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ORIGINAL RESEARCH

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Improvement in food environments may help prevent childhood obesity: Evidence from a 9-year cohort study

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Summary

Background: Effects of food environments (FEs) on childhood obesity are mixed.

Objectives: To examine the association of residential FEs with childhood obesity and variation of the association across gender and urbanicity.

Methods: We used the US Early Childhood Longitudinal Study—Kindergarten Cohort data, with 9440 kindergarteners followed up from 1998 to 2007. The Dun and Bradstreet commercial datasets in 1998 and 2007 were used to construct 12 FE measures of children, ie, changes in the food outlet mix and density of supermarkets, convenience stores, full-service restaurants, fast-food restaurants, retail bakery, dairy-product stores, health/dietetic food stores, confectionery stores, fruit/vegetable markets, meat/fish markets, and beverage stores. Two-level mixed-effect and cluster robust logistic regression models were fitted to examine associations.

Results: Decreased exposures to full-service restaurants, retail bakeries, fruit/vegetable markets, and beverage stores were generally obesogenic, while decreased exposure to dairy-product stores was generally obesoprotective; the magnitude and statistical significance of these associations varied by gender and urbanicity of residence. Higher obesity risk was associated with increased exposure to full-service restaurants among girls, and with decreased exposures to fruit/vegetable markets in urban children, to beverage stores in suburban children, and to health/dietetic food stores in rural children. Mixed findings existed between genders on the associations of fruit/vegetable markets with child weight status.

Conclusion: In the United States, exposure to different FEs seemed to lead to different childhood obesity risks during 1998 to 2007; the association varied across gender and urbanicity. This study has important implications for future urban design and community-based interventions in fighting the obesity epidemic.

KEYWORDS

adolescents, body mass index, children, food environment, obesity, overweight

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1 | INTRODUCTION

Food environment (FE) is defined as "the availability, affordability, convenience, and desirability of various foods" surrounding individuals.[1] There is growing attention to the influences of FEs on globally increasing childhood obesity,[2-4] as the FE, particularly in residential neighborhoods, has been recognized to play a vital role in shaping individual purchasing and eating behaviors.[1] For example, many cross-sectional studies have shown that higher neighborhood access to grocery stores,[5,6] supermarkets,[7-9] and full-service restaurants[9,10] is associated with higher consumption of healthy food, lower body mass index (BMI), and less severe obesity outcomes in youth; children living in neighborhoods with a higher density of or proximity to fast-food restaurants[10,11] and convenience stores[12,13] tend to have less healthy eating behaviors and a higher BMI and weight status.

Mixed findings on the relationships between residential neighborhood FE and weight status have been reported from previous cross-sectional studies.[2,14] For example, the association between access to full-service restaurants in the neighborhood and weight status was found to be negative in some studies,[15] but not significant in other studies.[12,16] Studies regarding the associations between weight status and access to convenience stores and fast-food outlets have also reported negative[9,11,17] and not significant findings.[18-20] Hence, it is imperative to conduct a large-scale study to deepen our understanding of the roles of different food venues in the obesity epidemic. There has been limited evidence from longitudinal studies.[21-23] Two existing nationally longitudinal studies using the food outlet data extracted from InfoUSA both examined the relationships between FEs and adolescents' BMI and weight status during the fifth to eighth grades.[2,3] However, relying exclusively on one source of secondary data to characterize the FE may result in substantial error,[24] and national-scale studies using other FE data sources are needed to provide more robust evidence.[22] Moreover, previous studies have suggested that gender-specific and urbanicity-specific differences may exist in the relationships between neighborhood FE and child obesity risk,[25-28] and these differences have not been examined in a longitudinal context. In addition, most of previous studies focus on common food venues (eg, grocery store and full-service and fast-food restaurants).[14,29] It has been suggested that simultaneously accounting for multiple types of healthy and unhealthy food outlets could yield more precise estimates of health effects than when considering only a small number of FE dimensions.[30-33] Some types of food outlet are sparsely distributed in the United States, such as retail bakery and beverage store. The associations between those food outlets and child obesity have been little examined in local studies due to insufficient study samples and/or variability in exposure to the FE. All these limitations warrant further research and investigation.

Considering that it may take long to observe significant changes in neighborhood FEs, and perhaps even longer to cause behavioral changes and subsequently children's weight status, this study aimed to examine longitudinal associations between residential FEs and children's weight status over 9 years, as well as variations in these associations across gender and urbanicity. The findings of this study have important implications for future urban design and community-based interventions in fighting the obesity epidemic.

2 | METHODS

2.1 | Study design and subjects

This cohort study used the US nationally representative data in the Early Childhood Longitudinal Study—Kindergarten (ECLS-K) Cohort, collected from 22 000 kindergarteners aged 4 to 7 in 1998 to 1999 and with 9440 successfully followed up until their eighth grade (2007).[34] Data collected in 1998 to 1999 (baseline data, called "the 1998 wave" in this paper) and 2007 were analyzed, considering that it may take long to observe significant changes in FEs and perhaps even longer to cause behavioral changes and subsequently children's weight status. The study included the children who lived in the contiguous United States and had complete basic sociodemographic information, residential location (ZIP code), and a measured BMI in 1998 and 2007. Our final analytical samples included 6100 children.

2.2 | Key study variables

2.2.1 | Outcome variables

The *BMI* (in kg/m^2) for each child was calculated by body weight and height, which were measured twice and averaged if they differed <5.08 cm and <2.3 kg, respectively.[35] *Obesity* was defined as sex-age-specific BMI ≥95th percentile of the 2000 CDC Growth Chart, while *overweight* as ≥85th percentile.[36]

2.2.2 | Exposure variables

The Dun and Bradstreet (D&B) commercial datasets in 1998 and 2007, along with the year 2000 US ZIP code boundaries, were used to characterize FEs surrounding the children in 1998 and 2007. According to the hierarchical Standard Industrial Classification (SIC) codes (Table S1), 11 categories of food outlets were extracted from D&B datasets and geocoded in the contiguous US ZIP code boundaries: supermarket, convenience store, full-service restaurant, fast-food restaurant/stand, retail bakery, dairy-product store, health/dietetic food store, candy/nut/confectionery store, fruit/vegetable market, meat/fish market, and beverage store. The *density of each category of food outlets* (per km^2) in 1998 and 2007 was separately calculated within children's residential ZIP codes, at which FEs have been associated with child obesity[3,14,37] and also the residential location of ECLS-K children was recorded. The *changes in each category of food outlets* during 1998 to 2007 were calculated by subtracting the density in 1998 from the density in 2007 in each ZIP code, with each sample labeled as one of the three categories for each variable: *increased* (positive change), *constant* (no change), and *decreased* (negative change).

Considering the degree of overall healthiness of the food mainly provided in each type of food outlets, we hypothesized that decreased exposure to supermarket, full-service restaurant, health/dietetic food store, fruit/vegetable market, and beverage store was associated with higher weight status, while decreased exposure to convenience store, fast-food restaurant, retail bakery, dairy-product store, candy store, and meat/fish market was associated with lower weight status.[38-40]

A widely accepted hypothesis that healthier weight status often relates to a greater land use mix[41] was adapted to this study to examine the association between the *food outlet mix* (ie, the heterogeneity of the FE) and weight status. An *entropy score*[41] was used to describe the food outlet mix within a given ZIP code and defined as $-\sum_{i=}\mathbf{1}^{\boldsymbol{n}}(\boldsymbol{p_i}*\ln(\boldsymbol{p_i}))/\boldsymbol{ln(n)}$, where p_i is the proportion of the *i*th category of food outlet within the ZIP code, and n = 11 in this study. It equals to 0 when only one type of food outlet is present, and equals to 1 when all types of food outlet are equally mixed. We hypothesized that the increased food outlet mix was associated with lower weight status.

2.2.3 | Covariates

Child-level covariates included age, gender, race/ethnicity (White, Black, Hispanic, Asian, and others), parental education, and socioeconomic status (SES). Parental education was determined based on the parent who had the higher education level, recoded as four categories: high school and below, vocational/tech/college, bachelor's degree, and graduate degree. Children's SES was defined as four categories, based on parental report on their household annual income: ≤$30 000, $30 000 to 50 000, $50 000 to 75 000, and >$75 000.

