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Road network intersection density and Childhood obesity risk in the U.S.: A national longitudinal study

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Abstract

Objectives: Road intersection density is an important indicator of walkability. The objectives of this study were to examine the trends in intersection density in the U.S. from 2007–2011, and assessed the associations between intersection density and childhood obesity risk at the state level.

Study design: Longitudinal analyses were conducted to assess the spatial-temporal changes of population-weighted intersection density in relation to the risk of childhood obesity in the US.

Methods: Road network data from the Topologically Integrated Geographic Encoding and Referencing (TIGER) (2007–2011), the prevalence of overweight and obesity data from the National Survey of Children’s Health (NSCH) (2007–2011), and the American Community Survey (ACS) data (2011) were used. Geographic information system (GIS) visualization, spatial and regression analyses were conducted. Mixed effect models were fit to assess the longitudinal relationship between intersection density and childhood obesity.

Results: Between 2007 and 2011, population-weighted intersection density remained relatively stable in most states. Low-intersection-density states were clustered in the Southeastern region in both 2007 and 2011. The high- intersection-density states were clustered in the Middle Atlantic Division. California and Nevada also were identified as high- intersection-density clusters in 2011. States with lower road intersection density corresponded with states with higher childhood obesity prevalence. Our mixed effect model estimates suggested that increased intersection density was associated with decreased obesity prevalence.

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Ethical Statement: This study is a non- human subject secondary data analysis study and ethical approval is not required for this study.

Conclusions: This study provided empirical evidence for longitudinal associations between neighborhood intersection density and child obesity prevalence based on national data, and offered a new perspective of the role that road network plays in childhood obesity prevention.

Keywords

Childhood obesity; Geographic information system; neighborhood environment; Spatial analysis; Walkability

INTRODUCTION

In the US, the prevalence of obesity among children aged 2–19 years has increased from 14% in 1999 to 17% in 2011, and remained relatively stable since then.^{1–3} Childhood obesity has drawn special attention due to its associations with increased risk of adverse health consequences across life span, such as adulthood obesity, hypertension, Type 2 diabetes, cardiovascular diseases, and cancer.^{4, 5}

Geographic variations of the prevalence of childhood obesity among states are evident in the US.⁶ The observed variation of the prevalence of obesity by regions can be partly explained by spatial differences in food environments, that may affect healthy/unhealthy eating behavior, and in the built environment that may influence physical activity.⁷ In particular, walkability, which refers to the friendliness of an area for walking, has been identified as an important built environment indicator of obesity risk.⁸

Walkability can be measured in a variety of formats, such as intersection density, block length, sidewalk completeness, and residential density.^{8–10} Among these measures, intersection density has been most widely used due to its ability to capture the wellness that destinations are connected by walkable trails and its ease of implementation.^{7, 11} Intersection density is defined as the number of intersections per square kilometer at a local scale, where intersections are the junctions at which three or more road segments intersect.^{7, 12} A high intersection density indicates a walking-friendly environment.

Existing findings regarding the relationship between intersection density and the risk of childhood obesity remains mixed,^{7, 11–13} partly due to the limited longitudinal studies conducted at an appropriate scale, and the use of over simplified measure.¹⁴ For example, a simple average measure may be inappropriate to indicate the risk of obesity at an aggregate level (e.g. county and state) as it does at the neighborhood level, since it fails to consider the effects of uneven distribution of population within aggregated units.⁷ Increased intersection density occurring in a sparsely-populated town within a state would raise the intersection density of that state, but would not increase the walking opportunities for the population out of the town. Therefore, a population-weighted intersection density is more desirable to reflect the population's exposure to walkable neighborhoods.⁷

To address these gaps, the aims of the present study were 1) to examine the spatial-temporal changes of population-weighted intersection density in the U.S. from 2007–2011, and (2) to assess the association between intersection density and childhood obesity risk using national longitudinal data.

