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Identifying potential predictors of Type 2 diabetes mellitus prevalence and incidence: a national county-level analysis

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Abstract

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The seventh leading cause of death in the United States is diabetes mellitus, with 9.3% of the population having the condition, with rates continuing to increase. More than 90% of people diagnosed with diabetes have type 2 diabetes. The objective of this study is to identify social, economic, and built environment factors associated with both increasing and decreasing changes in diabetes prevalence and incidence at the county-level. This repeated cross-sectional ecologic study links 2009 and 2013 diabetes-related data from the Behavioral Risk Factor Surveillance System (BRFSS) to several county-level measures of the built environment and socioeconomic inequality. Data cover 3,137 US counties or county-equivalents. Outcome measures are the absolute change in diabetes prevalence and incidence. Candidate predictors include county-level obesity prevalence, physical inactivity prevalence, median income, poverty rate, access to parks, grocery stores per 1,000 persons, recreation and fitness facilities per 1,000 persons, and urbanization. Median income and poverty rate were also evaluated as potential effect modifiers. Sixty-eight percent (68%) of counties experienced increased diabetes prevalence. High-income counties have lower obesity prevalence, higher prevalence of physical activity, and greater access to parks compared to low-income counties. High-poverty counties were more obese, had fewer grocery stores, and had fewer recreation and fitness facilities compared to low-poverty counties. Diabetes increased most in counties with higher physical inactivity prevalence at baseline, fewer grocery stores, and fewer recreation and fitness facilities. Physical inactivity was associated with worsening diabetes incidence. Large central metro counties have better behavioral, economic, and environmental risk profiles. In conclusion, the findings suggest that behavioral and built environment factors are associated with changes in diabetes prevalence and incidence.

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Table of Contents

CHAPTER I: BACKGROUND/LITERATURE REVIEW

The US burden of diabetes mellitus

The seventh leading cause of death in the United States is diabetes mellitus, with 9.3% of the population having the condition, a rise from roughly 4% in 2000 (1-3). Diabetes is a condition characterized by high blood glucose levels (2). Type 1 diabetes is a result of insufficient insulin production, and Type 2 occurs when the body is unable to properly use insulin (2, 3). In 2012, there were 7.8 new cases per 1,000 of diabetes – a hefty increase from 3.3 cases per 1,000 in 1980 (2, 4). Approximately 1 in 3 people will develop Type 2 Diabetes in their lifetime, and more than 1 in 3 adults have prediabetes (2). More than 90% of people with diabetes have type 2 (3, 5). Nine out of 10 people with prediabetes (elevated blood glucose levels but not high enough for a diagnosis) do not even know they have the condition (3, 6). Serious complications of diabetes include heart disease, stroke, blindness, kidney failure, and leg amputations, which can develop after having the condition for many years (3). As a result, people with diabetes spend twice as much on medical costs than those without it, with a risk of death 50% greater than their counterparts (5). Diabetes cost an estimated $245 billion of direct and indirect expenses in 2012 (2, 6).

Oftentimes, these higher costs are due to people with diabetes having comorbid conditions, such as hypertension, hyperlipidemia, cardiovascular disease, kidney disease, and other chronic conditions, adding complexity to their diabetes management (1). Because of these comorbidities and complications of them, Type 2 diabetes can reduce an individual's life expectancy by 7 years, on average (5). In 2010, diabetes was listed on over 230,000 death certificates as either the leading or underlying cause of death (3). The common risk factors for diabetes, both modifiable and non-modifiable, include age, family history, diet, obesity, and physical inactivity. Thus, the most effective efforts to prevent or delay diabetes are directed toward weight loss, dietary changes, and increased physical activity (7).

Disparities in diabetes

Racial and ethnic, regional, and socioeconomic differences in diabetes prevalence and incidence exist. Racial groups disproportionately affected by diabetes include Latinos, African-Americans, and American-Indians/ Alaska Natives (3, 8). Racial/ ethnic disparities exist both in adolescence as well as adulthood (3). These minority groups also have a higher prevalence of severe diabetes complications, such as kidney failure and amputations, compared to White populations (8). A 2014 study identified a race-poverty-place gradient on diabetes prevalence, demonstrating that individuals in poor Black neighborhoods have a higher odds of having diabetes, exacerbated by individual poverty (9). The researchers also noted that living in poverty increased the odds of diabetes, regardless of race. Geographically, a disparity is noted in what is referred to as the diabetes belt (10). In the diabetes belt, prevalence is significantly higher in more than 600 counties across 15 states, primarily in the South, where people are more often a member of a minority group. The authors attribute part of this difference to a higher likelihood of a sedentary lifestyle and obesity.

Trends in diabetes

The problem of diabetes has been getting worse over the past 20 years. From 1990 to 2009, the number of adult cases quadrupled from 5.5 million to 21.9 million, and the incidence of diabetes in adults has increased from 3.6 to 8.6 per 100, a change of 139%; from 2009 to 2014, the change has slowed (11). Increases in incidence are significantly greater for racial and ethnic minorities (11, 12). The incidence (per 100) among Whites increased between 1990 and 2009 from 2.5 to 6.0 (140%), 4.7 to 9.7 for Blacks (106%), and 3.3 to 6.7 for Asians (103%) (11). Comparing the increase in diabetes among educational levels, a disparity further exists (12). For those with education beyond high school, the increase in diabetes was minimal initially from 1989 to 2014, doubles in the late 90s, and slowed around 2003, characterizing a change from 2.6 to 6.7 per 100. For those with a high school education similarly changed little at first, but then quadrupled from 1989-2014, from 2.6 to 9.5 per 100. As expected, those without a high school education have the highest rate of diabetes, tripling from 4.0 to 12.9 per 100 during this time period.

Geographically, the change in diabetes prevalence ranged from 8.5% to 226.7% by state (13). In 42 states, the prevalence increased by 50% or more, and 18 states increased by 100% or more. The greatest increase was seen in Southern states, followed by the West, Midwest, and Northeast (13). Selvin, Parrinello, and Sacks suggested that differences in prevalence may be due to comparable differences in sedentary lifestyle, obesity prevalence, proportion of African-American population, nutrition status, and health behaviors (13). However, in terms of differences in incidence, there is little to no literature discussing factors that may contribute to why some places change faster than others, a gap this study aims to address.

Risk factors for diabetes mellitus: food environment, built environment, and socioeconomic environment

Various factors impact the risk of diabetes. There are both behavioral/ lifestyle factors and built environment factors that can affect an individual's risk of developing type 2 diabetes. Previous studies suggest that geographic disparities are due to social and environmental structures resulting from the contextual effects of socioeconomic disadvantage, rather than due to individual-level poverty alone (14-15). Lifestyle factors, specifically physical activity and diet, are the strongest risk factors for reducing an individual's chance of developing diabetes, but these behaviors can be impacted by the built environment (1). The built environment may be associated with a population's ability to maintain a balanced diet or exercise plan if there are not sufficient factors that promote these behaviors. For example, a person's access and proximity to structures promoting healthy eating habits or physical activity can direct their health behaviors (1). These structures include local parks, sidewalks, grocery stores and their costs, fast food restaurants, and physical activity/ recreational facilities. Environmental factors related to obesity, overeating, and physical inactivity are discussed later.

Obesity

Obesity is associated with greater risk of developing type 2 diabetes (16). Lifestyle factors may affect obesity, and rates of obesity are increasing in the US with increased difficulty in losing or maintaining a healthy weight (1). Disparities in obesity exist; groups known to be socially disadvantaged, including African-American/ Black people, Hispanics people, and people low socioeconomic status, have higher rates of obesity compared to White people (16). This review addresses how factors of the built environment may impact these observed disparities in obesity. Many of the aforementioned dynamics of the built environment's influence on diabetes also translate to obesity (15-17). County-level obesity is not spatially random; unemployment, fitness centers, education, and race, among other factors, were correlated with obesity, as these factors are clustered by region in a similar manner as obesity (15). However, this same study did not find the food environment to be associated with obesity prevalence, while controlling for other factors (15). Dwyer-Lindgren *et al.* found that obesity, physical inactivity, poverty, and race are associated with a county's likelihood of being in a High-High diabetes cluster (near other counties of high diabetes prevalence) versus non-cluster, concluding that several county-level factors can influence diabetes and obesity prevalence (18).