Neighborhood-level covariates included SES and urbanicity of residence. The median household income of children's census tracts of residence was used to indicate their neighborhood SES and categorized in the same way as children's SES. Seven categories representing the urbanicity were grouped into urban (large and mid-size city), suburban (large and mid-size suburb), and rural regions (large and small town, and rural).

2.3 | Statistical analysis

χ^2 tests (for categorical variables) and *t*-tests (for continuous variables) were conducted to identify significant disparities in children's sociodemographic and FE characteristics between genders. McNemar's tests (for categorical variables) and paired *t*-tests (for continuous variables) were used to examine the significance of temporal changes in children's weight status and FEs during 1998 to 2007.

Given the nested data structure (ie, children within ZIP codes), two-level mixed-effect and cluster robust logistic regression models were performed to estimate associations of the changes in residential FEs during 1998 to 2007 with children's BMI and weight status (ie, overweight/obesity and obesity only) in 2007, respectively. All models adjusted for children's baseline age, gender, race/ethnicity, parental education, BMI, exposures to FEs, and urbanicity, as well as for time-varying (ie, two waves) SES at individual and neighborhood levels. For more meaningful analyses and interpretation of model coefficients, children's baseline exposures to FEs were converted into categorical variables where samples were ranked based on each FE variable and classified into quartiles.[3] If the percentage of the children living in the ZIP codes without that type of food outlet was >25% but ≤50%, then all samples in those ZIP codes were assigned as one category (density = 0), with the remaining samples ranked and evenly divided into two categories. If that percentage was >50%, then all samples were divided into *absence* (density = 0) and *presence* groups (density > 0). We also fitted separate models to examine potential effect modification by gender and urbanicity. In addition, sensitivity analyses were conducted based on a subset of children who had not changed their residential neighborhoods during 1998 to 2007 (Tables S2-S4).

All spatial operations and analyses were conducted in ArcGIS (Version 10.4.1, Esri, Redlands, CA). All statistical analyses were performed in 2017 using Stata 14 (College Station, TX) with the stratification of the survey design and the study's sampling weights taken into account.

3 | RESULTS

3.1 | Sample characteristics

The mean age of these children was 6.2 years at baseline in 1998, with boys slightly older than girls on average ($P < 0.001$) (Table 1). The baseline weight status was similar between genders, with a mean BMI of 16.4 kg/m^2 and the prevalence of overweight/obesity and obesity being 27.2% and 11.9%, respectively. The significant increases that occurred during 1998 to 2007 in mean BMI (from 16.4 to 22.9, $P < 0.001$) and prevalence of overweight/obesity (from 27.2% to 35.6%, $P < 0.001$) and obesity (from 11.9% to 19.7%, $P < 0.001$) also occurred in boys and girls separately. In 2007, although girls had a higher BMI than boys (23.2 vs 22.6, $P = 0.020$), boys had higher prevalence of obesity than girls (21.6% vs 17.7%, $P = 0.029$).

During 1998 to 2007, children's exposure levels to all types of food outlet had increased ($P < 0.01$), also with an increased degree of mixture of food outlets within their ZIP codes (Table 2). No gender differences were found for any type of food outlet in both 1998 and 2007.

3.2 | Associations of FEs and child BMI

The children who lived in neighborhoods with the presence of candy stores ($\beta = 0.52$, $P < 0.05$) and meat/fish markets ($\beta = 0.58$, $P < 0.01$) in 1998 showed a higher BMI in 2007, compared with their counterparts who lived in neighborhoods without those food outlets in 1998 (Table 3). A higher BMI in 2007 was observed among children who have been exposed to decreased full-service restaurants ($\beta = 0.68$, $P < 0.05$) and constant retail bakeries ($\beta = 0.43$, $P < 0.05$) during 1998 to 2007, compared with their counterparts who experienced an increase of those types of food outlet in their neighborhoods over

TABLE 1 Sociodemographic characteristics and weight status of the US children at baseline (1998, kindergarten) and fifth wave (2007, at eighth grade) of ECLS-K[a]

Variables	% or Mean ± SD All (n = 6100)	Boy (n = 3030)	Girl (n = 3070)	*P*-Value[b]
1998 (baseline)				
Age (years)	6.2 ± 0.4	6.3 ± 0.4	6.2 ± 0.3	**<0.001**
Race/ethnicity				0.464
White	60.0	60.8	59.1	
Black	15.6	15.8	15.5	
Hispanic	18.5	18.3	18.7	
Asian	2.6	2.1	3.2	
Others	3.3	3.0	3.5	
Parental education				0.196
≤High school	33.2	35.2	31.3	
Vocational/college	31.1	30.1	32.1	
Bachelor	20.3	20.4	20.2	
≥Graduate	15.4	14.3	16.5	
Urbanicity				0.650
Urban	35.1	35.2	35.0	
Suburban	39.4	38.5	40.2	
Rural	25.5	26.3	24.8	
Household annual income ($)				0.651
≤30 000	34.0	34.9	33.1	
>30 000 but ≤50 000	22.5	22.4	22.5	
>50 000 but ≤75 000	19.5	18.5	20.5	
>75 000	24.0	24.2	23.9	
Weight status[c]				
BMI (kg/m^2)	16.4 ± 2.4	16.4 ± 2.2	16.4 ± 2.5	0.955
Overweight and obesity	27.2	26.7	27.6	0.650
Obesity	11.9	11.9	11.9	0.965
Median household income within neighborhood ($)				0.674
≤30 000	20.3	21.1	19.6	
>30 000 but ≤50 000	23.1	22.3	24.0	
>50 000 but ≤75 000	26.0	26.6	25.3	
>75 000	30.6	30.0	31.1	
2007 (fifth wave)				
Household annual income ($)				0.882
≤30 000	25.1	25.3	24.9	
>30 000 but ≤50 000	22.3	21.9	22.6	
>50 000 but ≤75 000	18.0	17.6	18.5	
>75 000	34.6	35.2	34.0	
Weight status[c]				
BMI (kg/m^2)	22.9 ± 5.9	22.6 ± 5.3	23.2 ± 6.1	**0.020**
Overweight and obesity	35.6	35.7	35.5	0.961
Obesity	19.7	21.6	17.7	**0.029**

(Continues)

TABLE 1 (Continued)

Variables	% or Mean ± SD All (n = 6100)	Boy (n = 3030)	Girl (n = 3070)	*P*-Value[b]
Median household income within neighborhood ($)				0.370
≤30 000	18.3	19.3	17.3	
>30 000 but ≤50 000	19.1	17.4	20.7	
>50 000 but ≤75 000	27.9	27.9	28.0	
>75 000	34.7	35.4	34.0	

[a]Sampling weights were used in the analyses.

[b]*P*-values tested the differences in each variable between genders and were based on χ^2 tests for categorical variables or *t*-tests for continuous variables. Boldfaced numbers indicate *P*-values < 0.05.

[c]Children were classified as overweight and obesity if their sex-age-specific body mass index (BMI) ≥ 85^{th} and 95^{th} percentiles of the 2000 CDC Growth Chart, respectively.

the 9-year period. These effects were stronger among girls (*β* = 1.60, *P* < 0.01 for decreased full-service restaurants; *β* = 0.91, *P* < 0.01 for constant retail bakeries) and suburban children (*β* = 2.96, *P* < 0.001 for decreased full-service restaurants; *β* = 0.97, *P* < 0.05 for constant retail bakeries). The children exposed to decreased beverage stores showed a higher BMI (*β* = 0.86, *P* < 0.05), especially boys (*β* = 1.61, *P* < 0.01) and suburban children (*β* = 2.68, *P* < 0.01). A higher BMI was also associated with decreased health/dietetic food stores in girls (*β* = 0.87, *P* < 0.05) and decreased fruit/vegetable markets in boys (*β* = 1.22, *P* < 0.01), although girls exposed to decreased fruit/vegetable markets showed a lower BMI (*β* = −1.23, *P* < 0.05). The children exposed to constant fruit/vegetable markets also showed a higher BMI (*β* = 0.49, *P* < 0.05), especially boys (*β* = 0.57, *P* < 0.05) and urban (*β* = 0.55, *P* < 0.05) and suburban children (*β* = 1.27, *P* < 0.05), compared with those exposed to increased fruit/vegetable markets. In addition, according to sensitivity analyses on the basis of children who had not changed residence over 9 years, girls exposed to constant supermarkets showed a higher BMI (*β* = 0.79, *P* < 0.05) compared with their counterparts who had experienced an increase of supermarkets in their neighborhoods (Table S2).