METHODS

Data

This study used three major data sets: 1) the National Survey of Children's Health (NSCH) data from 2007–2011, 2) the Topologically Integrated Geographic Encoding and Referencing (TIGER) data from 2007–2011, and 3) American Community Survey (ACS) data in 2011. NSCH is the only state-level representative dataset for childhood obesity in the U.S.¹⁵ NSCH data have been collected every four years since 2003 by the National Center of Health Statistics at the Centers for Disease Control (CDC), under the direction and sponsorship of the Federal Maternal and Child Health Bureau.¹⁶ The sample size ranged from 1,000–2,000 in each state, with a total sample size of about 43,800 and 44,100 children aged 10–17 surveyed in 2011 and in 2007, respectively. The estimates of the prevalence of obesity are representative at the state level. Children's weight and height as reported by parents were only available for those aged 10–17 years.¹⁵ Although measured weights and heights are the gold standard, parent-reported heights and weights are commonly used in large scale surveys for the estimation of prevalence of overweight and obesity in children due to costs and practical reasons, such as the National Health Interview Survey (NHIS) {Health, 2016 #16} and the National Survey of Children's Health (NSCH). {van Dyck, 2004 #17} Empirical research suggests that parent-reported height and weight could be reasonably valid for classifying children as obese or non-obese in large epidemiological studies.^{17–20}

TIGER data contained information on roads, railroads, rivers, as well as legal and statistical geographic areas that were pre-joined with demographic information. They are available to the public in the form of spatial databases covering the entire U.S., updated annually by the Census Bureau.²¹ The intersection density estimates were obtained from the road network data across the contiguous U.S (48 adjoining states plus Washington D.C) in 2007 and 2011 from the TIGER data to match with the NSCH data. The population of children aged 10–17 years at the census tract level was obtained from ACS 2010.

Key variables

Outcome

1. Children's Body Mass Index (BMI). Children's BMI was calculated based on parent-reported height and weight, and CDC 2000 age- and gender-specific growth charts were used to determine children's weight status (85th percentile for overweight and 95th percentile for obesity).
2. Prevalence of Overweight and Obesity. The state-level prevalence of childhood obesity only and the prevalence of overweight and obesity combined were estimated based on individual children's weight status defined according to CDC 2000 criteria.

Key exposure variables

1. Intersection density. An intersection was defined as the junction of three or more eligible road segments.^{7, 9, 22} Intersection density at the census tract level was

used to represent walkability in this study⁷. To identify eligible street intersections aligned with the specific aims of this study, local roads potentially more suitable for walking and biking were extracted according to the MAF/TIGER Feature Class Code (MTFCC), which included S1400 (local neighborhood roads, rural roads, and city streets), S1710 (walkway or pedestrian trails), and S1820 (bike paths or trails).²¹ Other roads, such as highways and ramps, were excluded as they were assumed to offer fewer walking or biking opportunities. The census tract-level intersection density in 2007 and 2011 was calculated by dividing the number of intersections in each year within 2010 census tracts by the land area (square kilometer) of census tracts.

2. Population-weighted intersection density. At the aggregated level, population-weighted intersection density was adapted to reflect children's exposure to walkable neighborhoods.⁷ The population of children (aged 10–17) was used to weight each of the census tracts. The state-level population-weighted walkability was expressed as:

$$W_c = \frac{\sum_{i=1}^{n_c} p_i x_i}{\sum_{i=1}^n p_i}$$

where W_c is the *population-weighted intersection density* within the state c , x_i is the intersection density of the i th census tract in that state, p_i is the population of children (aged 10–17) of the i th census tract in that state, and n_c is the total number of census tracts in that state. Population-weighted intersection density were summarized as high (>30 intersections/km²), moderate (>20 intersections/km² and <30 intersections/km²) and low (<20 intersections/km²).