Physical activity

Higher physical activity as compared to lower (fewer than 3 times per week) may be important for diabetes because it is a risk factor likely to increase the risk of developing diabetes (7). People residing in places of low-income have reported perceptions of less access to indoor and outdoor physical activity opportunities (16). Previous studies have also found that areas with great minority populations and low education are less likely to have physical activity facilities, and areas with higher education have a twice as much facility access (19). This is relevant because the greater access to physical activity facilities, the lower the chances of an individual developing obesity, as they are more likely to be active (19). It is important to note that some studies have found that obesity and physical activity are independently related to the risk of diabetes (1, 18). A previous study found that built environment factors, including grocery stores and exercise facilities, provoke obesogenic environments (15, 16). People belonging to disadvantaged socioeconomic groups are often found to have worse environmental conditions, leading to increased health disparities in obesity, and consequently diabetes (16).

Urbanization schemes

The newer 2013 urbanization schemes by the National Center for Health Statistics have been extensively evaluated to identify differences in health outcomes between differing urbanization levels, which have been defined by location and population density (22). Studies have found that the six-tier urbanization categories enable the identification of relevant health inequities across the levels, with the best health outcomes in those who reside in larger metropolitan areas (22). Similar trends are also seen across the differing levels in median household income, poverty rates, and education, which have all been found to be directly or indirectly associated with diabetes (1, 15, 16, 19). Metropolitan counties have the highest median household income and lowest poverty rates, while more rural areas have lower median household income and less racial diversity (22). Consequently, urbanization is related to food availability in an area (21). Compared to middle-income neighborhoods, lower-income neighborhoods, likely rural areas, have few chain grocery stores, while urban areas have even fewer (21, 22). Low-income minority areas have more non-chain markets and grocery stores than any other area, demonstrating systematic differences in quality and access to grocery stores (21). Overall, there are associations between urban versus rural environments and their impact on behavior, consequently affecting the health of a neighborhood or county; utilizing this six-category scheme helps reveal associations that may otherwise be missed (23). This study aims to assess the association between urbanization scheme and diabetes, while controlling for other characteristics, such as income and food access, based on previous literature.

Factors of the built environment

Access to parks

The presence of parks serves as encouragement for people to engage in physical activity (24). Studies have found that the closer someone lives to a park, the more likely they are to be physically active (24, 25). Researchers believe that increasing the number of parks can increase a population's physical activity levels, which would be beneficial considering how few Americans live in close proximity (half-mile or less) to a park (24). However, research shows that parks are equally distributed, but are unequally used or accessible for physical fitness (26).

The literature on park use has mixed results. Low-income minorities living in urban areas are more likely to report park use, yet, they are still the least likely to meet physical activity requirements (25, 26). A common explanation for low physical activity is because this population often reports safety being their biggest concern for public parks (25). Contrastingly, another study found that minorities in low-income neighborhoods engage in high levels of energy expenditure (27). Cohen *et al*. concluded that proximity to a public park is positively associated with physical activity and park use, based on a study of public parks in low-income neighborhoods (28). This study may add to the literature evidence of an association between county-level income and diabetes prevalence and incidence, diversifying the spatial scale of the literature utilizing different data sources. If populations at the county-level have access to more parks, less physical activity, and more diabetes, this may imply that parks should be more accessible and safer for residents.

Access to fitness and recreation facilities

A recent systematic review reported a positive association between self-reported access to exercise facilities and physical activity (29). Availability and affordability of these facilities can be barriers to those who cannot pay for memberships of these facilities (29). Lower income areas and places with a large minority population are less likely to have these types of facilities (26, 30). Fitness and recreational facilities are unequally distributed across neighborhoods (26). Recreation facilities are most likely to be seen in suburban areas, and fewer in urban areas (30). An appropriate measure of this factor is the number of recreation and fitness facilities in the county (29).

Food access

A previous study found that proximity to grocery stores is associated with diabetes and obesity, a risk factor for diabetes (16). Obesity may be influenced by food choices, which are driven by taste, cost, convenience, health, and variety (20). Debate exists around the opportunity for a healthy, balanced diet; some argue that healthy eating is equitably possible for all, while others argue that diet quality is reflective of one's socioeconomic status (*e.g.*, the wealthier an individual, the better the diet) (17, 20). Meyer *et al.* found that in lower-density geographical areas, some neighborhood spatial clusters (based on population-density) have access to greater food diversity and consequently, an associated higher diet quality compared to other clusters; similarly, in higher-density areas, some clusters have more natural/ specialty grocery stores, fewer convenience stores, and more physical activity access compared to the rest of the area, which is again associated with higher diet quality (17). This demonstrates that built environment factors of neighborhoods can influence dietary choices, influenced by access to resources (17, 21). These same methods found that there is not spatial clustering of fast food among the neighborhood clusters (17).

The importance of socioeconomic inequality/ disadvantage

Previous studies have found that diabetes prevalence is often higher in individuals of low socioeconomic status due to poorer access to healthy foods and decreased access to physical activity opportunities (1, 19, 34). However, the evidence of this is widely mixed at the county-level, based on what factors are controlled for: some studies find an association, while others do not (35). A study utilizing 32 US census tracts concluded that those of lower socioeconomic status, through measures of median household income, unemployment, per capita income, and poverty rate, have less control of their opportunities for physical activity as a result of the quality of their environments (34). Similar research supports the notion that inequality in the built environment causes differences in fitness facilities and physical activity, leading to disparity in obesity (19). A study on obesity and the built environment discusses the importance of including measures of the built environment to assess neighborhood level health outcomes, such as obesity (36). For example, disadvantaged areas have fewer grocery options, safe public spaces, and worse traffic, all limiting the environment's ability to support healthier behaviors to prevent diabetes (16). Studies identify a need for research examining the environmental dissimilarity among geographic units based on varying economic positions, in order to identify best practices to intervene on larger communities, in a more cost-effective manner compared to individual approaches through improved resource allocation (15, 37, 38).

Relevance of county-level data

This research will involve the use of county-level data. Visually, the CDC's maps of diabetes prevalence noticeably vary over time and are worthy of further investigation (31). Diabetes disproportionately affects minority populations, who generally live in areas of low resources, providing the necessity to identify differences between high-resource and low-resource counties (1, 19, 22). Counties have long been considered the primary unit of local government, which has the potential to invoke great amount of change among communities (22). County-level measures of health and built environment characteristics are widely and publically available, making county-level data more attractive for use (22). Using counties as the geographic scale allows for conclusions to be drawn on health outcomes at the population level (32). Counties capture some amount of socioeconomic and demographic diversity, representing the environments in which individuals make behavioral decisions; counties are more homogenous than measures at larger scales (33). Further, multilevel analyses have found associations at the county-level related to obesity, physical activity, and other factors; however, utilizing multiple sources of national county-level data to examine changes in diabetes measures is a novel approach in this area of research (32).

Diabetes has increased nationally for most racial groups and geographies from 2009 to 2013 (8-10, 13). Because there is evidence that certain attributes of the built environment affect risk factors for diabetes, it is possible that the magnitude of change varies as a function of the built environment. Differences in how places change reflect variations in the presence or absence of positive risk factors that protect people from diabetes. Therefore, this study will measure exposures at the baseline (2009-2010) and assess magnitude of change in diabetes prevalence and incidence between 2009 and 2013.

