Characterizing food environments near schools in California: A latent class approach simultaneously using multiple food outlet types and two spatial scales

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ARTICLE INFO

Keywords:
Unhealthy food outlets
Food environment near schools
Urbanicity differences
Disparities

ABSTRACT

It is challenging to evaluate associations between the food environment near schools with either prevalence of childhood obesity or with socioeconomic characteristics of schools. This is because the food environment has many dimensions, including its spatial distribution. We used latent class analysis to classify public schools in urban, suburban, and rural areas in California into food environment classes based on the availability and spatial distribution of multiple types of unhealthy food outlets nearby. All urban schools had at least one unhealthy food outlet nearby, compared to seventy-two percent of schools in rural areas did. Food environment classes varied in the quantity of available food outlets, the relative mix of food outlet types, and the outlets’ spatial distribution near schools. Regardless of urbanicity, schools in low-income neighborhoods had greater exposure to unhealthy food outlets. The direction of associations between food environment classes and school size, type, and race/ethnic composition depends on the level of urbanicity of the school locations. Urban schools attended primarily by African American and Asian children are more likely to have greater exposures to unhealthy food outlets. In urban and rural but not suburban areas, schools attended primarily by Latino students had more outlets offering unhealthy foods or beverages nearby. In suburban areas, differences in the spatial distribution of food outlets indicate that food outlets are more likely to cluster near K-12 schools and high schools compared to elementary schools. Intervention design and future research need to consider that the associations between food environment exposures and school characteristics differ by urbanicity.

1. Introduction

The past two decades have featured growth in research examining the food environment and its impact on diet and health (Westbury et al., 2021; Mah et al., 2019; Caspi et al., 2012). Among children, several (but not all) studies suggest the food environment near schools may have substantial influence on dietary choices (Sallis and Glanz, 2006; Story et al., 2006; Story et al., 2009; Clark et al., 2014; Smith et al., 2013), obesity (Goncalves et al., 2021; da Costa Peres et al., 2020; Williams et al., 2014), and disparities (Matsuzaki et al., 2020). Fast food restaurants, convenience stores, and other food outlets often concentrate near schools and tend to offer high calorie food and sugary beverages (Neckerman et al., 2010; Borradaile et al., 2009; Austin et al., 2005). Their presence near schools varies by urbanicity (Neckerman et al., 2010; Howard et al., 2011), income (Neckerman et al., 2010; Sturm, 2008; Simon et al., 2008; Zenk and Powell, 2008), and race/ethnic composition of schools (Neckerman et al., 2010; Sturm, 2008; Kwate and Loh, 2010; Sanchez et al., 2012). With few exceptions, school-based studies have focused on single dimensions of accessibility, availability and/or types of outlets. For example, studies used a single distance buffer around the schools within which food outlet counts are assessed; or, considered a single type of food outlet at a time with the vast majority focused on fast food restaurants (Davis and Carpenter, 2009; Currie et al., 2009).

The lack of comprehensive measurement of the food environment makes evidence synthesis difficult (da Costa Peres et al., 2020) and may...
be partially the reason for some studies finding associations and others not (Wilkins et al., 2019). The food environment is complex, as it encompasses multiple outlet types whose availability and spatial distribution can vary widely across the levels urbanicity of school neighborhoods. Yet, relatively little research has considered multiple outlet types (Sturm, 2008), and while researchers sometimes summarize availability of multiple outlet types as a ratio of healthy relative to unhealthy outlets (Health CDoP, 2020), the associations between school characteristics and outlet availability is nevertheless assessed using one outlet at a time. No previous research has investigated the joint availability of multiple unhealthy food outlet types near schools simultaneously with their relative proximity to schools. Thus, prior work has been unable to examine whether unhealthy outlets of different types co-cluster near schools (Austin et al., 2005). Furthermore, it is unknown whether the mix or co-clustering of outlets near schools differs by urbanicity or other school characteristics.