The exposure to decreased dairy-product stores was associated with a lower BMI (*β* = −0.70, *P* < 0.05), especially in girls (*β* = −0.99, *P* < 0.05) and suburban children (*β* = −1.19, *P* < 0.05). A decrease of meat/fish markets was also associated with a lower BMI among suburban children (*β* = −1.39, *P* < 0.01). Sensitivity analyses found that rural children exposed to constant candy stores showed a lower BMI (*β* = −1.19, *P* < 0.05) compared with their counterparts experiencing an increase of candy stores in their neighborhoods.

3.3 | Associations of FEs and child weight status

Despite an increased (decreased) overweight/obesity risk associated with more exposure to some categories of food outlet (Table 4), no increased (decreased) obesity risk was observed (Table 5). For example, the increased overweight/obesity risk was associated with decreased exposures to convenience stores during 1998 to 2007 among rural children (OR = 2.01 [95%CI = 1.20-3.35]) (Table 4), and constant exposures to dairy-product stores (OR = 1.56 [95%CI = 1.17-2.10]) and retail bakeries (OR = 1.38 [95%CI = 1.06–1.80]) among girls, compared with those experiencing an increase of those types of food outlet in their neighborhoods. The children experiencing constant fruit/vegetable markets showed increased overweight/obesity risk (OR = 1.31 [95%CI = 1.09-1.57]), especially boys (OR = 1.37 [95%CI = 1.07-1.76]) and urban (OR = 1.47 [95%CI = 1.11-1.97]) and suburban children (OR = 2.60 [95%CI = 1.35-5.00]), which was consistent with associations with BMI (Table 3). However, the association between constant fruit/vegetable markets and increased obesity risk was only observed among rural children (OR = 2.97 [95%CI = 1.19-7.42]) in sensitivity analyses (Table S4). Also, the decreased overweight/obesity risk was found among boys exposed to constant meat/fish markets (OR = 0.77 [95%CI = 0.59-0.99]) and rural children exposed to decreased candy stores (OR = 0.44 [95%CI = 0.24-0.81]). Both associations, however, were not observed for obesity risk (Table 5).

The decreased exposure to beverage stores among suburban children was associated with not only higher overweight/obesity risk (OR = 2.27 [95%CI = 1.11-4.66]) (Table 4) but also higher obesity risk (OR = 2.50 [95%CI = 1.11-5.65]) (Table 5). Girls exposed to constant full-service restaurants showed both lower overweight/obesity risk (OR = 0.51 [95%CI = 0.29-0.91]) and obesity risk (OR = 0.35 [95%CI = 0.16-0.74]), compared with girls who had been exposed to increased full-service restaurants. The higher obesity risk was also observed in rural children exposed to decreased health/dietetic food stores (OR = 4.89 [95%CI = 1.35-17.77]) and in urban children exposed to decreased fruit/vegetable markets (OR = 1.95 [95%CI = 1.11-3.45]). The food outlet mix was associated with neither overweight/obesity nor obesity risk.

4 | DISCUSSION

This is a large-scale longitudinal study using nationally representative data in the United States to investigate the relationships between

TABLE 2 Residential food environments surrounding the US children at baseline (1998, kindergarten) and fifth waves (2007, at eighth grade) of ECLS-K and their changes during 1998 to 2007[a]

Food Environments	% of Children or Mean ± SD			
	All (n = 6100)	Boy (n = 3030)	Girl (n = 3070)	*P*-Value[b]
Food outlet density (/km^2)				
Supermarket				
1998	0.52 ± 2.16	0.51 ± 2.07	0.52 ± 2.14	0.883
2007	0.91 ± 4.12	0.91 ± 4.18	0.90 ± 3.83	0.967
1998-2007				0.255
Decreased	15.4	14.1	16.7	
Constant	11.1	11.6	10.5	
Increased	73.5	74.3	72.8	
Convenience store				
1998	0.13 ± 0.20	0.13 ± 0.18	0.13 ± 0.21	0.626
2007	0.21 ± 0.43	0.21 ± 0.42	0.21 ± 0.42	0.832
1998-2007				0.672
Decreased	17.6	17.1	18.1	
Constant	19.5	20.2	18.9	
Increased	62.9	62.7	63.0	
Full-service restaurant				
1998	1.29 ± 7.17	1.25 ± 6.43	1.34 ± 7.52	0.637
2007	2.00 ± 6.99	1.96 ± 5.72	2.05 ± 7.79	0.684
1998-2007				0.411
Decreased	6.0	6.5	5.4	
Constant	4.1	3.8	4.4	
Increased	89.9	89.7	90.2	
Fast-food restaurant				
1998	0.23 ± 0.48	0.22 ± 0.46	0.24 ± 0.47	0.479
2007	0.48 ± 1.10	0.48 ± 1.03	0.49 ± 1.10	0.674
1998-2007				0.276
Decreased	3.7	3.5	3.9	
Constant	10.2	9.2	11.2	
Increased	86.1	87.3	84.9	
Retail bakery				
1998	0.15 ± 0.56	0.14 ± 0.49	0.15 ± 0.59	0.603
2007	0.23 ± 0.73	0.22 ± 0.57	0.24 ± 0.84	0.363
1998-2007				0.998
Decreased	16.1	16.2	16.1	
Constant	28.0	27.9	28.0	
Increased	55.9	55.9	55.9	
Dairy product store				
1998	0.05 ± 0.18	0.04 ± 0.17	0.05 ± 0.19	0.380
2007	0.09 ± 0.22	0.09 ± 0.18	0.10 ± 0.24	0.237
1998-2007				0.382
Decreased	6.4	6.2	6.5	
Constant	29.5	28.3	30.8	

(Continues)

TABLE 2 (Continued)

Food Environments	% of Children or Mean ± SD All (n = 6100)	Boy (n = 3030)	Girl (n = 3070)	*P*-Value[b]
Increased	64.1	65.5	62.7	
Health food store				
1998	0.07 ± 0.27	0.07 ± 0.23	0.07 ± 0.30	0.466
2007	0.12 ± 0.42	0.11 ± 0.33	0.12 ± 0.48	0.755
1998-2007				0.137
Decreased	13.3	12.1	14.5	
Constant	33.9	33.2	34.6	
Increased	52.8	54.7	50.9	
Candy store				
1998	0.04 ± 0.35	0.04 ± 0.28	0.04 ± 0.40	0.479
2007	0.04 ± 0.28	0.04 ± 0.15	0.05 ± 0.35	**0.033**
1998-2007				0.303
Decreased	13.9	15.1	12.7	
Constant	51.3	50.8	51.9	
Increased	34.8	34.1	35.4	
Fruit/vegetable market				
1998	0.03 ± 0.23	0.03 ± 0.17	0.03 ± 0.26	0.627
2007	0.05 ± 0.26	0.05 ± 0.21	0.05 ± 0.29	0.870
1998-2007				0.868
Decreased	7.2	7.5	6.9	
Constant	62.5	62.2	62.7	
Increased	30.3	30.3	30.4	
Meat/fish market				
1998	0.07 ± 0.37	0.07 ± 0.31	0.07 ± 0.41	0.649
2007	0.09 ± 0.45	0.09 ± 0.39	0.10 ± 0.48	0.682
1998-2007				0.721
Decreased	12.7	12.4	13.0	
Constant	51.3	50.7	51.9	
Increased	36.0	36.9	35.1	
Beverage store				
1998	0.04 ± 0.34	0.04 ± 0.33	0.04 ± 0.34	0.875
2007	0.11 ± 0.42	0.11 ± 0.34	0.12 ± 0.47	0.903
1998-2007				0.870
Decreased	5.2	4.9	5.4	
Constant	31.9	32.1	31.7	
Increased	62.9	63.0	62.9	
Food outlet mix (ranging from 0 to 1)				
Entropy score				
1998	0.59 ± 0.14	0.59 ± 0.13	0.59 ± 0.14	0.852
2007	0.64 ± 0.11	0.65 ± 0.11	0.64 ± 0.11	0.603
1998-2007				0.687

(Continues)

TABLE 2 (Continued)

Food Environments	% of Children or Mean ± SD All (n = 6100)	Boy (n = 3030)	Girl (n = 3070)	*P*-Value[b]
Decreased	26.7	26.0	27.3	
Constant	1.4	1.5	1.3	
Increased	71.9	72.5	71.4	

[a]Sampling weights were used in the analyses.