The present study

Diabetes has serious and costly health complications (2). Research is needed on environmental factors related to physical activity and obesity because they are key to prevention and treatment of diabetes, and are associated with risk of diabetes (1). This research may contribute to the literature areas necessitating population-wide intervention in order to reduce diabetes prevalence and slow diabetes incidence. This work can be considered an extension of Barker *et al.*, who developed the nation-wide county-level estimates of diabetes prevalence and incidence (39). To the knowledge of the author, the spatial scale, measures, and timeframe involved in this study have not been conducted together in research in order to evaluate how the behavior, socioeconomic status, and built environment may influence the change of diabetes prevalence and incidence over time. This study will allow researchers to compare factors leading to the greatest changes of diabetes prevalence and incidence, at the community-level or greater.

The outcome of this study is changes in diabetes prevalence and incidence from 2009 to 2013, a five-year comparison to avoid overlapping estimates resulting from the data's manipulation. The exposures of interest include physical inactivity, urbanization, access to parks, grocery stores per 1,000 persons, recreation and fitness facilities per 1,000 persons, median household income, and poverty rate. This study aims to identify factors of the social, economic, and built environment potentially associated with changes in diabetes prevalence and incidence based on national county-level data on obesity, physical activity, as well as variations resulting from differences in income and poverty. To strengthen the evidence, this study utilizes a repeated cross-sectional design, and will not only show what might be a confounded correlation, but also measure whether county-factors predict change over time. A potential for confounding still persists, but the introduction of time is a strength.

CHAPTER II: MANUSCRIPT

Identifying potential predictors of Type 2 diabetes mellitus prevalence and incidence: a national county-level analysis

By Tara Carey

Introduction

The seventh leading cause of death in the United States is diabetes mellitus, with 9.3% of the population having the condition, a rise from roughly 4% in 2000 (1-3). In 2012, there were 7.8 new cases per 1,000 of diabetes – a hefty increase from 3.3 cases per 1,000 in 1980 (2, 4). Approximately 1 in 3 people will develop Type 2 Diabetes in their lifetime, and more than 1 in 3 adults have prediabetes (2). More than 90% of people with diabetes have type 2 (3, 5).

The burden of diabetes has been growing over the past 20 years. From 1990 to 2009, the number of adult cases quadrupled from 5.5 million to 21.9 million, and the incidence of diabetes in adults has increased from 3.6 to 8.6 per 100, a change of 139%; from 2009 to 2014, the change was small (11). Differences in increase are significantly greater for racial and ethnic minorities (11-12). The incidence (per 100) among Whites increased between 1990 and 2009 from 2.5 to 6.0 (140%), 4.7 to 9.7 for Blacks (106%), and 3.3 to 6.7 for Asians (103%) (11).

Various factors increase the risk of diabetes. There are both behavioral/ lifestyle factors and built environment factors that can increase an individual's risk of developing type 2 diabetes. Previous studies suggest that geographic disparities are due to social and environmental structures resulting from the contextual effects of socioeconomic disadvantage, rather than due to individual-level poverty alone (14-15). Lifestyle factors, specifically physical activity and diet, are the strongest risk factors for reducing an individual's chance of developing diabetes, but these behaviors can be impacted by the built environment (1).

This study aims to identify factors influencing changes in diabetes prevalence based on national county-level data on obesity, physical activity, and other related risk factors, as well as several built environmental factors. This study takes an exploratory approach where there are many candidate predictors, due to the mixed findings in previous literature. The objective is to identify social, economic, and built environment factors associated with both positive and negative changes in diabetes prevalence and incidence at the county-level. This may allow for comparison of what factors may further promote diabetes inequities between counties.

Methods

Research design

This repeated cross-sectional ecologic study links 2009 and 2013 diabetes-related data from the Behavioral Risk Factor Surveillance System (BRFSS) to several county-level measures of the built environment and socioeconomic inequality. Data cover 3,137 US counties or county-equivalents that did not have missing data for the predictors of interest. In this study, there is not a single exposure; this is more exploratory evaluating a suite of measures to examine what is most strongly correlated with changes in diabetes prevalence and incidence due to the mixed findings of previous literature.

Data sources

The data were drawn from the Centers for Disease Control (CDC), the National Center for Health Statistics, American Community Survey, and US Department of Agriculture (USDA) (22, 24, 31, 40, 41).

Outcome measures. The data for the outcome variables of age-adjusted diabetes prevalence and incidence come from a publically available CDC dataset, derived from the BRFSS, a telephone survey conducted by state health departments. Diabetes prevalence was determined by whether respondents answered "yes" to being asked if a doctor has ever told them that they have diabetes; excluded were women with a history of gestational diabetes. Diabetes incidence was determined based on the age of diagnosis and age at the time of survey; if the difference was less than 1 year, they were considered a new case; if the difference was 1-2 years, they were considered half a new case; incidence is measured by number of new cases per 1,000 (42). These data were restricted to respondents 20+ years of age to correspond with the census population estimates. The CDC developers performed statistical summarization from the BRFSS to produce county-level estimates based on the U.S. Census Bureau's Population Estimates Program. Data were collected at the state level, and counties with no data available have imputed values based on previous years and neighboring counties (31, 42). County-level estimates were based on Bayesian multilevel modeling techniques performed by CDC (42). Age (in tertiles), sex, and race were developed into multilevel Poisson regression models with random effects (42). CDC developers used temporal smoothing to increase the precision of the estimates by pooling 3 years of data to create each year's estimates. Spatial smoothing was employed to increase the strength of county estimates by "borrowing" from neighboring counties. Lastly, predictive checking assessed the consistency of the models and the quality of the model fit (39, 43).

Exposure measures. The exposure variables, from various data sources, utilize data as close to the baseline (2009) wherever possible so that change is a function of the exposure at the beginning of observation. Six risk factor (aggregated to the scale of the county) or built-environment factors were used to assess potential associations with changes in diabetes prevalence and incidence at the county level. ***Obesity*** is measured based on respondents' self-reported height and weight; Body Mass Index (BMI) was calculated as weight kg/height $(m)^2$. If BMI was ≥ 30, they were considered obese (31, 42). Data from 2009 are used, and are reported as the prevalence of obesity in each county. ***Leisure-time physical inactivity*** is the prevalence of physically inactive adults in each county, based on survey respondents' response to answering "no" to the following question: "During the past month, other than your regular job, did you participate in any physical activities or exercises such as running, calisthenics, golf, gardening, or walking for exercise?" (31). These data are also from 2009. Both obesity and physical inactivity data are from the same BRFSS dataset described above (31). The ***urbanization scheme*** is based on the Urban-Rural Classification Scheme for Counties in 2013, which are based on the 2010 Census and developed by the National Center for Health Statistics (22). There are six classification levels: four metropolitan (large central metro, large fringe metro, medium metro, and small metro) and two nonmetropolitan (micropolitan and noncore) based on population and city containment. All metropolitan categories are in a metropolitan statistical area. Classification levels are determined by statistical area and population size. The use of 6 categories has been found to be more useful than the dichotomous urban versus rural often used, as it better assesses differences among communities (22). ***Access to parks*** is calculated by the percent of the population living within a half-mile radius of a park boundary at the census block level in 2010, which were then aggregated to county level, and divided by the total number of people in the county (24). The data are from CDC's Environmental Public Health Tracking Network (24). Parks include infrastructure that may encourage physical activity, but completeness and causality of the data are not well-understood (44). ***Grocery stores*** are measured by the number of grocery stores and supermarkets in a county in 2012, including all stores and smaller markets engaged in retail of food products, per 1,000 persons (40). Convenience stores and large general-merchandise stores (supercenters and warehouse club stores) are excluded. ***Recreation and fitness facilities*** includes establishments that engage in fitness and recreational sports activities, including exercise and physical fitness conditioning and recreational sports (swimming, biking, racquet sports) (40). These data, from the USDA's Food Environment Atlas, are measured per 1,000 persons in 2012 (40).