Covariates—The following variables were controlled in the regression analyses: state-level poverty rate (percentage of population under poverty line), percentage of urban areas, and population density (population per squared kilometer) obtained from ACS, and racial/ethnic composition measured by Shannon entropy index based on the data from the demographic profile of the US Census Bureau.^{23–25}

Statistical analysis

We calculated the 2007 and 2011 population-weighted intersection density at the state level. The density distribution was analyzed in both spatial and temporal perspectives. The spatial-temporal patterns were examined and summarized by census division area.²⁶ Mixed effect models with cluster-robust errors were used to explore the longitudinal associations between intersection density and children's weight status.

First, the 48 contiguous U.S. states, including Washington D.C., were grouped into quartiles based on population-weighted intersection density. We then compared the prevalence of obesity and overweight and obesity combined across quartiles.

Then, a hot spot analysis (Getis-Ord G_i^*) was used to identify spatial clusters of intersection density and obesity, and overweight and obesity combined prevalence.²⁷ The resulting clustering patterns of intersection density, the prevalence of obesity, and prevalence of overweight and obesity were visually compared.

Spatial clusters of intersection density and obesity prevalence were then estimated. Mixed effect models were fit to handle the longitudinal data structure and explore the associations between the prevalence of obesity and population-weighted intersection density, controlled for population density, poverty rate, and percentage of urban areas. All analyses were conducted using *ArcGIS* (ArcGIS 10.3), *GeoDa* (GeoDa 1.67), *R* (R 3.1.3), and STATA 14.

RESULTS

The spatial-temporal pattern of intersection density

The population-weighted intersection density was heterogeneous across regions. The highest level (>40 intersections/km²) was found in Pacific and Middle Atlantic areas where the lowest level (<20 intersections/km²) was found in East South Central area (Table 1). Nebraska, Florida, and Illinois also had a high population-weighted intersection density while the surrounding states were from moderate to low population-weighted intersection density.

Most of the states had a stable or increased population-weighted intersection density except for Iowa which had a slight decrease (0.12 intersections/km²). The temporal difference in population-weighted intersection density from 2007 to 2011 showed a 3-level declined pattern from the west coastline to the central area (Table 1). The 1st level was observed in the states along the west coast line (Pacific) which had the highest increase in population-weighted intersection density ($=5.04$ intersections/km²). The states in the mountain area, north to Idaho and Wyoming, south to Arizona and New Mexico, form the 2nd level of increase ($=3.93$ intersections/km²). The other regions, including West North Central, East North Central, East North Central, and East South Central, constructed the 3rd level with a moderate to low increase in population-weighted intersection density.

Obesity prevalence by intersection density quartile

All contiguous states were classified into quartiles based on the values of population-weighted intersection density in 2007. Both childhood obesity and overweight and obesity combined prevalence were presented for each population-weighted density quartile (Figure 1). The lowest density quartile had the highest prevalence of obesity and prevalence of overweight and obesity combined in both 2007 and 2011, indicating that people living in the least walkable states might be at higher risk for overweight and obesity. An increased intersection density beyond the lowest quartile, however, did not correspond to decreased obesity or overweight prevalence.

Spatial clusters of intersection density and obesity prevalence

The spatial clusters of high and low population-weighted intersection density, obesity, and overweight and obesity combined prevalence in 2007 and 2011 were separately identified.

Figure 2 (a) and (b) represent the clusters of population-weighted intersection density in 2011 and the clusters of childhood obesity in 2011, respectively. Other cluster patterns, including intersection density in 2007, childhood obesity, and overweight and obesity combined in 2007 and 2011, were similar to 2011 and were not reported.

Low-intersection-density states were clustered in the Southeastern region in both 2007 and 2011. The high- intersection-density states were clustered in the Middle Atlantic Division. California and Nevada also were identified as high-walkable clusters in 2011.

The states with high obesity prevalence and overweight and obesity combined prevalence were clustered in the Southeastern region as well. Spatially, the high-obesity clusters generally overlapped with the low- intersection-density clusters (Figure 2). Both the states with low obesity and low overweight and obesity combined prevalence were distributed horizontally across the northern U.S. mainland from Washington to Maine. The low obesity and low overweight and obesity clusters, however, did not overlap with the high intersection density clusters.