[b]*P*-values tested the differences in each variable between genders and were based on χ^2 tests for categorical variables or *t*-tests for continuous variables. Boldfaced numbers indicate *P*-values < 0.05.

the changes in residential neighborhood FEs over 9 years and childhood obesity after considering multilevel covariates. We found that (a) decreased exposures to full-service restaurants, retail bakeries, fruit/vegetable markets, and beverage stores were generally obesogenic, while decreased exposure to dairy-product stores was generally obesoprotective; (b) the magnitude and statistical significance of these associations varied by gender and urbanicity of residence; (c) higher obesity risk was associated with increased exposure to full-service restaurants among girls, and with decreased exposures to fruit/vegetable markets in urban children, to beverage stores in suburban children, and to health/dietetic food stores in rural children; and (d) mixed findings existed—for example, decreased exposure to fruit/vegetable markets was associated with higher BMI in boys but lower BMI in girls.

Given the previous mixed findings at different local scales[14] and the increasing trend of nearly all types of food venue over the 9-year period across the country, understanding their association with population weight status, although possibly confounded to some extent, is important for urban and land-use planning in the future. In addition to adding new knowledge to this field, given that many food items are provided in more than one type of food outlet, to include those sparsely distributed food outlets (ie, controlling for these variables) may in turn produce more reliable evidence on the associations between common food outlets and obesity risk.

Although half of our hypotheses were supported by our findings, ie, the effects on children's weight status of supermarket, health/dietetic food store, candy store, fruit/vegetable market, meat/fish market, and beverage store, we need more local studies with the involvement of field validation and the consideration of actual food acquisition and consumption, to elucidate the relationships between some types of food venues and child obesity with unknown pathways. Most types of food venue provide a variety of foods, both healthy and unhealthy. Candy, for example, provided in supermarkets (normally considered as a healthy venue), would be classified as unhealthy when housed in a separate venue. Likewise, the venues classified as convenience stores may also provide healthy options, and the food variety in convenience stores is more varying across regions than in supermarkets (usually chain stores). These reasons might help to explain why we found no significant associations of the exposure to supermarkets with child overweight/obesity risk. Also, boys with less exposure to beverage stores and girls with more exposure to retail bakeries and dairy-product stores showed a higher weight status, which could be explained by either different social and eating behaviors or actual access to those food venues. However, more ancillary data are needed to substantiate these links. Thus, these results should be interpreted with caution.

Fruit/vegetable markets are usually available in a more mobile form, which may take place only during certain times of a day on certain days of a week (eg, a farmer's market). Previous studies have reported failure of on-site validation for this category.[42] Due to our national study design, we were only able to conduct a visual validation in Google Maps for a limited sample of records, during which we failed to find fruit/vegetable stands either. An additional critique is that availability is not equal to consumption. These reasons may underlie the seemingly counterintuitive association between decreased exposure to fruit/vegetable markets and higher BMI in girls (no obesity risk observed though). Also, the protective effects of the presence of fruit/vegetable markets in 1998 on overweight/obesity of rural children may imply the detriments of food deserts and the importance of balancing different food venues.

This study has some limitations that highlight profitable directions for future research. First, the classification of food venues needs to be improved. Due to the limited number of children relative to a wide range of food outlets of interest, we did not differentiate many detailed categories of food outlets represented by six-digit or eight-digit SIC codes (a deeper level in the hierarchy than six-digit codes). This prevented us from discriminating effects of distinct types of food outlet falling under one main category, such as seafood and pizza restaurants. However, simply using six-digit or eight-digit SIC codes cannot easily solve this problem, because (a) a six-digit category still includes both healthy and unhealthy venues; (b) the roles of many eight-digit categories in the obesity epidemic remain unclear; and (c) a venue in an eight-digit category may still provide both healthy and unhealthy food, which makes it a contradictory locale. To construct latent diet factors on the basis of intake categories of foods typically offered at each type of FE is a future direction.[43] Furthermore, food offerings in the same type of food outlets may greatly vary by region, except for the case of national chain stores. More work is needed in the future to untangle these complexities, eg, the inclusion of household surveys and individual purchasing and consumption data.[44]

TABLE 3 Associations (coefficient and standard error) of residential food environments in 1998 (at baseline) and their changes during 1998 to 2007 with child body mass index (BMI) in 2007[a]

Food Environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
Supermarket density												
1998 (/km^2)												
<0.02 (ref)												
0.02-0.08	0.38	(0.30)	0.38	(0.42)	0.52	(0.42)	−0.81	(0.65)	−0.08	(0.71)	0.58	(0.42)
0.08-0.34	0.73	(0.40)	0.34	(0.55)	1.13*	(0.57)	−0.44	(0.77)	0.59	(0.81)	−1.55	(1.13)
>0.34	0.64	(0.48)	0.08	(0.66)	1.28	(0.69)	−0.29	(0.87)	0.74	(0.91)	–	–
1998-2007												
Increased (ref)												
Constant	0.40	(0.28)	−0.15	(0.39)	0.77	(0.40)	−0.57	(0.48)	1.06	(0.62)	0.09	(0.46)
Decreased	−0.24	(0.25)	−0.46	(0.33)	−0.07	(0.35)	−0.30	(0.42)	−0.27	(0.52)	−0.86	(0.47)
Convenience store density												
1998 (/km^2)												
<0.01 (ref)												
0.01-0.04	−0.10	(0.27)	0.37	(0.37)	−0.58	(0.38)	0.51	(0.53)	0.29	(0.55)	−1.09**	(0.41)
0.04-0.15	0.05	(0.30)	0.39	(0.41)	−0.23	(0.42)	−0.59	(0.49)	0.96	(0.54)	2.13	(1.25)
>0.15	0.11	(0.37)	0.26	(0.51)	−0.00	(0.53)	−0.01	(0.55)	0.68	(0.67)	–	–
1998-2007												
Increased (ref)												
Constant	0.17	(0.22)	0.27	(0.30)	−0.00	(0.32)	0.14	(0.35)	0.14	(0.42)	0.53	(0.46)
Decreased	0.40	(0.24)	0.21	(0.32)	0.61	(0.34)	0.32	(0.37)	0.53	(0.46)	0.33	(0.48)
Full-service restaurant density												
1998 (/km^2)												
<0.06 (ref)												
0.06-0.27	−0.45	(0.38)	−0.38	(0.51)	−0.47	(0.53)	0.17	(0.80)	0.22	(0.83)	−0.50	(0.59)
0.27-1.34	−1.75***	(0.52)	−1.15	(0.69)	−2.26**	(0.74)	0.20	(0.98)	−2.61**	(0.99)	–	–
>1.34	−2.02**	(0.65)	−1.48	(0.86)	−2.47**	(0.94)	−0.57	(1.12)	−2.91*	(1.19)	–	–
1998-2007												
Increased (ref)												
Constant	−0.02	(0.55)	1.24	(0.78)	−1.05	(0.76)	–	–	0.94	(1.06)	−0.27	(0.68)
Decreased	**0.68***	(0.35)	−0.16	(0.46)	**1.60****	(0.50)	−0.27	(0.60)	**2.96*****	(0.83)	0.96	(0.52)
Fast-food restaurant density												
1998 (/km^2)												
<0.01 (ref)												
0.01-0.07	−0.10	(0.34)	−0.28	(0.46)	0.13	(0.49)	0.05	(0.70)	−1.03	(0.63)	1.00	(0.57)
0.07-0.30	0.53	(0.40)	−0.02	(0.54)	0.91	(0.59)	0.47	(0.76)	0.04	(0.72)	–	–
>0.30	0.84	(0.47)	0.63	(0.63)	0.84	(0.69)	0.72	(0.81)	0.19	(0.83)	–	–
1998-2007												
Increased (ref)												
Constant	−0.20	(0.35)	0.09	(0.49)	−0.52	(0.48)	−0.20	(0.64)	−0.14	(0.76)	0.23	(0.48)
Decreased	−0.25	(0.43)	0.28	(0.60)	−0.84	(0.61)	0.09	(0.54)	−0.78	(0.96)	0.96	(1.12)
Retail bakery density												
1998 (/km^2)												
0 (ref)												

(Continues)

TABLE 3 (Continued)