Potential effect modifiers. Two variables are used as a proxy for comparing high- versus low- resource counties: median household income and poverty rate. ***Median household income*** is measured by the 2009-2013 five-year estimates in 2013 inflation-adjusted dollars, in thousands of dollars. ***Poverty status*** measures the percent of the population below the poverty level by 2009-2013 five-year estimates. Both measures are from the U.S. Census Bureau (41).

Statistical analysis

The primary objectives of the analysis were to evaluate the associations of county-level characteristics with changes in diabetes prevalence and incidence. For continuous variables, mean and standard deviation are reported and any comparisons were between groups were tested with ANOVA. Chi-squared analyses were used to compare proportions between groups. The outcome variable was calculated as a continuous absolute percent change in diabetes prevalence or incidence in each county between 2009 and 2013. In addition to analyzing continuous change in prevalence or incidence, three categories were developed to reflect the direction of the change in diabetes prevalence or incidence: worsened, stayed the same, and improved (prevalence: between ±0.2, < -0.2, and > 0.2; incidence: between ±0.5, < -0.5, and > 0.5, respectively), with worsened representing any increases in diabetes prevalence or incidence. The categories do not center around an absolute change of zero because there is little to no variation when using zero as a central cut-off. Wider and narrower cut-offs were also considered, but again showed little variation between the groups. To assess any county-level differences attributed to location and population size, bivariate statistics were calculated and tested for each characteristic by urbanization scheme. Models stratified on income and poverty quintiles were fit to assess economic differences.

Prior to employing regression analysis, first, regression diagnostics were performed to assess issues such as collinearity. The tests revealed no substantial issues. Second, predictors of continuous change in diabetes prevalence and incidence were estimated through bivariate and multiple linear regressions. Third, binary logistic regression was performed, comparing in pairs the groups of diabetes prevalence and incidence: no change vs. worsened, no change vs. improved, improved vs. worsened, improved vs. not, and worsened vs. not; this allowed the identification of which predictors that may contribute to the directionality of changes in diabetes prevalence and incidence. Fourth, for each modeling approach, crude fully-adjusted models were used, including all candidate exposure covariates, and then backwards elimination was employed to identify the most parsimonious model with adequate control for confounding, where factors were significant at $p < 0.05$. Finally, sensitivity analysis models were employed on the final models to assess whether the association between change in diabetes outcomes and exposures depend on baseline diabetes prevalence or incidence. All statistical analyses were conducted using SAS 9.4 (SAS Institute Inc., Cary, NC).

Results

Table 1 provides descriptive characteristics of US counties included in this study. The majority of US counties (82%) had an increase in diabetes prevalence from 2009-2013. In contrast, 89% of counties experienced a decreased incidence rate of diabetes over the 5-year time period. Overall change in diabetes prevalence ranged from -3.1 to 5.2. Change in incidence has greater variation, ranging from -7.2 to 4.2. The overall average prevalence of obesity is 30%, ranging from 14-48%. Park access ranges from 0-100%, with on average, 20% of people living within half a mile of a park boundary.

Socioeconomic stratification. When stratifying the data by median household income quintiles, statistically significant differences ($p \leq .0001$) are found for every characteristic, except for change in diabetes incidence (Table 2). Counties belonging to the lowest median household income quintile, on average, have larger mean increases in diabetes prevalence, larger mean decreases in diabetes incidence, higher obesity (differing by more than 6%), higher physical inactivity (differing by nearly 7%), less access to parks (more than 19% less), more grocery stores per 1,000, fewer recreation and fitness facilities per 1,000, earn more than $30,000 less annually, and a higher poverty rate, differing by nearly 15%, compared to those belonging to the highest quintile, the counties earning the greatest income. More counties are in noncore areas in the lowest quintile (67%), while those in the highest quintile primarily live in large fringe metro or small metro areas (58%).

When stratifying by poverty rate quintiles, high-poverty counties have significantly higher increases in diabetes prevalence, more obesity and physical inactivity, and less access to all of the built environment factors. For these high-poverty counties, a similar trend to the median household income variations is found. The only difference is among the urbanization scheme: the majority of counties with less poverty live either in noncore or large fringe metro areas.

Change in diabetes outcomes. Compared to counties with decreasing or no change in diabetes prevalence or incidence, counties with increasing prevalence or incidence were different in several ways (see Appendix). For change in prevalence groups, the worsened counties differ significantly from the reference group (no change) and improved counties for physical inactivity and median household income. Obesity prevalence is significantly higher in counties with worsened prevalence compared to counties with no change, but only modestly. Worsened counties have fewer grocery stores compared to improved counties. Comparing improved counties to the counties with no change, the only significant difference is in the average change in incidence. For change in incidence groups, improved counties only differ from the reference group in access to parks. Improved counties have, on average, significantly higher obesity, physical inactivity, and poverty rates, and lower median income. Overall, this analysis shows that counties with worsening diabetes prevalence or incidence differ more so from no change counties that from improving counties.

Urbanization. The urbanization scheme is found to be associated with all of the characteristics of interest, except for change in diabetes incidence. Micropolitan counties have the highest change in diabetes prevalence, with an average of 0.60. Counties belonging to the large central metro level have the lowest diabetes prevalence and fewer negative risk factors. For example, this level has, on average, the smallest increase in diabetes prevalence, the highest access to parks, lowest obesity prevalence, and the most recreation and fitness facilities per 1,000. On the opposite end of the spectrum, noncore counties (most rural areas) have the lowest access to parks (15%), fewest grocery stores per 1,000

(0.40), fewest recreation and fitness facilities per 1,000 (0.05), and the lowest median household income (differing by nearly $20,000 annually compared to large central metro areas). Large fringe metro counties have the highest median income (more than $61,000 per year) and consequently the lowest poverty rate (12%). Median income accounts for 29% of the variation between the urbanization schemes (See Appendix).

Regression analysis. Associations between the county-level characteristics and continuous change in diabetes incidence and prevalence are displayed in Table 3. In bivariate analyses, obesity prevalence, physical inactivity prevalence, and poverty rate were associated with worsening diabetes prevalence, whereas median income, access to parks, and grocery stores per 1,000 were associated with improving diabetes prevalence; none remained significant in the full model. In the final model, physical inactivity prevalence and recreation and fitness facilities per 1,000 were associated with worsening diabetes prevalence, and median income, poverty rate, and grocery stores per 1,000 were associated with improving diabetes prevalence. For bivariate analyses of continuous change in diabetes incidence, median income, access to parks, and recreation and fitness facilities per 1,000 were associated with worsening diabetes incidence, while obesity prevalence, physical inactivity prevalence, and poverty rate were associated with improving diabetes incidence. Only poverty rate and its interaction term with obesity remained significant in the full model. In the final model, obesity, poverty rate, and their interaction are in the final model and are substantially attenuated. No other significant interaction between median income and poverty rate was found in regression analysis. Because the magnitude of change in diabetes prevalence or incidence might be dependent on the baseline value in the county, a final model adjusting for baseline prevalence (incidence) was fit. The results of this sensitivity analysis are in Table 4. Results show considerable change from the initial final models for both diabetes prevalence and incidence. The association of change in diabetes prevalence and physical inactivity, poverty rate, and grocery stores per 1,000 are strengthened by the adjustment, while recreation and fitness facilities per 1,000 and median income are moderately attenuated. With the adjustment, the association of change in diabetes incidence and poverty rate is strengthened, while obesity and its interaction with poverty rate are weakened.

Figure 1 displays the significant associations between covariates and binary change trajectories in county diabetes prevalence and incidence. Every 10% increase in physical inactivity was associated with a 12% increased odds (OR = 1.12, 95% confidence interval: 1.05, 1.18) of a county's incidence worsening as compared to remaining the same, and 10% increased odds of worsening compared to improving. Every 1 per 1,000 increase in grocery stores per 1,000 was associated with a 39% decrease in the odds of worsening diabetes prevalence as compared to improving. Other comparisons across binary changes are modest.