To fully evaluate associations with the food environment, it is critical to characterize it more comprehensively. This would enable, for example, assessing the combined effects of the availability of several types of food outlets simultaneously (Jennings et al., 2011; Spence et al., 2009; Morland et al., 2006), and or evaluating the spatial scale at which disparities in food outlet availability are present. Novel research questions require methods that assess exposure by simultaneously considering multiple outlet types, while accounting for their relative proximity to schools and the potentially high correlation in the availability among multiple outlets (e.g., areas with high fast food restaurant availability may also have a high number of convenience stores). Outlets may be more likely to cluster near some schools but not others (Austin et al., 2005), and closer proximity to schools may be associated with stronger health effects (Baek et al., 2016). Differential exposure to the food environment and its health effects cannot be thoroughly examined without analytical approaches that can simultaneously incorporate many features, including multiple outlet types and their relative distances from schools.

This study describes food environment types near schools in urban, suburban and rural areas and examines socio-economic disparities in school neighborhood food environments, while jointly considering the food environment’s multidimensionality and its spatial distribution near schools. Our study uses latent class analysis (LCA) to jointly model the availability of multiple unhealthy food outlet types simultaneously within two distances of public schools for the entire state of California. Schools are then assigned to distinct food environment types or classes.

We hypothesize schools within lower income neighborhoods and with greater concentrations of minority students are more likely classified into food environment classes with higher and relatively closer availability of unhealthy food outlets. Importantly, given the large variations in food outlet density across different levels of urbanicity, we hypothesize the associations between food environment types and socio-economic characteristics are context dependent.

2. Methods
2.1. Data
2.1.1. School locations and school characteristics
School locations and enrollment for the year 2010 were obtained from the California Department of Education (CDE, 2014). We used a spatial join in ArcGIS to identify the 2010 Census tract where the school was located. We then used the median household income of the school’s census tract as a proxy of school neighborhood SES (ArcGIS Desktop, 2014; US Census, 2010). Proprietary Nielsen PRIZM data on the school census tract (The Nielsen Company, 2013) was used to assign each school to an urbanicity classification (urban, suburban, second city, rural). Briefly, urban areas contain high density neighborhoods and tend to be employment centers, and may expand into densely populated areas outside the city limits. Suburban areas are moderately densely populated, and while they are connected to urban areas they are not themselves population centers. Second cities are moderately densely populated, like suburbs, but differ in that they are the primary population center of the surrounding areas. Rural areas have the lowest population density and are located outside the outer suburban reaches of cities. Schools in second cities and suburban areas were combined into a single group, hereafter ‘suburban’, due to their similarity in food outlet availability.

Schools were included in the analysis if they: 1) had ≥ 1 enrolled students in 2010–2011; 2) had complete covariate information (covariates listed in Table 1); 3) enrolled children were in any grades between K-12. Out of the 9557 schools included, 1108 had identical geocodes with another school, due to building or campus sharing. These schools were combined as a single observation; data on enrollment, grade level, and racial/ethnic composition were aggregated. School enrollment by race/ethnicity was used to label schools according to the majority (>50%) racial/ethnic group of their enrolled students; otherwise, it was labelled as “no majority”. The final analytic sample was comprised of 8926 unique school locations, which we refer to as “schools” although

Table 1
Summary statistics of school covariates stratified by urbanicity.

