	0.04 (−0.17, 0.26)	−0.06 (−0.20, 0.08)	0.09 (−0.04, 0.21)
Unemployed/student	1.10 (0.81, 1.49)	−0.08 (−0.30, 0.15)	−0.02 (−0.16, 0.13)	−0.04 (−0.14, 0.05)	−0.01 (−0.09, 0.07)
Annual household income (ref: ≥$50,000)					
< $15,000	0.92 (0.65, 1.29)	0.36 (0.10, 0.62)**	−0.17 (−0.34, 0.003)	0.01 (−0.10, 0.12)	0.09 (−0.01, 0.18)
$15,000 to < $30,000	0.95 (0.65, 1.39)	0.19 (−0.02, 0.41)	−0.05 (−0.20, 0.10)	−0.06 (−0.16, 0.03)	0.02 (−0.07, 0.10)
$30,000 to < $50,000	1.08 (0.82, 1.42)	0.13 (−0.07, 0.32)	−0.02 (−0.16, 0.12)	−0.03 (−0.12, 0.06)	0.04 (−0.04, 0.12)
Baseline BMI	1.04 (1.03, 1.05)***		0.01 (0.002, 0.02)*	0.002 (−0.002, 0.01)	−0.006 (−0.010, −0.002)**
Baseline RAPA	0.97 (0.88, 1.07)	0.05 (−0.02, 0.12)		−0.08 (−0.10, −0.05)***	0.05 (0.03, 0.08)***
Baseline healthy diet score	0.92 (0.77, 1.09)	0.002 (−0.09, 0.09)	−0.19 (−0.25, −0.12)***		
Site level characteristics:					
Median household income > median	0.65 (0.47, 0.90)**				
Summary neighborhood socioeconomic score > median		−0.18 (−0.34, −0.03)*	−0.02 (−0.13, 0.09)	0.04 (−0.03, 0.11)	0.02 (−0.04, 0.08)
% of AIAN population > median[b]	1.16 (0.86, 1.58)	0.32 (0.16, 0.48)***	−0.19 (−0.30, −0.08)***	−0.02 (−0.09, 0.05)	0.04 (−0.02, 0.10)
% of private vehicle occupancy > median	0.93 (0.69, 1.26)	−0.28 (−0.43, −0.14)***	−0.02 (−0.11, 0.08)	0.08 (0.02, 0.15)**	−0.06 (−0.12, −0.01)*

Abbreviations: BMI, body mass index; RAPA, Rapid Assessment of Physical Activity; AIAN, American Indian and Alaska Native: H.R., hazard ratio; CI, confidence interval; ref: reference group.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.
[a] Participant level characteristics included gender, age, employment status, income and baseline BMI, physical activity and healthy diet score.
[b] Above median represents disadvantaged socioeconomic level.

4. Discussion

To our knowledge, this study is the first to assess the association between neighborhood characteristics and behavioral intervention outcomes in the AI/AN population. Our findings suggest neighborhood characteristics significantly impacted the effectiveness of lifestyle intervention in a diverse set of AI/AN communities, independent of individual socioeconomic characteristics. Consistent with our hypothesis, participants from sites with lower neighborhood household income had higher diabetes incidence. Along the same lines, those from sites with lower neighborhood socioeconomic scores lost less weight. These observations expand our previous findings that participants with lower personal level socioeconomic status made fewer improvements after intervention (Jiang et al., 2015), potentially due to their constrained resources to make such improvements, highlighting the critical role of socioeconomic status at both personal and neighborhood levels for successful lifestyle intervention. Furthermore, it calls for enhanced diabetes prevention strategies that not only target individual behavioral changes but also intervene the social context of this disease for many individuals living in socioeconomically disadvantaged neighborhoods (Bonilla et al., 2016).

In addition to neighborhood socioeconomic status, SDPI-DP participants from neighborhoods with a higher percentage of AI/AN population experienced less BMI reduction and a smaller increase in physical activity. Most SDPI-DP grantee sites are located on reservations, with a resultant high proportion of AI/AN residents. These reservation neighborhoods often experience high levels of poverty and many other environmental barriers to physical activity, such as unfavorable cli- mate, neighborhood safety issues, and long distances to recreational or exercise facilities, if any exist (Acton and Bullock, 2009). Such structural realities among predominantly AI/AN communities, many of which reflect historical policies, likely explain the strong effects of neighborhood racial composition on BMI and physical activity found in this study.

To date, only a few studies have investigated the association of neighborhood racial composition with metabolic conditions such as obesity and diabetes. None have focused upon AI/ANs (Kershaw and Pender, 2016). Most previous studies reported no relationship between racial segregation and diabetes prevalence (Gaskin et al., 2014; Grigsby-Toussaint et al., 2015; Lim et al., 2017; Piccolo et al., 2015), but higher segregation was associated with higher diabetes mortality among Blacks (Hunt et al., 2014; Rosenstock et al., 2014). Such findings imply that greater neighborhood concentration of racial minorities may impact the management, but not necessarily the development, of the disease (Kershaw and Pender, 2016). The results here partially support previous findings. No relationship was found between neighborhood concentrations of AI/ANs and most baseline diabetes risk factors, but a strong association was seen between neighborhood AI/AN homogeneity and improvements in the lifestyle intervention outcomes. It is important to contextualize the meaning of these results. While in the past, reservations were imposed on AI/AN people as a form of segregation; today, many AIANs choose to reside in more homogeneous tribal communities because of ties to family, land, and culture, despite an all- too-often marked history of trauma and impoverishment evident in many such communities. In order to improve intervention outcomes, then, we must address the underlying socioeconomic and historical factors that may impede progress in reservation communities.