Discussion

The results of this study support that geographic variations in the rate of change in diabetes prevalence and incidence may be predicted by environmental and behavioral characteristics of populations at the county-level. Higher county-level obesity was found to be associated with worsening diabetes outcomes, regardless of how the data were presented. Physical inactivity differs across income and poverty strata, and is associated with worsening incidence of diabetes when compared to improving counties. Pertaining to urbanization scheme, location and population size may matter in the determination of county-level characteristics that influence diabetes prevalence and incidence based on the stratified analysis in the Appendix, and the potential effect medication of urbanization should be further evaluated. Previous studies have associated lower income and more poverty with fewer available resources, including opportunities for physical activity, food choices and affordability, and obesity (1, 16, 19, 21, 34). The findings of this study show that the associations from both regressions between the two socioeconomic measures and the diabetes outcomes are significant yet fairly small; however, the magnitude of all other factors involved in the analysis differ significantly by median income and poverty levels. Further, the associations of the predictors with diabetes prevalence and incidence are homogenous across strata of median income and poverty, based on the lack of significant interaction by these two variables, with the exception of obesity and poverty when assessing change in incidence. Sensitivity analysis showed that there are differences in whether a county improved or worsened depending on the baseline measure of diabetes prevalence or incidence. Thus, counties doing worse may decline more frequently, while counties improving are less likely to decline further, if at all.

Assessing changes in diabetes prevalence and incidence by categorical groups revealed that increased access to parks does not necessarily predict changes in diabetes outcomes. The mixed results of previous research claim that proximity to parks is not the only element influencing park use; other elements to be considered include a person's sense of safety and motivation to exercise, and should be further investigated (24-26). People in low-resource settings may not be aware of all the resources available around them or how to use or access the resources. Low-income and high-poverty counties have significantly lower access to grocery stores, but often have a higher concentration of fast food restaurants. Communities are segregated in a sense by providing lower-income areas with fewer resources to be healthy; this can be due to poor city planning or improperly allocated resources, leading to health disparities. Recreation and fitness facilities per 1,000 were positively associated with diabetes prevalence, a surprising finding. This could be due to lack of use or low access to large parts of the population in the county. This finding is requires further research since the lowest-income and highest-poverty counties have significantly fewer facilities per 1,000. There could be a funding issue at the county level, lack of prioritization, or some other element. Physical inactivity, median income, poverty rate, grocery stores and fitness and recreation facilities per 1,000 were found to be the best predictors of changes in diabetes prevalence, while obesity and poverty were found to be the best predictors of changes in diabetes incidence.

Strengths & limitations

The use of cross-sectional studies hinders causal inference. The present study utilizes a repeated cross-sectional study design that could strengthen evidence by measuring whether county factors predict change over time. There could still be confounding, but the introduction of time is a major strength. This study was limited by several key challenges. From the CDC dataset, demographics have been modeled into the estimates for diabetes prevalence and incidence. Thus, the estimates of diabetes prevalence and incidence may be underestimated as a result of socioeconomic modeling. In addition, the BRFSS collection method changed in 2011, and may affect prevalence estimates, as the use of cell phone numbers began, permitting a better representation of the US. Access to parks may be underestimated, as it does not take into consideration populations that are willing to travel farther to access a park or populations that may visit parks near work or school. There is also not a consistent measure to identify other public spaces utilized for physical activity, and thus, these locations may not be entirely included in the data. The Great Recession of 2007-2009 led to drastic changes in income and poverty across the country, and residuals of this lasted well into 2010. It can be argued that the recession created a new economic reality, primarily for the middle class (45). Job instability and higher unemployment, lower income, and change in access to healthcare are all lingering effects of the recession. Many families make financial sacrifices, which can influence some of the factors assessed in this study, such as food selections, exercise preferences, etc. This potentially relevant finding has not been taken into consideration in the present study.

In conclusion, the findings suggest that behavioral and built environment factors are may be important for predicting changes in diabetes prevalence and incidence, for both improving and worsening conditions. The built environment and behavioral factors differ significantly across poverty and income levels. Interventions are warranted to improve the resources available to low-income areas that perpetuate health disparities, including higher prevalence and incidence of diabetes, as well as methods to improve the lifestyle of people in these counties.

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TABLES

Table 1. Distribution of county-level characteristics and diabetes mellitus outcomes across 3,137 US counties

County Characteristic	Mean (SD) or %	Min	Max
Diabetes outcomes (2013 - 2009)			
Change in diabetes prevalence	0.50 (1.09)	-3.10	5.20
Change in diabetes incidence	1.67 (1.35)	-7.20	4.20
Behavioral factors (2009)			
Obesity prevalence (BMI ≥ 30)	30.30 (4.23)	13.50	47.90
Leisure-time physical inactivity prevalence (in past 30 days)	26.91 (4.95)	10.60	42.80
Socioeconomic factors			
Median income, thousands of dollars	45.93 (11.92)	19.99	122.24
Poverty rate	16.69 (6.50)	0.90	53.20
Built environment factors			
Access to parks (%) (2010)	19.55 (18.97)	0.00	100.00
Grocery stores per 1,000 (2012)	0.29 (0.24)	0.00	3.23
Recreation & fitness facilities per 1,000 (2012)	0.07 (0.07)	0.00	0.77
Urbanization scheme (%) (2013)			
Large central metro	2.17		
Large fringe metro	11.73		
Medium metro	11.86		
Small metro	11.41		
Micropolitan	20.43		
Noncore	42.40		

Note: Diabetes decline was calculated from differences in two year-specific summaries of cross-sectional rates publicly available from CDC. Data shows overall averages and distribution of all variables.

Table 2. County-level characteristics and diabetes outcomes by socioeconomic quintiles

County Characteristic	Median Household Income			Poverty		
Quintile	Highest (N = 627)	Lowest (N = 628)	*p* value	Highest (N = 621)	Lowest (N = 639)	*p* value
Diabetes outcomes						
Change in diabetes prevalence	0.30 (0.92)	0.68 (1.27)	< .0001	0.57 (1.21)	0.36 (0.95)	0.001
Change in diabetes incidence	1.62 (1.20)	1.75 (1.59)	0.09	1.79 (1.53)	1.54 (1.17)	0.002
Behavioral factors						
Obesity prevalence (BMI ≥ 30)	27.23 (4.20)	33.28 (4.18)	< .0001	33.24 (4.20)	27.97 (4.06)	< .0001
Leisure-time physical inactivity prevalence (in past 30 days)	23.05 (4.48)	30.98 (4.43)	< .0001	30.45 (4.61)	23.95 (4.32)	< .0001
Socioeconomic factors						
Median income, thousands of dollars	63.95 (11.21)	32.45 (3.44)	< .0001	34.03 (5.29)	60.22 (13.50)	< .0001
Poverty rate	10.25 (3.17)	25.14 (5.82)	< .0001	26.59 (4.77)	8.82 (1.82)	< .0001
Built environment factors						
Access to parks (%)	27.69 (22.65)	8.49 (11.97)	< .0001	11.11 (14.73)	25.90 (20.24)	< .0001
Grocery stores per 1,000	0.25 (0.26)	0.30 (0.19)	< .0001	0.28 (0.20)	0.33 (0.34)	0.001
Rec & fitness facilities per 1,000	0.10 (0.09)	0.04 (0.06)	< .0001	0.04 (0.05)	0.10 (0.10)	< .0001
Urbanization scheme (%)			< .0001			< .0001
Large central metro	5.26	0.32		1.29	1.1	
Large fringe metro	38.44	1.11		1.77	28.79	
Medium metro	19.94	4.46		7.57	11.42	
Small metro	10.53	5.57		8.53	11.27	
Micropolitan	11.8	21.66		26.25	11.58	
Noncore	14.04	66.88		54.59	35.84	

Note: Diabetes decline was calculated from differences in two year-specific summaries of cross-sectional rates publicly available from CDC. Data in the table were calculated by stratification of highest and lowest income or poverty quintiles, and use of two-way ANOVA and chi-square tests to show differences between socioeconomic groups.