Relationships between intersection density and obesity prevalence

We examined the effect of intersection density on the prevalence of childhood obesity using mixed effect model estimates (Table 2), controlled for population density, and percentage of urban areas, the population of the urban area, racial/ethnic diversity measured by Shannon entropy index, and the poverty rate for each state. Our estimates suggest a 10-unit-decrease in population-weighted intersections density was significantly associated with a 0.5% increase in the prevalence of childhood obesity ($p = 0.047$).

DISCUSSION

This study used a combination of traditional epidemiological methods and GIS techniques, including GIS visualization and spatial statistics, to analyze spatiotemporal trends of road intersection density and its associations with the prevalence of childhood obesity at the state level, based on the U.S. national datasets between 2007 and 2011. Due to the uneven distribution of population, the population-weighted street intersection density was used as a proxy measure to assess the exposure of children aged 10–17 to neighborhood walkability. Our results suggest that the population-weighted intersection density dramatically varied across states. The states with high intersection density (e.g. Pacific and Middle Atlantic regions) contain a large proportion of urban areas, especially metropolitan cities. Temporally, intersection density in most states remained stable from 2007–2011, with a slight decrease in Iowa and some moderate increases primarily in Mountain (e.g. Utah, Wyoming and New Mexico) and Pacific regions (e.g. California and Washington).

Our longitudinal statistical analyses suggested that the association between intersection density and the prevalence of childhood obesity was negative and statistically significant at the state level. This finding is consistent with our GIS visualization in which we found that the high-obesity clusters overlapped with the low- intersection-density clusters. Previous cross-sectional studies identified similar relationship.^{13, 14} Density, pedestrian-friendly design, and diversity, namely “3Ds”, are associated with walking.²⁸ Intersections density is

an important indicator of street connectivity, a measure of pedestrian-friendly design. A higher intersection density indicates greater street connectivity and walkability which would increase physical activity through encouraging active transportation such as walking and biking. Therefore, in line with existing findings which identified an inverse relationship between intersection density and weight-related measures,^{29, 30} our study found a negative association between intersection density and prevalence of childhood obesity. This finding indicates that an improved road systems may be associated with a lower prevalence of childhood obesity at the state level. However, large-scale, longitudinal, and individual-level data on food purchasing and consumption and data on physical activity/inactivity are still needed in future research to add further evidence on the relationship between road system and risk for obesity.

The present study has several strengths. First, the study design is unique by focusing on the variation in the physical environment across the U. S. and over time. Second, compared to cross-section studies, the longitudinal estimates of this study provide better evidence regarding the effect of the built environment on the risk of childhood obesity. Third, this study is at the national and state level, which may provide more relevant estimates to support effective state-level and national planning and implementation for childhood obesity prevention and control.

Some limitations of this study should also be noted. First, unavailability of individual-level data which allow the linkage between intersection density at the community level and the neighborhood that the study participants actual live limits our analytical capacity to assess the relationship between pedestrian-friendly environment as indicated by intersection density and the risk of obesity at the individual level. Therefore, the present study design is subject to the ecologic fallacy which occurs when applying aggregate level results at the individual level. Cautions should be taken when interpreting the results. Second, more factors could be considered for constructing a composite indicator for walkability in an integrative way, for example, presence of the sidewalk, land use mix, etc which may also influence walkability.^{8,31} However, the availability of empirical data on these factors was a big challenge in reality, which is expected to be solved by advanced spatial technologies. {Jia, 2017 #15} Another limitation of this study is the use of BMI based on parent-reported weight and height to estimate the prevalence of obesity in children. Due to data availability, NSCH is the only national survey data that allow analyses at the state level and cover a wide age range of children and adolescents. The accuracy of parent-reported data varies and the impact on prevalence estimate remains unclear,^{32, 33} for example, some studies reported that use of parent-reported data may lead to overestimating of prevalence of overweight and obesity,^{33, 34} some studies suggested an underestimate of prevalence.^{35, 36} Therefore, further research with more accurate weight and height data is warranted to confirm our findings.