| Urban (N = 3,686) | Suburban* (N = 3,472) | Rural (N = 1,768) |
|-------------------|-----------------------|-------------------|
| **Percent of schools with at least one outlet** | | |
| Outlet of any type | 100% | 98% | 72% |
| Fast food chain restaurant (FFC) | 97% | 76% | 29% |
| Fast food non-chain restaurant (FFN) | 90% | 65% | 29% |
| Convenience stores (CON) | 95% | 71% | 36% |
| Grocers (GRO) | 99% | 88% | 59% |
| Bakery or ice cream shop (BAK)* | 99% | 87% | 42% |
| Non-alcoholic drinking places (NAL) | 91% | 75% | 31% |
| Count of food outlets within 1 mile of schools, median (Q1, Q3); | | |
| Fast food chain restaurant (FFC) | 7 (4, 10) | 3 (1, 6) | 0 (0, 1) |
| Fast food non-chain restaurant (FFN) | 3 (2, 6) | 1 (0, 3) | 0 (0, 1) |
| Convenience stores (CON) | 4 (2, 6) | 1 (0, 3) | 0 (0, 1) |
| Grocers (GRO) | 11 (6, 19) | 3 (1, 6) | 2 (0, 2) |
| Bakery or ice cream shop (BAK)* | 9 (5, 9) | 3 (1, 6) | 0 (0, 2) |
| Non-alcoholic drinking places (NAL) | 3 (2, 6) | 2 (0, 3) | 0 (0, 3) |
| Median household income (1000 dollars), mean (± SD) | 59.2 (± 25.5) | 73.5± (± 31.9) | 56.6 (± 25.0) |
| **Majority race/ethnic group of enrolled students in 2010,** % of column | | |
| African American | 3.2 | 0.4 | 0* |
| Asian | 3.7 | 1.9 | 0* |
| Latino | 61.2 | 40.2 | 33.9 |
| No majority | 24.3 | 27.1 | 14.0 |
| White | 7.7 | 30.4 | 52.1 |
| **School level, % of column** | | |
| Combined (K-12) | 4.3 | 5.7 | 10.0 |
| High school | 17.8 | 19.2 | 22.7 |
| Intermediate/Middle/Junior High | 13.5 | 14.1 | 11.9 |
| Elementary | 64.4 | 61.1 | 55.4 |
| **Number of enrolled students, mean (± SD)** | 3748 (± 608) | 759 (± 400) | 603 (± 406) |

* Includes 2nd City classification.
* Includes stores that sell candy and/or nuts.
* 23 schools had majority race/ethnicity other than the categories listed, but were excluded as they were too few to conduct meaningful analysis.
* Two majority African American and two majority Asian schools were excluded from analysis.
some consist of a group of schools at the same address.

2.1.2. Data on food outlets

Food outlet locations for 2010 were obtained from the National Establishment Time Series (Walls, 2007). We selected the following six food outlets types because they have been deemed relevant to students (Neckerman et al., 2010): fast food restaurants, chains and non-chain; convenience stores; small grocers (excludes supermarkets and convenience stores); non-alcoholic drinking places (e.g., coffee shops, juice bars); and bakeries, pastry, candy, nuts, ice cream shops. All of these outlets are considered unhealthy given their food or beverage offerings (Auchincloss et al., 2012). As in previous research (Powell and Bao, 2009; Sanchez et al., 2012), outlets were classified by primary Standard Industry Classification codes and auxiliary information (see Appendix).

Food outlet counts were ascertained within a ½-mile and 1-mile Euclidean distance of schools; these spatial scales have been previously used in school-based studies, as they represent relatively walkable distances for children (Austin et al., 2005; Baek et al., 2016). To simultaneously examine the quantity and relative proximity in the same model, as described below, the difference in the count of outlets between the buffers was obtained—i.e., the outlet count within the outer ring-shaped area formed by the concentric ½-mile and 1-mile buffers. The abbreviation “HMB” denotes the ½-mile buffer, and “OutR” denotes the outer ring-shaped area.

2.2. Statistical analysis

All study variables were examined within urbanicity strata. LCA was used to derive food environment classes because it is an effective approach to identify subgroups from multivariate data such as multiple food outlet counts.

We apply a new approach to form the latent classes by using the counts of each food outlet type within HBM and OutR in the same model. Compared to prior uses of LCA, which relied on quantity of food outlets within a single buffer size, this innovative strategy has two advantages. First, it avoids the potential lack of consistency in the classification of schools’ environments that can arise when using separate analysis with the counts from either the ½ mile or 1-mile buffer. Second, and more importantly, this innovative approach is advantageous because it allows us to identify whether outlets cluster near schools—i.e., schools where the density of outlets is higher within HMB compared to the OutR area.