Table 3. County-level associations between age-adjusted diabetes prevalence and incidence and behavioral, socioeconomic, and built environment factors

Characteristics	**Bivariate analysis**			**MLR analysis - Full model†**			**MLR analysis - Final model‡**		
	β	95% CI	*p* value	β	95% CI	*p* value	β	95% CI	*p* value
Prevalence									
Intercept				0.51	(-2.15, 3.17)	0.71	0.59	(0.11, 1.07)	0.02
Behavioral factors									
Obesity prevalence (BMI ≥ 30)*	0.28	(0.19, 0.37)	< .0001	-0.50	(-1.63, 0.62)	0.38			
Leisure-time physical inactivity prevalence (in past 30 days)*	0.31	(0.23, 0.39)	< .0001	1.06	(-0.09, 2.21)	0.07	0.26	(0.17, 0.35)	<.0001
Socioeconomic factors									
Median income, thousands of dollars	-0.01	(-0.014, -0.008)	< .0001	0.005	(-0.03, 0.04)	0.80	-0.01	(-0.02, -0.01)	<.0001
Poverty rate*	0.01	(0.01, 0.02)	< .0001	-0.54	(-1.23, 0.14)	0.12	-0.11	(-0.20, -0.03)	0.01
Built environment factors									
Access to parks*	-0.02	(-0.04, 0.00)	0.06	0.01	(-0.16, 0.19)	0.89			
Grocery stores per 1,000	-0.24	(-0.40, -0.08)	0.003	-0.49	(-1.55, 0.57)	0.36	-0.30	(-0.46, -0.14)	0.0002
Rec & fitness facilities per 1,000	-0.26	(-0.77, 0.25)	0.32	-0.99	(-4.56, 2.60)	0.59	0.56	(0.01, 1.10)	0.04
Interaction									
Obesity & Med. income				0.003	(-0.01, 0.02)	0.76			
Physical inactivity & Med. income				-0.01	(-0.03, 0.004)	0.15			
Parks & Med. Income				< .01	(-0.002, 0.002)	0.95			

Grocery stores & Med income				0.006	(-0.01, 0.02)	0.46			
Rec & fitness facilities & Med. Income				0.008	(-0.04, 0.06)	0.76			
Obesity & Poverty				0.24	(-0.03, 0.50)	0.08			
Physical inactivity & Poverty				-0.15	(-0.43, 0.13)	0.30			
Parks & Poverty				< - .01	(-0.05, 0.05)	0.98			
Grocery stores & Poverty				- 0.07	(-0.36, 0.22)	0.64			
Rec & fitness facilities & Poverty				0.77	(-0.32, 1.86)	0.17			

Incidence	**Bivariate analysis**			**Full model[θ]**			**Final model[•]**		
Intercept				2.76	(-0.55, 6.08)	0.10	0.87	(0.05, 1.68)	0.04
Behavioral factors									
Obesity*	-0.37	(-0.49, -0.26)	< .0001	-1.36	(-2.77, 0.05)	0.06	-0.83	(-1.10, -0.56)	<.0001
Physical inactivity*	-0.2	(-0.30, -0.12)	< .0001	0.18	(-1.25, 1.62)	0.80			
Socioeconomic factors									
Median income	0.005	(0.001, 0.009)	0.02	-0.02	(-0.07, 0.02)	0.35			
Poverty rate*	-0.1	(-0.18, -0.03)	0.01	-1.43	(-2.28, -0.58)	0.001	-0.84	(-1.29, -0.38)	0.0003
Built environment factors									
Access to parks*	0.06	(0.03, 0.08)	< .0001	0.07	(-0.15, 0.29)	0.52			
Grocery stores per 1,000	-0.001	(-0.20, 0.19)	0.99	-0.81	(-2.13, 0.50)	0.23			
Rec & fitness facilities per 1,000	1.06	(0.43, 1.69)	0.001	0.08	(-4.39, 4.54)	0.97			
Interaction									
Obesity & Med. income				0.003	(-0.02, 0.02)	0.81			

Physical inactivity & Med. income	< -.01	(-0.02, 0.02)	1.00			
Parks & Med. Income	< - 0.01	(-0.003, 0.003)	0.87			
Grocery stores & Med income	0.01	(-0.004, 0.03)	0.13			
Rec & fitness facilities & Med. Income	-0.01	(-0.07, 0.05)	0.70			
Obesity & Poverty	0.46	(0.13, 0.79)	0.006	0.27	(0.13, 0.41)	0.0002
Physical inactivity & Poverty	-0.06	(-0.41, 0.29)	0.73			
Parks & Poverty	-0.01	(-0.07, 0.05)	0.71			
Grocery stores & Poverty	0.02	(-0.34, 0.39)	0.90			
Rec & fitness facilities & Poverty	0.65	(-0.71, 2.00)	0.35			

Note: Diabetes decline was calculated from differences in two year-specific summaries of cross-sectional rates publicly available from CDC. Data in the table were calculated by simple linear regression, crude fully adjusted multiple linear regression, and results of backwards elimination.

CI = confidence interval

* adjusted scale to 10% as one-unit

[†] overall F-test $p < .0001$; adjusted $R^2 = 0.0283$

[‡] no interaction model, overall F-test $p < .0001$; adjusted $R^2 = 0.0311$

[θ] overall F-test $p < .0001$; adjusted $R^2 = 0.0158$

[•] overall F-test $p < .0001$; adjusted $R^2 = 0.0170$

Table 4. Sensitivity analysis of the final models from multiple linear regression using baseline prevalence and incidence

	Prevalence			Incidence		
	β	95% CI	*p* value	β	95% CI	*p* value
Intercept	0.68	(0.22, 1.14)	0.004	1.52	(0.79, 2.24)	< .0001
Baseline prevalence/ incidence	-0.21	(-0.24, -0.18)	< .0001	-0.41	(-0.43, -0.38)	< .0001
Behavioral factors						
Obesity prevalence (BMI ≥ 30)*				0.06	(-0.18, 0.31)	0.63
Leisure-time physical inactivity prevalence (in past 30 days)*	0.71	(0.60, 0.82)				
Socioeconomic factors						
Median income, thousands of dollars	-0.007	(-0.01, -0.001)	0.01			
Poverty rate*	0.16	(0.07, 0.26)	0.0008	-1.21	(-1.62, -0.81)	< .0001
Built environment factors						
Access to parks*						
Grocery stores per 1,000	-0.56	(-0.72, -0.41)	< .0001			
Rec & fitness facilities per 1,000	0.34	(-0.19, 0.86)	0.21			
Interaction						
Obesity & Poverty				0.54	(0.42, 0.67)	< .0001

Note: Diabetes decline was calculated from differences in two year-specific summaries of cross-sectional rates publicly available from CDC. Data in the table were calculated by multiple linear regressions of the final continuous models with the inclusion of baseline (2009) diabetes prevalence and incidence.