Food Environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
>0-0.06	0.68[*]	(0.29)	0.51	(0.40)	0.81[*]	(0.41)	0.60	(0.51)	1.20[*]	(0.58)	0.02	(0.56)
>0.06	0.15	(0.37)	0.11	(0.51)	0.18	(0.53)	0.05	(0.54)	0.61	(0.69)	–	–
1998-2007												
Increased (ref)												
Constant	**0.43**[*]	(0.22)	0.03	(0.30)	**0.91**[**]	(0.31)	0.06	(0.34)	**0.97**[*]	(0.42)	−0.47	(0.45)
Decreased	−0.18	(0.25)	0.09	(0.33)	−0.44	(0.35)	−0.17	(0.33)	−0.10	(0.51)	0.36	(0.65)
Dairy product store density												
1998 (/km^2)												
0 (ref)												
>0-0.04	0.24	(0.24)	0.21	(0.33)	0.31	(0.35)	−0.28	(0.39)	0.62	(0.48)	0.55	(0.50)
>0.04	0.65[*]	(0.26)	0.78[*]	(0.35)	0.64	(0.37)	0.62	(0.34)	0.67	(0.49)	–	–
1998-2007												
Increased (ref)												
Constant	−0.04	(0.20)	−0.22	(0.28)	0.01	(0.29)	−0.04	(0.30)	0.28	(0.44)	−0.20	(0.44)
Decreased	**−0.70**[*]	(0.32)	−0.60	(0.43)	**−0.99**[*]	(0.46)	−0.69	(0.45)	**−1.19**[*]	(0.60)	0.62	(0.87)
Health food store density												
1998 (/km^2)												
0 (ref)												
>0-0.04	0.01	(0.26)	0.14	(0.35)	−0.18	(0.36)	0.19	(0.43)	0.36	(0.50)	−0.41	(0.48)
>0.04	−0.18	(0.29)	−0.41	(0.39)	0.09	(0.42)	−0.30	(0.39)	0.74	(0.57)	–	–
1998-2007												
Increased (ref)												
Constant	−0.07	(0.20)	−0.06	(0.27)	−0.02	(0.29)	−0.26	(0.31)	0.01	(0.39)	0.26	(0.46)
Decreased	0.39	(0.25)	0.02	(0.34)	**0.87**[*]	(0.36)	−0.43	(0.35)	0.99	(0.51)	1.35	(0.79)
Candy store density												
1998 (/km^2)												
0 (ref)												
>0	0.52[*]	(0.21)	0.08	(0.29)	0.86[**]	(0.30)	0.38	(0.30)	1.15[**]	(0.42)	−0.74	(0.68)
1998-2007												
Increased (ref)												
Constant	0.12	(0.19)	0.30	(0.26)	−0.07	(0.27)	0.19	(0.27)	0.39	(0.38)	−0.80	(0.49)
Decreased	−0.31	(0.29)	0.15	(0.40)	−0.72	(0.41)	−0.21	(0.41)	−0.20	(0.55)	0.36	(1.03)
Fruit/vegetable market density												
1998 (/km^2)												
0 (ref)												
>0	0.15	(0.20)	0.30	(0.28)	0.02	(0.29)	−0.35	(0.30)	0.69	(0.40)	−1.29[**]	(0.46)
1998-2007												
Increased (ref)												
Constant	**0.49**[**]	(0.19)	**0.57**[*]	(0.26)	0.34	(0.27)	**0.55**[*]	(0.27)	0.23	(0.37)	**1.27**[*]	(0.50)
Decreased	0.07	(0.36)	**1.22**[**]	(0.47)	**−1.23**[*]	(0.52)	0.20	(0.47)	0.12	(0.69)	0.78	(1.36)
Meat/fish market density												
1998 (/km^2)												
0 (ref)												
>0	0.58[**]	(0.21)	0.59[*]	(0.28)	0.53	(0.29)	0.18	(0.28)	1.24[**]	(0.42)	0.57	(0.57)

(Continues)

TABLE 3 (Continued)

Food Environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
1998-2007												
Increased (ref)												
Constant	0.13	(0.19)	0.14	(0.26)	0.21	(0.27)	−0.07	(0.27)	0.08	(0.39)	−0.53	(0.48)
Decreased	−0.27	(0.28)	0.17	(0.38)	−0.57	(0.40)	0.41	(0.40)	**−1.39****	(0.50)	−0.39	(1.16)
Beverage store density												
1998 (/km^2)												
0 (ref)												
>0	−0.06	(0.20)	0.21	(0.27)	−0.30	(0.27)	0.10	(0.27)	−0.61	(0.39)	−1.21	(0.70)
1998-2007												
Increased (ref)												
Constant	0.33	(0.21)	0.36	(0.28)	0.36	(0.29)	0.22	(0.31)	0.71	(0.43)	−0.00	(0.46)
Decreased	**0.86***	(0.42)	**1.61****	(0.59)	0.19	(0.57)	−0.01	(0.51)	**2.68****	(0.84)	−3.08	(1.76)
Entropy score												
1998 (/km^2)												
<0.63 (ref)												
0.63-0.68	−0.06	(0.29)	0.02	(0.40)	−0.12	(0.41)	0.55	(0.47)	−0.78	(0.58)	0.63	(0.60)
0.68-0.73	−0.01	(0.33)	−0.03	(0.46)	−0.08	(0.46)	0.36	(0.50)	0.20	(0.63)	0.24	(0.69)
>0.73	−0.10	(0.38)	0.30	(0.52)	−0.57	(0.54)	0.55	(0.57)	−0.92	(0.72)	0.87	(0.89)
1998-2007												
Increased (ref)												
Constant	0.04	(0.93)	–	–	–	–	–	–	–	–	0.94	(0.85)
Decreased	−0.15	(0.23)	−0.40	(0.32)	0.20	(0.33)	−0.11	(0.32)	−0.47	(0.44)	0.13	(0.60)

[a]All models were adjusted for age, sex, race/ethnicity, socioeconomic status, parental education, and urbanicity. Boldfaced numbers indicate statistical significance of the variables of interest ($^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$).

Second, although unrealistic at present, the accuracy of the D&B data needs more ground-verification work or remote assessment tools to validate it.[45-47] In addition to geographic locations, some entities might experience changes in primary markets or become closed during our 9-year study period. Hence, more of the nonspatial information in the D&B datasets, such as the number of employees and business startups and failures, should be better collected and considered to refine the measures of FE changes and construct more robust FE indicators.

Third, individual exposure needs to be measured at a refined level with consideration of food affordability and consumption.[48] For outdoor exposure, the "neighborhood" boundary or individual activity space needs to be delineated, thus enabling individual exposure to the surrounding FEs to be estimated more accurately.[49] Interaction with the surrounding FE is normally assumed to be static, which, however, is rarely true in reality.[26] For indoor exposure, many social factors may play critical roles in children's food and nutrition intakes, such as parenting and feeding styles and practices,[50] frequency of family dinners (ie, frequency of children eating dinner with family),[51] and home/family FEs.[52,53] Considering all these factors could help to shed light on the mechanisms of influence of FEs on obesity. Moreover, we did not consider FEs in neighboring ZIP codes, which may disproportionately affect the included children. For example, a child living near the boundary of a given ZIP code may be more affected by the neighboring ZIP code. The irregular size of ZIP codes and the presumably size variability between urban, suburban, and rural ZIP codes may also affect our results. We are also aware that children's realistic interactions with the organizational FE may also be affected by age and other factors (eg, availability of school buses), which should be included in future studies.

In conclusion, this study revealed the relationships between residential FEs and children's BMI and obesity risk over a 9-year follow-up period in a US nationally representative study. The findings are especially important for those relatively sparsely distributed food outlets. In addition to adding those new knowledge and producing more reliable evidence on the relationships between common food outlets and obesity risk, it also suggests the potential benefit of improving residential FEs for preventing childhood obesity. This study has important public health implications in terms of both neighborhood-level intervention design and urban planning in the future. Survey and consumer purchasing data could be integrated in future research to unravel the mechanisms of how neighborhood FEs affect individual and family behaviors.