CONCLUSION

This study provided empirical evidence for longitudinal associations between neighborhood intersection density and child obesity prevalence based on national data. The present study has important public health implications in that it demonstrated the importance of improving

community built environments for childhood obesity prevention, and offered a new perspective of the role that road system plays in childhood obesity prevention.

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Abbreviations:

NSCH	National Survey of Children's Health
TIGER	Topologically Integrated Geographic Encoding and Referencing
ACS	American Community Survey
GIS	Geographic Information System
CDC	Centers for Disease Control
BMI	Body Mass Index
MTFCC	MAF/TIGER Feature Class Code

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Highlights

- Road network intersection density is an important indicator of walkability;
- Population-weighted intersection density was associated with childhood obesity;
- Road network plays an important role in obesity prevention.

Figure 1. Prevalence of overweight and obesity combined (a) and obesity only (b) for the U.S. children aged 10–17 years by quartile group of population-weighted intersection density across the U.S. in 2007 and 2011

Figure 2.

Clusters of the population-weighted walkability in 2011 (a) and clusters of childhood obesity in 2011 (b)

Note: A hot/cold spot is a cluster of a state and its neighbors with significantly higher/lower value of interest (e.g. prevalence of obesity, population-weighted walkability) compared to other states not due to random chance. The grey areas and areas in hatch lines represent the highest and the lowest significant clusters, respectively, while the blank areas does not include any significant clusters. A higher degree of darkness or density of hatch lines of the clustering area indicates a higher significance level of the hot/cold spots.

Table 1.

Temporal trends of population-weighted intersection density between 2007 and 2011 by U.S. Census Division.

Census Divisions ^a	Population-intersection density 2007 (intersections/km ²)	Population-weighted intersection density 2011 (intersections/km ²)	Walkability change ^b (intersections/km ²)
<i>East North Central</i>	24.3	26.5	2.2
<i>East South Central</i>	12.9	14.0	1.1
<i>Middle Atlantic</i>	52.7	53.4	0.7
<i>Mountain</i>	29.2	33.2	4.0
<i>New England</i>	31.5	32.4	0.9
<i>Pacific</i>	40.6	45.6	5.0
<i>South Atlantic</i>	22.6	23.5	0.9
<i>West North Central</i>	21.3	23.3	2.0
<i>West South Central</i>	24.2	24.3	0.1

^aNew England Division: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island and Vermont;

Middle Atlantic Division: New Jersey, New York and Pennsylvania;

East North Central Division: Illinois, Indiana, Michigan, Ohio and Wisconsin;

West North Central Division: Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota and South Dakota;

South Atlantic Division: Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia and West Virginia;

East South Central Division: Alabama, Kentucky, Mississippi and Tennessee;

West South Central Division: Arkansas, Louisiana, Oklahoma and Texas;

Mountain Division: Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah and Wyoming;

Pacific Division: Alaska, California, Hawaii, Oregon and Washington.

^b: Δ represents the difference between population-weighted walkability in 2011 and 2007.

Table 2.

Mixed effect model estimate of the impact of population-weighted intersection density on the prevalence of childhood obesity in the US 2007–2011^a

Variables	β [95% CI]
Population-weighted intersection density (<i>intersections/km²</i>)	−0.05 [−0.11, −0.00] **
Median income (<i>dollar</i>)	−0.0001 [−.0003, 0.00004]
Poverty rate (%)	0.04 [−0.37, 0.46]
Population density 2010 (<i>population/km²</i>)	0.001 [−0.0002, 0.0027] *
Racial/ethnic composition (Shannon entropy)	1.67 [0.93, 2.42] ***
Percentage of urban area (%)	0.03 [−0.04, 0.09]
Percentage of urban population (%)	−0.05 [−0.12, 0.01] *
Constant	19.08 [7.07, 32.04] ***

*
 $p < 0.1$

**
 $p < 0.05$

 $p < 0.01$