CI = confidence interval

* adjusted scale to 10% as one-unit

FIGURES

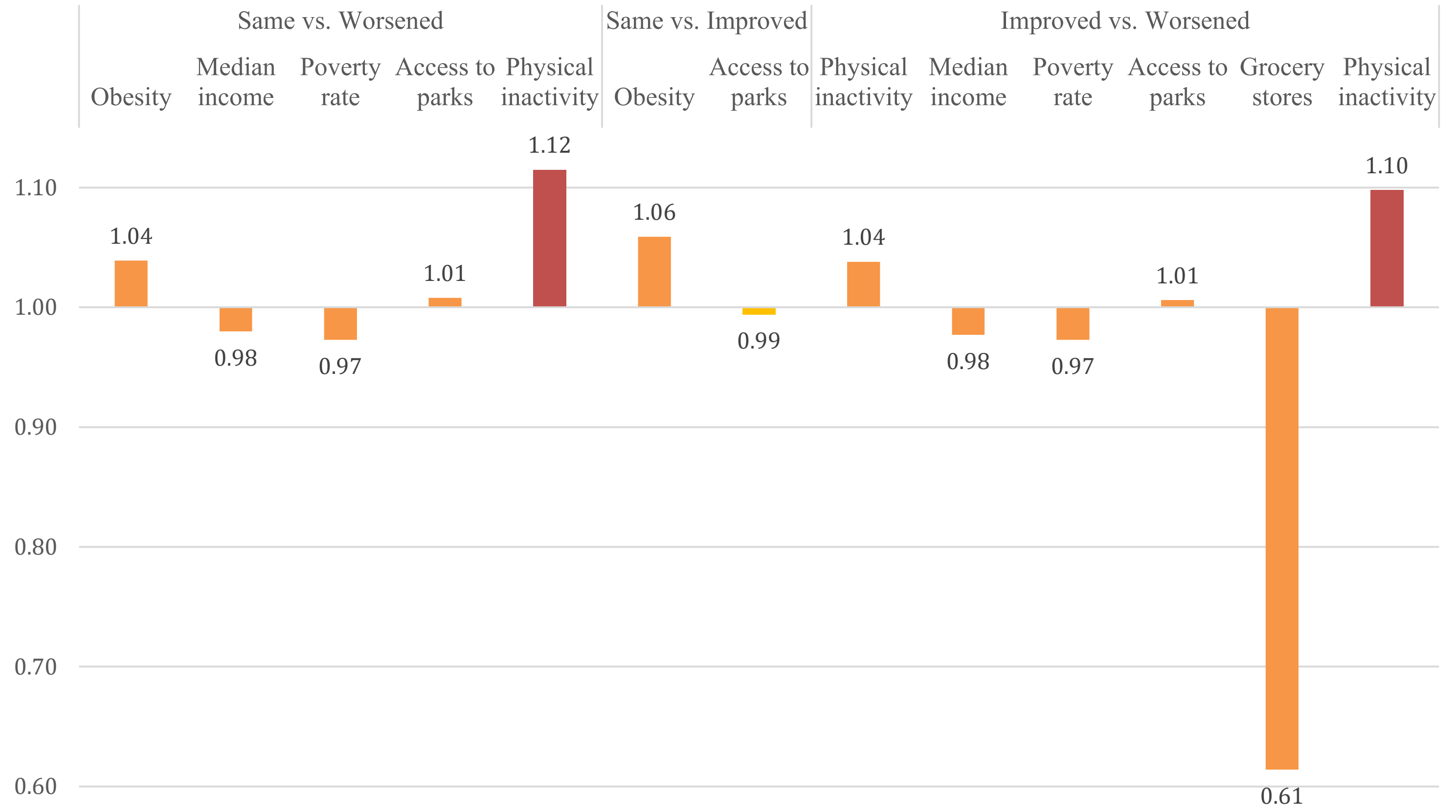

Figure 1. Significant odds ratios ($p < .05$) resulting from binary logistic regression for change in prevalence and incidence. Reference groups are same, same, and improved, respectively. Orange bars represent the models for diabetes prevalence, and red bars represent the models for diabetes incidence.

CHAPTER III: SUMMARY, PUBLIC HEALTH IMPLICATIONS, AND POSSIBLE FUTURE DIRECTIONS

This study employed an exploratory approach aiming to identify the behavioral, economic, and built environment factors influencing changes in diabetes prevalence and incidence using national county-level data. The study found that the factors associated with changes in diabetes prevalence, increases and decreases, are physical inactivity, median income, poverty rate, access to parks, grocery stores per 1,000 and recreation and fitness facilities per 1,000. Factors associated with changes in incidence are obesity prevalence and poverty, which were found to significantly interact.

Public Health Implications

The findings of this study may allow researchers and policy-makers to compare factors leading to the greatest changes of diabetes prevalence and develop interventions or policies surrounding the findings.

Findings support the need for better behavioral education and improved environmental resources in low-income, high-poverty counties. Interventions are needed to address the health-related problems that come with living in poorer areas, such as better availability and access to healthier food options, more and better quality recreational facilities, and increased opportunities for physical activity. There is a question of affordability; many people of the middle class do not have the financial resources to keep up with inflation and the growing cost of food and other basic needs. There has been a shift in priorities from optimal health to survival. Physical inactivity is a strong predictor of increased diabetes prevalence, indicating a need for physical activity interventions at a larger scale than the individual level. Lovasi *et al.* discusses the need to make physical activity more "attractive", prompting a more suitable environment to engage in physical activity (16). Another potential alternative is to offer counties of low income incentives to improve physical activity prevalence, which could reduce healthcare costs in the long-run. To impact diabetes incidence, interventions need to focus on larger-scale weight loss programs, including not only increased exercise but also making better food choices with available resources.

This study has helped identify predictors for which counties may see a continued increase in diabetes prevalence and what factors can be intervened on in order to decrease the likelihood of this occurring. Interventions can now focus on how to move counties from 'worsened' to 'no change' to 'improved.' This research has permitted the narrowing of the context of where and what to emphasis in order to reduce diabetes morbidity.

Future Directions

The adjusted R^2 values are low for the models in this study indicate several factors are missing from the regression models. Little of the variation of diabetes prevalence and incidence is accounted for in this study and can be improved through the addition of other relevant behavioral, economic, and built environment factors.

Regardless of how the data were assessed, few variables were found to be associated with change in diabetes incidence. Additional research on this area is warranted to understand how to reduce the number of new cases in small geographical areas. It may also be beneficial to further investigate types of grocery stores being most frequented, amount of healthy food options available, and the primary source of food (*e.g.*, chain grocery store, fast food restaurant, neighborhood corner store). In other words, studies can assess the affordability of healthy and unhealthy foods at the county level. Park usage is also still not well-understood in diabetes research; this study found that park access is not a predictor of changes in diabetes prevalence or incidence. Rather than focusing on proximity, future studies may focus on how and how often parks are used, and potential barriers for not using them for physical activity, as well as where physical activity requirements are met in general. This same idea applies to recreation and fitness facilities, as this characteristic was not significant across the categorical groups of diabetes prevalence and incidence, but was significant in the continuous regression model for prevalence only. It may be of interest to investigate geographic differences at the county-level, both across the typical southern trend as well as in the Midwest region where county-level maps show an increase in diabetes prevalence in this throughout this region. Lastly, future research should focus on income instead of class and race, because the latter two do not necessarily encompass income as it varies across both class and race. This study has shown that income and poverty of a county directly influence the resources and behaviors of its population.

APPENDIX

Additional tables developed from analysis not included in manuscript chapter.