TABLE 4 Associations (odds ratio and 95% confidence interval) of residential food environments in 1998 (at baseline) and their changes during 1998 to 2007 with childhood overweight and obesity (BMI ≥ 85th percentile) in 2007[a]

Food Environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
Supermarket density												
1998 (/km²)												
<0.02 (ref)												
0.02-0.08	1.20	[0.89,1.62]	1.44	[0.99,2.10]	1.01	[0.65,1.58]	0.82	[0.40,1.71]	0.91	[0.53,1.56]	1.76[*]	[1.09,2.84]
0.08-0.34	1.33	[0.93,1.90]	1.38	[0.82,2.34]	1.32	[0.80,2.19]	1.00	[0.46,2.21]	0.91	[0.53,1.56]	0.96	[0.22,4.29]
>0.34	1.29	[0.85,1.97]	1.13	[0.61,2.07]	1.55	[0.83,2.86]	1.00	[0.41,2.45]	1.11	[0.62,1.99]	–	–
1998-2007												
Increased (ref)												
Constant	1.06	[0.81,1.38]	0.98	[0.69,1.39]	1.13	[0.76,1.69]	1.01	[0.61,1.66]	1.32	[0.87,2.01]	0.88	[0.49,1.58]
Decreased	1.03	[0.81,1.32]	0.91	[0.65,1.29]	1.21	[0.86,1.69]	1.01	[0.63,1.63]	1.11	[0.71,1.73]	0.83	[0.48,1.44]
Convenience store density												
1998 (/km²)												
<0.01 (ref)												
0.01-0.04	0.87	[0.65,1.15]	1.04	[0.71,1.51]	0.71	[0.48,1.04]	1.04	[0.58,1.88]	1.19	[0.73,1.92]	0.50[*]	[0.28,0.89]
0.04-0.15	0.74[*]	[0.55,1.00]	0.87	[0.58,1.32]	0.61[*]	[0.40,0.94]	0.43[**]	[0.24,0.76]	1.11	[0.74,1.68]	1.42	[0.25,8.13]
>0.15	0.90	[0.64,1.28]	1.01	[0.62,1.63]	0.78	[0.47,1.29]	0.95	[0.51,1.79]	0.87	[0.54,1.42]	–	–
1998-2007												
Increased (ref)												
Constant	0.96	[0.77,1.20]	1.03	[0.76,1.41]	0.86	[0.63,1.16]	0.85	[0.59,1.23]	1.15	[0.83,1.61]	1.47	[0.82,2.63]
Decreased	1.00	[0.80,1.25]	0.86	[0.63,1.17]	1.20	[0.86,1.69]	0.80	[0.55,1.17]	1.15	[0.80,1.66]	**2.01**[**]	[1.20,3.35]
Full-service restaurant density												
1998 (/km²)												
<0.06 (ref)												
0.06-0.27	0.94	[0.63,1.39]	0.69	[0.43,1.12]	1.40	[0.81,2.41]	0.84	[0.35,2.01]	1.10	[0.56,2.18]	0.69	[0.29,1.62]
0.27-1.34	0.88	[0.52,1.48]	0.71	[0.37,1.40]	1.13	[0.54,2.35]	0.85	[0.29,2.49]	1.05	[0.50,2.20]	–	–
>1.34	0.96	[0.50,1.82]	0.67	[0.29,1.55]	1.43	[0.58,3.53]	0.78	[0.23,2.64]	1.16	[0.48,2.82]	–	–
1998-2007												
Increased (ref)												
Constant	0.85	[0.53,1.36]	1.43	[0.62,3.30]	**0.51**[*]	[0.29,0.91]	–	–	0.77	[0.38,1.54]	0.87	[0.32,2.35]
Decreased	1.14	[0.83,1.55]	1.18	[0.79,1.76]	1.09	[0.63,1.87]	1.00	[0.57,1.77]	0.97	[0.55,1.72]	1.57	[0.80,3.10]
Fast-food restaurant density												
1998 (/km²)												
<0.01 (ref)												
0.01-0.07	1.18	[0.84,1.66]	0.92	[0.60,1.43]	1.45	[0.89,2.35]	1.98	[0.82,4.79]	0.68	[0.41,1.12]	3.17[**]	[1.35,7.43]
0.07-0.30	1.23	[0.85,1.79]	1.00	[0.60,1.65]	1.47	[0.82,2.65]	2.63[*]	[1.11,6.19]	0.77	[0.44,1.32]	–	–
>0.30	1.29	[0.85,1.96]	1.31	[0.73,2.36]	1.29	[0.66,2.53]	2.41	[1.00,5.85]	0.87	[0.47,1.61]	–	–
1998-2007												
Increased (ref)												
Constant	1.11	[0.80,1.54]	1.17	[0.73,1.88]	1.04	[0.62,1.73]	1.23	[0.64,2.35]	0.95	[0.57,1.59]	1.51	[0.81,2.82]
Decreased	1.07	[0.75,1.53]	1.35	[0.76,2.39]	0.80	[0.45,1.41]	1.29	[0.76,2.19]	1.19	[0.61,2.33]	0.38	[0.07,2.10]
Retail bakery density												
1998 (/km²)												
0 (ref)												

(Continues)

TABLE 4 (Continued)

Food Environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
>0-0.06	1.03	[0.77,1.38]	1.11	[0.74,1.68]	0.95	[0.64,1.41]	1.09	[0.62,1.90]	1.13	[0.69,1.88]	0.75	[0.35,1.60]
>0.06	0.75	[0.52,1.10]	1.01	[0.60,1.71]	0.55*	[0.33,0.93]	0.62	[0.33,1.17]	0.92	[0.52,1.63]	–	–
1998-2007												
Increased (ref)												
Constant	1.24	[1.00,1.54]	1.04	[0.77,1.42]	**1.56****	[1.17,2.10]	1.02	[0.73,1.43]	1.32	[0.94,1.85]	1.34	[0.77,2.33]
Decreased	1.14	[0.89,1.44]	1.15	[0.84,1.57]	1.16	[0.81,1.66]	1.09	[0.73,1.62]	1.26	[0.83,1.93]	1.50	[0.71,3.20]
Dairy product store density												
1998 (/km^2)												
0 (ref)												
>0-0.04	1.12	[0.89,1.42]	0.95	[0.69,1.30]	1.38	[1.00,1.91]	0.82	[0.54,1.25]	1.47	[1.00,2.18]	1.20	[0.65,2.24]
>0.04	1.11	[0.87,1.42]	0.96	[0.67,1.37]	1.36	[0.94,1.97]	0.84	[0.59,1.21]	1.62*	[1.10,2.38]	–	–
1998-2007												
Increased (ref)												
Constant	1.13	[0.94,1.36]	0.90	[0.69,1.16]	**1.38***	[1.06,1.80]	1.21	[0.89,1.64]	1.28	[0.90,1.80]	1.19	[0.61,2.31]
Decreased	0.82	[0.60,1.12]	0.87	[0.57,1.33]	0.73	[0.45,1.20]	0.94	[0.55,1.63]	0.83	[0.53,1.29]	0.59	[0.20,1.75]
Health food store density												
1998 (/km^2)												
0 (ref)												
>0-0.04	0.86	[0.68,1.10]	1.07	[0.76,1.50]	0.70*	[0.50,0.98]	0.89	[0.56,1.41]	1.09	[0.71,1.65]	0.60	[0.31,1.18]
>0.04	0.96	[0.73,1.27]	0.97	[0.66,1.42]	0.96	[0.65,1.42]	0.92	[0.62,1.36]	1.40	[0.86,2.27]	–	–
1998-2007												
Increased (ref)												
Constant	0.95	[0.79,1.14]	0.84	[0.64,1.10]	1.11	[0.85,1.46]	0.88	[0.63,1.22]	0.91	[0.68,1.22]	1.60	[0.97,2.64]
Decreased	0.97	[0.75,1.25]	0.80	[0.57,1.12]	1.28	[0.87,1.86]	0.76	[0.51,1.14]	1.17	[0.77,1.78]	1.24	[0.43,3.54]
Candy store density												
1998 (/km^2)												
0 (ref)												
>0	1.10	[0.89,1.36]	1.03	[0.77,1.37]	1.13	[0.84,1.52]	1.22	[0.90,1.66]	1.02	[0.70,1.47]	1.08	[0.48,2.43]
1998-2007												
Increased (ref)												
Constant	0.93	[0.77,1.13]	1.08	[0.83,1.39]	0.78	[0.59,1.03]	0.96	[0.73,1.27]	0.96	[0.68,1.35]	**0.44****	[0.24,0.81]
Decreased	0.94	[0.71,1.23]	0.95	[0.64,1.41]	0.93	[0.63,1.36]	0.89	[0.59,1.37]	0.96	[0.62,1.48]	0.91	[0.27,3.04]
Fruit/vegetable market density												
1998 (/km^2)												
0 (ref)												
>0	1.01	[0.84,1.21]	1.27	[0.97,1.66]	0.79	[0.61,1.03]	0.85	[0.62,1.16]	1.34	[0.97,1.85]	0.85	[0.52,1.38]
1998-2007												
Increased (ref)												
Constant	**1.31****	[1.09,1.57]	**1.37***	[1.07,1.76]	1.22	[0.94,1.60]	**1.47****	[1.11,1.97]	1.08	[0.79,1.47]	**2.60****	[1.35,5.00]
Decreased	0.83	[0.60,1.14]	0.98	[0.65,1.48]	0.63	[0.39,1.01]	0.99	[0.63,1.55]	0.84	[0.50,1.41]	0.42	[0.11,1.62]
Meat/fish market density												
1998 (/km^2)												
0 (ref)												
>0	0.89	[0.74,1.07]	0.86	[0.66,1.13]	0.92	[0.69,1.21]	0.82	[0.61,1.10]	0.84	[0.60,1.16]	1.06	[0.60,1.89]