Another intriguing finding of this study is the strong impact of neighborhood private vehicle occupancy on intervention effectiveness. Participants from neighborhoods with a lower percentage of private vehicle occupancy were less successful in improving their food choices and reducing their weight. Adopting a healthier diet might be particularly challenging when large supermarkets with more healthy food choices are not within walking distance. Therefore, the association between private vehicle occupancy and intervention outcomes found in this study likely reflects the emerging link between healthy food environment and lifestyle-related chronic diseases (Auchincloss et al., 2009; Leal and Chaix, 2011; Lovasi et al., 2009). However, a recent study reported no association between geographic proximity to healthy food stores and incident type 2 diabetes, but rather a significant correlation between residents' perceived local food environment and risk of diabetes (Christine et al., 2015). Private vehicle occupancy may be one factor accounting for the inconsistencies between perceived and objective measures of healthy food availabilities. As most SDPI-DP participants live in rural areas without easy access to public transportation, a private vehicle may be particularly important for enabling them to make diet-related behavioral changes.

A major strength of this study is its prospective design within a national multi-site intervention project and a large diverse sample of an under-studied population. Several recent longitudinal studies (Auchincloss et al., 2009; Christine et al., 2015; Krishnan et al., 2010; Schootman et al., 2007) have investigated the association of neighborhood characteristics with incident type 2 diabetes, providing a stronger foundation for causal conclusions than previous cross-sectional analyses (Leal and Chaix, 2011). However, those studies were observational in nature and did not attempt to intervene on the health outcomes of interest. The current study, for the first time, revealed participants from disadvantaged neighborhoods were less likely to be successful at making recommended behavioral modifications instructed by an evidence-based curriculum, further strengthening the support for a causal link between neighborhood environments and metabolic dis- eases.

Nevertheless, a number of limitations need to be acknowledged. First, due to confidentiality considerations, the exact addresses of SDPI- DP participants were not collected. We used the postal delivery address of each participating site as a proxy. This precludes us from obtaining the exact neighborhood characteristics of everyone. However, as SDPI- DP is an intensive intervention for which each participant had to attend 16 in-person classes over a relatively short time, most participants lived near the health care program that housed the intervention. Furthermore, each site only represents one census tract this way, making it difficult to distinguish neighborhood and site effects. Yet, we included site level random effects in the regression models to control for the unexplained site-level variations. Thus, the estimated association between neighborhood characteristics and intervention outcomes should mainly reflect the differences in outcomes associated with various neighborhood conditions.

Next, there is no direct, individual-level measure of participant transportation. Future studies of the role of personal level transportation in intervention adherence and outcomes may yield important, practical insights for program delivery. Similarly, each participant's length of time residing in the neighborhood was not available, which makes it impossible for us to adjust for this variable in our regressions. Third, the proportion of AI/ANs in each census tract was a proxy for neighborhood racial homogeneity. Although commonly used in previous literature, it does not incorporate the context of larger sur- rounding areas and hence cannot be considered a direct measure of racial homogeneity for SDPI-DP grantee sites (Kershaw and Pender, 2016).

Finally, the SDPI-DP sample included only AI/ANs who were interested in and eligible for a lifestyle intervention, which is possible to suffer from selection bias and may not be generalizable to other populations or those who are not interested in this kind of interventions. However, since the main focus of the current study is to investigate the impact of participants' neighborhood characteristics on lifestyle intervention outcomes and the selection bias is likely to be similar across all neighborhoods we investigated, the selection bias may not strongly affect the conclusions of this study.

5. Conclusions

In conclusion, in one of the largest initiatives to translate an evidence-based lifestyle intervention for implementation in a racial/ethnic minority population, we found intervention effectiveness was less than optimal in disadvantaged neighborhoods. As the field pursues behavioral modification interventions to prevent diabetes and related metabolic disorders, we must be aware of the characteristics of the settings in which such implementation takes place and intervene at that level when necessary. Furthermore, these findings strengthen the growing evidence for a causal link between neighborhood environments and metabolic diseases (Auchincloss et al., 2009; Christine et al., 2015; Krishnan et al., 2010; Schootman et al., 2007), as well as the arguments to design socioeconomic interventions to reduce neighborhood and environmental inequalities as a potentially more effective approach to eliminate the huge diabetes disparities that afflict minority populations (Bonilla et al., 2016).
Supplementary data to this article can be found online at https://

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Duality of interest

The authors claim no conflict of interests.

Author contributions

LJ designed the study, researched the data, contributed to the discussion, wrote, reviewed, and edited the manuscript. JC researched the data, performed data analysis, reviewed and edited the manuscript. JB participated in the design of the SDPI-DP project, contributed to the discussion, reviewed and edited the manuscript. AB contributed to the discussion, reviewed and edited the manuscript. SMM conceptualized and designed the SDPI-DP project, contributed to the discussion, reviewed and edited the manuscript. LJ is the guarantor of this work and, as such, 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.

Disclaimer

The findings and conclusions in this article are those of the authors and do not necessarily represent the official position of the Indian Health Service.

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