Table A1. Number of counties for prevalence and incidence categorical groups

	Incidence			
Prevalence	Same	Improved	Worsened	Total
Same	5	472	--	477
Improved	--	829	--	829
Worsened	397	1,256	178	1831
Total	402	2557	178	3,137

Note: Cross-tabs calculating prevalence and diabetes groups using author's cut-offs

Table A2. County-level characteristics and diabetes outcomes by prevalence and incidence categories

Characteristic	Diabetes prevalence**				Diabetes incidence**			
	Same (ref.) (N = 477)	Improved (N = 829)	Worsened (N = 1,831)	*p* value‡	Same (ref.) (N = 402)	Improved (N = 2,557)	Worsened (N = 178)	*p* value‡
Diabetes outcomes								
Change in diagnosed diabetes prevalence	0.003 (0.12)	0.75 (0.49)†	1.20 (0.82)†	< .0001	1.64 (0.62)	0.17 (0.83)†	2.76 (0.83)†	< .0001
Change in diagnosed diabetes incidence	2.18 (0.70)	3.04 (0.93)†	0.91 (1.06)†	< .0001	0.10 (0.30)	2.11 (1.02)†	1.23 (0.68)†	< .0001
Behavioral factors								
Obesity prevalence	29.79 (4.07)	30.19 (4.17)	30.49 (4.28)†	0.21	29.92 (4.80)	30.29 (4.12)	31.36 (4.30)†	0.003
Leisure-time physical inactivity	26.53 (4.87)	26.52 (4.79)	27.19 (5.02)†	0.004	26.55 (5.14)	26.83 (4.93)	28.88 (4.37)†	< .0001
Socioeconomic factors								
Median income	46.71 (12.57)	46.92 (12.82)	45.27 (11.26)†	0.003	46.31 (11.79)	46.07 (12.00)	42.98 (10.69)†	0.002
Poverty rate	16.52 (6.48)	16.52 (6.70)	16.80 (6.41)	0.56	16.49 (6.65)	16.61 (6.43)	18.24 (7.04)†	0.003
Built environment factors								
Access to parks (%)	18.66 (18.08)	19.30 (19.45)	19.90 (18.98)	0.73	21.83 (19.91)	19.39 (18.94)†	16.70 (16.62)†	0.16
Grocery stores per 1,000	0.30 (0.25)	0.30 (0.27)	0.28 (0.23)	0.04	0.27 (0.18)	0.29 (0.25)	0.27 (0.19)	0.44
Rec & fitness facilities per 1,000	0.07 (0.07)	0.07 (0.08)	0.07 (0.07)	0.95	0.08 (0.07)	0.07 (0.08)	0.06 (0.06)	0.60
Urbanization scheme (%)°				0.50				0.77
Large central metro	2.52	2.29	2.02		1.99	2.19	2.25	
Large fringe metro	12.58	11.7	11.52		11.19	11.89	10.67	

Medium metro	10.9	10.98	12.51	14.18	11.50	11.8
Small metro	11.53	11.10	11.52	9.2	11.97	8.43
Micropolitan	19.5	19.18	21.25	24.38	19.75	21.35
Noncore	42.98	44.75	41.18	39.05	42.71	45.51

† indicates value is significantly different from reference group at α=.05

‡ p-values compare improved vs. worsening groups

** cut-offs are:

Prevalence: same -0.2 to 0.2; improved < -0.2 ; worsened > 0.2

Incidence: same: -0.5 to 0.5; improved < -0.5; worsened > 0.5

Note: Diabetes decline was calculated from differences in two year-specific summaries of cross-sectional rates publicly available from CDC. Statistical tests in this table were developed from one-way ANOVA or chi-square tests

Table A3. Distribution of county-level characteristics by diabetes outcome categories

	By prevalence categories		By incidence categories	
	Min	Max	Min	Max
Change in prevalence				
same	0.20	0.20	0.10	3.50
improved	3.10	0.20	3.10	2.50
worsened	0.20	5.20	1.00	5.20
Change in incidence				
same	4.30	0.1	0.50	0.50
improved	7.20	0.6	7.20	0.50
worsened	4.30	4.20	0.50	4.20
Obesity				
same	13.50	41.80	15.00	41.90
improved	13.90	43.50	13.50	47.90
worsened	13.80	47.90	15.00	44.70
Physical inactivity				
same	11.10	41.10	11.10	42.00
improved	11.30	40.90	10.60	42.80
worsened	10.60	42.80	15.00	39.80
Access to parks				
same	0.00	95.00	0.00	100.00
improved	0.00	100.00	0.00	100.00
worsened	0.00	100.00	0.00	80.00
Grocery stores				
same	0.00	1.72	0.00	1.90
improved	0.00	2.96	0.00	3.23
worsened	0.00	3.23	0.05	1.43
Rec and fitness facilities				
same	0.00	0.49	0.00	0.42

improved	0.00	0.77	0.00	0.77
worsened	0.00	0.69	0.00	0.34
Median income				
same	19.99	97.11	22.33	101.59
improved	21.19	122.24	19.99	122.24
worsened	20.97	120.00	22.92	84.92
Poverty rate				
same	0.90	40.50	3.90	48.00
improved	3.10	44.50	0.90	53.20
worsened	3.90	53.20	4.40	44.60

Note: Diabetes decline was calculated from differences in two year-specific summaries of cross-sectional rates publicly available from CDC. Data in table are developed based on author's cut-offs for categorical groups to calculate the minimum and maximum of each variable.

Table A4. County-level characteristics and diabetes outcomes by urbanization scheme

Characteristic	Urbanization scheme							
	Large central metro (N = 68)	Large fringe metro (N = 368)	Medium metro (N = 372)	Small metro (N = 358)	Micropolitan (N = 641)	Noncore (N = 1,330)	R^2	*p* value
Diabetes outcomes								
Change in diagnosed diabetes prevalence	0.27 (0.84)	0.42 (1.02)	0.55 (1.14)	0.42 (1.02)	0.60 (1.13)	0.50 (1.11)	0.00	0.03
Change in diagnosed diabetes incidence	1.59 (1.19)	1.69 (1.29)	1.66 (1.45)	1.74 (1.28)	1.60 (1.39)	1.67 (1.36)	< .001	0.71
Behavioral factors								
Obesity prevalence	26.24 (4.34)	28.90 (4.28)	29.84 (3.91)	30.25 (3.99)	30.69 (4.29)	30.86 (4.12)	0.05	< .0001
Leisure-time physical inactivity	23.14 (4.46)	25.21 (4.88)	25.78 (4.80)	26.06 (4.82)	27.17 (5.13)	28.00 (4.64)	0.05	< .0001
Socioeconomic factors								
Median income	55.33 (13.32)	61.09 (15.85)	49.28 (9.77)	46.74 (8.57)	43.50 (9.08)	41.26 (8.63)	0.29	< .0001
Poverty rate	16.93 (4.67)	11.81 (4.72)	15.91 (5.38)	16.46 (5.67)	17.94 (6.34)	17.69 (6.92)	0.09	< .0001
Built environment factors								
Access to parks (%)	58.21 (20.76)	22.46 (20.88)	23.21 (20.18)	22.33 (19.68)	18.58 (15.61)	15.47 (16.44)	0.12	< .0001
Grocery stores per 1,000	0.25 (0.12)	0.18 (0.09)	0.19 (0.08)	0.21 (0.11)	0.23 (0.14)	0.40 (0.32)	0.15	< .0001
Rec & fitness facilities per 1,000	0.10 (0.04)	0.09 (0.06)	0.08 (0.05)	0.08 (0.06)	0.08 (0.07)	0.05 (0.09)	0.04	< .0001

Note: Diabetes decline was calculated from differences in two year-specific summaries of cross-sectional rates publicly available from CDC. Statistical tests in this table were developed from two-way ANOVA and Tukey-Kramer comparisons to assess differences between urbanization schemes.

Table A5. Correlation Matrix of County-Level Characteristics										
	Prevalence	Incidence	Obesity	Physical inactivity	Urbanization	Access to parks	Grocery stores	Rec facilities	Median income	Poverty rate
Prevalence	1.00									
Incidence	0.85	1.00								
Obesity	0.09	-0.14	1.00							
Physical inactivity	0.13	-0.09	0.69	1.00						
Urbanization	0.01	-0.005	0.17	0.23	1.00					
Access to parks	-0.001	0.10	-0.31	-0.36	-0.22	1.00				
Grocery stores	-0.02	0.02	0.02	0.07	0.44	-0.05	1.00			
Rec facilities	0.01	0.08	-0.28	-0.34	-0.33	0.31	-0.17	1.00		
Median income	-0.10	0.06	-0.48	-0.54	-0.46	0.38	-0.18	0.37	1.00	
Poverty rate	0.07	-0.07	0.43	0.46	0.21	-0.30	0.02	-0.26	-0.83	1.00

Note: Diabetes decline was calculated from differences in two year-specific summaries of cross-sectional rates publicly available from CDC. Statistical tests in this table were developed from correlation analysis.