(Continues)

TABLE 4 (Continued)

Food Environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
1998-2007												
Increased (ref)												
Constant	0.84	[0.70,1.01]	**0.77***	[0.59,0.99]	0.93	[0.72,1.20]	0.82	[0.61,1.10]	0.78	[0.57,1.08]	0.83	[0.47,1.47]
Decreased	1.02	[0.78,1.32]	1.26	[0.88,1.81]	0.82	[0.53,1.27]	1.26	[0.79,2.01]	0.84	[0.57,1.25]	1.31	[0.26,6.58]
Beverage store density												
1998 (/km^2)												
0 (ref)												
>0	1.03	[0.86,1.25]	1.09	[0.84,1.42]	0.97	[0.75,1.26]	1.25	[0.93,1.67]	0.75	[0.54,1.05]	0.98	[0.49,1.95]
1998-2007												
Increased (ref)												
Constant	0.90	[0.74,1.09]	0.88	[0.66,1.17]	0.92	[0.69,1.22]	0.81	[0.57,1.15]	1.16	[0.83,1.63]	1.29	[0.72,2.33]
Decreased	1.11	[0.76,1.61]	1.19	[0.72,1.96]	1.08	[0.62,1.88]	0.78	[0.48,1.26]	**2.27***	[1.11,4.66]	0.19	[0.01,3.06]
Entropy score												
1998 (/km^2)												
<0.63 (ref)												
0.63-0.68	1.01	[0.76,1.34]	0.97	[0.66,1.44]	1.06	[0.70,1.59]	1.43	[0.80,2.56]	0.62	[0.38,1.01]	2.71**	[1.32,5.56]
0.68-0.73	1.09	[0.78,1.54]	1.03	[0.65,1.61]	1.16	[0.73,1.85]	1.46	[0.81,2.64]	0.89	[0.53,1.51]	1.96	[0.79,4.90]
>0.73	1.10	[0.75,1.62]	1.03	[0.63,1.71]	1.16	[0.68,1.97]	1.40	[0.72,2.71]	0.79	[0.43,1.44]	2.94	[0.93,9.31]
1998-2007												
Increased (ref)												
Constant	0.88	[0.44,1.75]	–	–	–	–	–	–	–	–	0.68	[0.24,1.96]
Decreased	1.05	[0.85,1.31]	0.97	[0.72,1.31]	1.16	[0.85,1.59]	1.06	[0.76,1.47]	0.95	[0.66,1.36]	1.48	[0.67,3.28]

[a]All models were adjusted for age, sex, race/ethnicity, socioeconomic status, parental education, and urbanicity. Boldfaced numbers indicate statistical significance of the variables of interest ($^*P$ < 0.05, $^{**}P$ < 0.01, $^{***}P$ < 0.001).

TABLE 5 Associations (odds ratio and 95% confidence interval) of residential food environments in 1998 (at baseline) and their changes during 1998 to 2007 with childhood obesity (BMI ≥ 95th percentile) in 2007[a]

Food environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
Supermarket density												
1998 (/km^2)												
<0.02 (ref)												
0.02-0.08	1.16	[0.83,1.62]	1.12	[0.74,1.68]	1.53	[0.87,2.68]	1.01	[0.48,2.11]	0.99	[0.55,1.77]	1.66	[0.90,3.04]
0.08-0.34	1.12	[0.71,1.76]	1.12	[0.63,1.97]	1.28	[0.61,2.68]	0.91	[0.39,2.12]	1.04	[0.48,2.23]	0.95	[0.15,5.86]
>0.34	1.10	[0.64,1.89]	1.14	[0.57,2.29]	1.29	[0.55,3.00]	1.00	[0.37,2.69]	1.37	[0.59,3.22]	–	–
1998-2007												
Increased (ref)												
Constant	0.94	[0.65,1.36]	0.86	[0.57,1.28]	1.07	[0.63,1.82]	0.49	[0.24,1.01]	1.41	[0.73,2.72]	0.84	[0.41,1.72]
Decreased	0.94	[0.68,1.31]	0.90	[0.58,1.39]	1.06	[0.67,1.67]	0.60	[0.33,1.12]	1.13	[0.60,2.11]	0.78	[0.37,1.64]
Convenience store density												
1998 (/km^2)												
<0.01 (ref)												
0.01-0.04	1.02	[0.73,1.41]	1.35	[0.89,2.06]	0.72	[0.46,1.13]	1.24	[0.73,2.13]	1.83*	[1.05,3.19]	0.48*	[0.24,0.97]
0.04-0.15	0.90	[0.61,1.31]	1.05	[0.61,1.81]	0.70	[0.41,1.19]	0.34***	[0.19,0.59]	2.26**	[1.30,3.95]	1.09	[0.15,7.75]

(Continues)

TABLE 5 (Continued)

Food environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
>0.15	1.01	[0.66,1.55]	0.91	[0.49,1.68]	1.07	[0.57,1.99]	0.81	[0.42,1.55]	1.29	[0.66,2.51]	–	–
1998-2007												
Increased (ref)												
Constant	1.04	[0.79,1.37]	1.17	[0.81,1.70]	0.95	[0.63,1.43]	1.04	[0.64,1.68]	1.13	[0.73,1.75]	1.07	[0.51,2.26]
Decreased	1.18	[0.90,1.53]	1.16	[0.78,1.71]	1.31	[0.88,1.95]	0.89	[0.56,1.40]	1.12	[0.69,1.84]	1.92	[0.97,3.79]
Full-service restaurant density												
1998 (/km^2)												
<0.06 (ref)												
0.06-0.27	0.60*	[0.39,0.95]	0.60	[0.33,1.09]	0.59	[0.31,1.12]	0.65	[0.29,1.45]	0.39**	[0.19,0.78]	0.65	[0.22,1.87]
0.27-1.34	0.47*	[0.25,0.86]	0.31**	[0.14,0.66]	0.74	[0.29,1.90]	0.90	[0.34,2.36]	0.21**	[0.08,0.55]	–	–
>1.34	0.37*	[0.17,0.81]	0.21**	[0.08,0.58]	0.72	[0.22,2.34]	0.51	[0.16,1.58]	0.20**	[0.06,0.63]	–	–
1998-2007												
Increased (ref)												
Constant	0.99	[0.56,1.74]	1.88	[0.88,4.02]	0.35**	[0.16,0.74]	–	–	1.08	[0.40,2.92]	0.76	[0.26,2.20]
Decreased	1.46	[0.95,2.23]	1.62	[0.89,2.92]	1.24	[0.69,2.24]	1.62	[0.74,3.56]	1.51	[0.62,3.68]	1.52	[0.69,3.34]
Fast-food restaurant density												
1998 (/km^2)												
<0.01 (ref)												
0.01-0.07	0.97	[0.67,1.41]	0.94	[0.54,1.64]	1.00	[0.56,1.79]	1.24	[0.60,2.57]	0.85	[0.48,1.52]	1.82	[0.65,5.13]
0.07-0.30	1.33	[0.84,2.12]	1.67	[0.84,3.32]	0.93	[0.43,2.01]	1.61	[0.76,3.44]	1.31	[0.65,2.65]	–	–
>0.30	1.68	[0.97,2.93]	2.75*	[1.16,6.51]	0.86	[0.36,2.05]	1.86	[0.81,4.27]	1.52	[0.68,3.39]	–	–
1998-2007												
Increased (ref)												
Constant	1.08	[0.74,1.58]	1.37	[0.84,2.23]	0.77	[0.40,1.47]	1.20	[0.54,2.65]	1.23	[0.70,2.17]	0.94	[0.49,1.82]
Decreased	0.82	[0.49,1.36]	0.68	[0.33,1.38]	1.00	[0.47,2.15]	0.94	[0.46,1.90]	0.90	[0.32,2.53]	0.78	[0.19,3.26]
Retail bakery density												
1998 (/km^2)												
0 (ref)												
>0-0.06	1.37	[0.95,1.98]	1.21	[0.72,2.02]	1.65*	[1.03,2.65]	1.03	[0.60,1.77]	1.69	[0.86,3.34]	1.08	[0.42,2.80]
>0.06	1.31	[0.83,2.07]	1.36	[0.71,2.62]	1.34	[0.72,2.51]	0.75	[0.40,1.38]	1.87	[0.88,3.99]	–	–
1998-2007												
Increased (ref)												
Constant	1.08	[0.85,1.38]	0.90	[0.65,1.25]	1.45	[1.00,2.11]	0.67	[0.43,1.03]	1.24	[0.85,1.82]	1.06	[0.53,2.11]
Decreased	0.91	[0.67,1.24]	1.00	[0.66,1.52]	0.73	[0.46,1.18]	0.93	[0.60,1.42]	0.74	[0.37,1.50]	1.33	[0.48,3.67]
Dairy product store density												
1998 (/km^2)												
0 (ref)												
>0-0.04	1.09	[0.79,1.49]	1.10	[0.75,1.61]	1.09	[0.68,1.73]	0.72	[0.47,1.12]	1.56	[0.93,2.63]	1.04	[0.42,2.56]
>0.04	1.21	[0.86,1.69]	1.26	[0.82,1.94]	1.24	[0.75,2.07]	1.07	[0.68,1.70]	1.52	[0.85,2.71]	–	–
1998-2007												
Increased (ref)												
Constant	1.11	[0.88,1.40]	1.13	[0.83,1.55]	0.96	[0.68,1.34]	1.17	[0.82,1.67]	1.34	[0.82,2.17]	1.34	[0.60,3.02]
Decreased	0.99	[0.65,1.51]	0.87	[0.50,1.51]	0.95	[0.52,1.74]	1.02	[0.51,2.01]	0.94	[0.48,1.80]	2.66	[0.91,7.80]