Since many schools had zero outlets, zero-inflated Poisson distributions were used to account for the excess of zero counts beyond what would be expected from standard Poisson distributions. LCA analyses were performed within urbanicity strata so that classification results were not driven by urbanicity differences in food outlet availability.

To determine the number of latent classes, we used a combination of statistical testing and substantive interpretation. First, we used Lo, Mendell, Rubin likelihood ratio tests, which suggested that models with two classes for urban schools, five for suburban schools, and four for rural schools had better fit. For urban areas we ultimately selected three classes, following inspection of the average counts of each food outlet type with one mile in urban and suburban areas, 90% of urban and 65% of suburban schools had at least one FFN, with non-alcoholic (NAL) drinking places closely following at 91% and 75%, respectively. In contrast, in rural areas, the prevalence of non-chain fast food restaurants (29%) within one mile was similar to fast food chains (29%) and NAL (31%) (Table 1). Similar urbanicity gradients were observed for the median number of outlets.

There were also differences in school neighborhood characteristics across urbanicity (Table 1). School neighborhoods in suburban areas had higher median household income (USD$73.5 K) than those in urban (USD$59.2) or rural areas (USD$56.6). Rural areas had a greater proportion of majority White schools (52.1%) in comparison to suburban (30.4%) and urban (7.7%) areas; on the other hand, urban areas had a greater proportion of majority Latino schools (61.2%) compared to suburban (40.2%) and rural areas (33.9%).

Table 2 shows the density of unhealthy outlets for the food environment classes identified, within the 1-mile and ½-mile buffers (HMB) and the outer-ring area (OutR), by urbanicity. Within urbanicity, there were clear differences in outlet availability across classes, as indicated

The HMB had higher outlet density than the OutR, we used ‘closer’; in the other direction, we used ‘farther’ (e.g., “Medium, Closer” implies the HMB had greater outlet density than the OutR).

Following established recommendations (Asparouhov and Muthén, 2014), school characteristics were then incorporated into the models as covariates predicting membership in the identified latent classes, using a multinomial logistic regression.

Descriptive statistics and plots were obtained with R; LCA were implemented using Mplus (Hallquist and Wiley, 2018). Associations with p-values less than 0.05 were considered statistically significant.

3. Results

Unhealthy food outlets of all types were common near schools in all areas. There were differences across areas and by specific outlet types (Table 1). Among urban schools, 100% had at least one unhealthy food outlet within a mile, compared to 98% of suburban schools and 72% of rural schools. Although non-chain fast food restaurants (FFN) were the least prevalent outlet type with one mile in urban and suburban areas, 90% of urban and 65% of suburban schools had at least one FFN, with non-alcoholic (NAL) drinking places closely following at 91% and 75%, respectively. In contrast, in rural areas, the prevalence of non-chain fast food restaurants (29%) within one mile was similar to fast food chains (29%) and NAL (31%) (Table 1). Similar urbanicity gradients were observed for the median number of outlets.

Table 2 Average density (count/mile²) of unhealthy outlets for each food environment class. Density includes unhealthy food outlets of any type within the 1- or ½-mile buffer, the outer-ring area (within 1/2 mile to 1 mile); and the ratio of the HMB vs. the OutR density.