(Continues)

TABLE 5 (Continued)

Food environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
Health food store density												
1998 (/km^2)												
0 (ref)												
>0-0.04	0.86	[0.64,1.15]	0.82	[0.56,1.18]	0.94	[0.59,1.51]	0.74	[0.44,1.24]	1.30	[0.77,2.21]	0.56	[0.25,1.27]
>0.04	0.86	[0.60,1.23]	0.83	[0.52,1.33]	0.90	[0.52,1.53]	0.68	[0.42,1.10]	1.74	[0.91,3.32]	–	–
1998-2007												
Increased (ref)												
Constant	0.93	[0.73,1.20]	0.92	[0.67,1.26]	0.99	[0.68,1.45]	0.91	[0.63,1.33]	0.99	[0.67,1.45]	0.94	[0.51,1.73]
Decreased	0.80	[0.57,1.12]	0.69	[0.43,1.10]	1.04	[0.63,1.70]	0.65	[0.40,1.04]	0.52	[0.27,1.01]	**4.89***	**[1.35,17.77]**
Candy store density												
1998 (/km^2)												
0 (ref)												
>0	1.11	[0.87,1.42]	1.03	[0.73,1.46]	1.23	[0.83,1.83]	0.99	[0.72,1.37]	1.07	[0.64,1.81]	0.51	[0.15,1.66]
1998-2007												
Increased (ref)												
Constant	0.88	[0.70,1.11]	0.97	[0.71,1.32]	0.78	[0.54,1.12]	0.86	[0.63,1.19]	0.93	[0.59,1.47]	0.81	[0.38,1.75]
Decreased	0.81	[0.56,1.18]	0.87	[0.52,1.45]	0.81	[0.46,1.40]	0.68	[0.40,1.17]	0.98	[0.52,1.83]	1.31	[0.28,6.17]
Fruit/vegetable market density												
1998 (/km^2)												
0 (ref)												
>0	0.85	[0.66,1.08]	0.97	[0.69,1.37]	0.77	[0.53,1.10]	0.64*	[0.43,0.94]	1.00	[0.65,1.54]	0.51*	[0.28,0.94]
1998-2007												
Increased (ref)												
Constant	1.07	[0.85,1.36]	1.28	[0.92,1.77]	0.89	[0.63,1.25]	1.17	[0.83,1.64]	1.02	[0.67,1.56]	2.41	[0.95,6.09]
Decreased	1.16	[0.75,1.78]	1.57	[0.90,2.74]	0.66	[0.32,1.33]	**1.95***	[1.11,3.45]	1.14	[0.55,2.34]	1.19	[0.22,6.41]
Meat/fish market density												
1998 (/km^2)												
0 (ref)												
>0	1.03	[0.81,1.31]	0.97	[0.69,1.37]	1.13	[0.79,1.61]	0.93	[0.66,1.30]	1.06	[0.69,1.63]	1.40	[0.67,2.96]
1998-2007												
Increased (ref)												
Constant	0.99	[0.79,1.24]	1.04	[0.76,1.43]	1.01	[0.72,1.42]	1.06	[0.76,1.49]	1.06	[0.69,1.63]	0.47	[0.21,1.06]
Decreased	0.83	[0.57,1.20]	1.05	[0.64,1.74]	0.66	[0.37,1.16]	1.14	[0.70,1.86]	0.65	[0.37,1.15]	0.45	[0.10,2.04]
Beverage store density												
1998 (/km^2)												
0 (ref)												
>0	1.12	[0.90,1.40]	1.22	[0.88,1.68]	1.02	[0.73,1.42]	1.09	[0.77,1.53]	0.98	[0.65,1.49]	0.59	[0.22,1.60]
1998-2007												
Increased (ref)												
Constant	1.01	[0.79,1.29]	1.08	[0.78,1.49]	1.04	[0.72,1.50]	0.82	[0.55,1.21]	1.25	[0.78,2.01]	1.14	[0.54,2.40]
Decreased	1.49	[0.99,2.26]	1.79	[0.99,3.25]	1.37	[0.76,2.49]	0.94	[0.55,1.63]	**2.50***	[1.11,5.65]	0.13	[0.01,1.81]
Entropy score												
1998 (/km^2)												
<0.63 (ref)												

(Continues)

TABLE 5 (Continued)

Food environments	All (n = 6100)		Boy (n = 3030)		Girl (n = 3070)		Urban (n = 2200)		Suburban (n = 2200)		Rural (n = 1700)	
0.63-0.68	0.89	[0.63,1.27]	1.07	[0.68,1.67]	0.75	[0.45,1.27]	1.93*	[1.06,3.50]	0.52*	[0.28,0.97]	1.43	[0.63,3.22]
0.68-0.73	0.88	[0.59,1.32]	1.02	[0.60,1.73]	0.72	[0.41,1.28]	2.09*	[1.13,3.86]	0.69	[0.35,1.33]	1.07	[0.40,2.83]
>0.73	0.92	[0.57,1.48]	1.47	[0.81,2.68]	0.48*	[0.23,0.96]	2.13*	[1.03,4.38]	0.62	[0.29,1.34]	1.41	[0.34,5.87]
1998-2007												
Increased (ref)												
Constant	0.73	[0.21,2.59]	–	–	–	–	–	–	–	–	1.15	[0.27,4.99]
Decreased	1.02	[0.77,1.37]	0.76	[0.52,1.13]	1.44	[0.92,2.26]	1.21	[0.79,1.85]	0.86	[0.51,1.43]	0.88	[0.36,2.14]

[a]All models were adjusted for age, sex, race/ethnicity, socioeconomic status, parental education, and urbanicity. Boldfaced numbers indicate statistical significance of the variables of interest (*P < 0.05, **P < 0.01, ***P < 0.001).

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Y.W. and P.J. designed the study and directed its implementation, including quality assurance and control. P.J. and X.C. prepared the data. P.J. drafted the manuscript. H.X. and Y.W. improved the manuscript. All coauthors have approved the final version.

CONFLICT OF INTEREST

No conflict of interest was declared.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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