| Latent class | for each urbanicity level | 1-mile buffer | ½ mile buffer (HMB) | Outer Ring from ½ mile to 1 mile (OutR) | HMB: OutR ratio |
|-------------|--------------------------|---------------|---------------------|----------------------------------------|-----------------|
| Urban       | Low                      | 9.4           | 9.6                 | 9.3                                   | 1.0             |
|            | Medium                   | 22.3          | 24.2                | 21.6                                  | 1.1             |
|            | High                     | 66.3          | 71.9                | 64.5                                  | 1.1             |
| Suburban    | Low                      | 1.2           | 1.5                 | 1.1                                   | 1.4             |
|            | Low-medium               | 4.3           | 2.9                 | 4.8                                   | 0.6             |
|            | Medium                   | 9.9           | 5.0                 | 11.5                                  | 0.4             |
|            | Farther                  | 7.0           | 13.4                | 4.9                                   | 2.7             |
|            | High, Closer             | 14.6          | 18.9                | 13.2                                  | 1.4             |
| Rural       | Low                      | 0.2           | 0.4                 | 0.1                                   | 3.3             |
|            | Medium                   | 4.3           | 2.6                 | 4.8                                   | 0.5             |
|            | Farther                  | 1.6           | 3.2                 | 1.1                                   | 3.0             |
|            | High, Closer             | 5.3           | 13.1                | 2.7                                   | 4.8             |
by the low, medium, and high labels. The table also illustrates the pronounced exposure differences across urbanicity strata. For example, in urban areas the low exposure class is associated with an average of about 9 unhealthy food outlets/mile² within the 1-mile buffer. In contrast, in rural schools an average of 5.3 outlets/mile² corresponds to the highest exposure class. Moreover, Table 2 also shows that exposure classes differed in the spatial proximity of outlets to schools, indicating clustering of outlets within closer proximity for some schools. Within suburban and rural areas, outlet density in the ‘medium’ exposure classes showed two spatial patterns. The “Medium, Closer” classes had at least twice the density of unhealthy food outlets within the HMB relative to the OutR, whereas the converse is true for the “Medium, Farther” classes.

Fig. 1 displays the average density of outlets for each latent class identified, disaggregated by outlet type. The figure illustrates the differences in how the mix of outlet types in each class differs within, as well as between, urbanicity levels. In urban areas, small grocers followed by bakeries and ice-cream shops (BAK) had a higher density compared to other outlets, a difference that was most pronounced in the highest exposure category. In suburban and rural areas, within each exposure class, the densities were relatively more uniform across outlet types. For example, the density of fast food chain restaurants was

A. Urban

![Graph showing urbanicity-specific density of food outlets](image)

B. Suburban

![Graph showing suburban density of food outlets](image)

C. Rural

![Graph showing rural density of food outlets](image)

**Fig. 1.** Urbanicity-specific density of food outlets (count/mile²) according to school’s food environment class*. Within each class, the first value for each outlet type (dot on the left) is the outlet density within the ½ mile buffer; the second value is the outlet density within the ½ to 1-mile outer ring. A decrease from left to right indicates the concentration is higher within the first ½ mile compared to the area from ½ to 1 mile. Note: the y-axis are on a log scale and are different across urbanicity levels. * Derived as the most likely latent class membership.
relatively on par with small grocers in the medium and high exposure classes. In suburban areas, the availability of fast food chains was about twice that of non-chain fast food in all classes. This was not the case for the highest urban exposure class nor some of the exposure classes in rural areas where chain and non-chain fast food had similar availability. Table S1 gives a numerical tabulation of Fig. 1, and Table S2 shows the probability that schools in each class have exactly zero counts nearby.

In descriptive analysis (Table 3), school characteristics varied across food environment classes, although not always consistently across urbanicity as hypothesized. For example, in urban and suburban but not rural areas, schools classified in the high exposure class tended to have smaller enrollments.

Adjusted odds ratios (aOR) for being classified into each of the food environment classes relative to the lowest exposure class show consistent patterns by income in all urbanicity areas (Table 4). Schools located in more affluent neighborhoods were less likely to be classified into higher exposure classes, compared with schools in the lower exposure classes. The income gradient was steepest in urban areas.

In contrast, the associations between exposure class and school’s racial/ethnic composition varied by urbanicity level. In urban areas, majority African American (aOR = 2.12), majority Asian (aOR = 4.65) and Majority Latino (aOR = 1.65) schools had significantly higher odds of being classified into the medium exposure class compared to majority White schools (Table 4). Similarly, all non-White majority schools also had higher odds of being in the high exposure class in urban areas, although the odds ratio for Majority Asian compared to Majority White schools achieved statistical significance. In suburban areas, Majority Asian schools had higher likelihood of being in the higher exposure classes, whereas Majority Latino schools had similar or lower odds of being classified into the higher exposure classes compared to majority White schools. While the odds of Majority Latino schools being in the ‘Medium, Farther’ class compared to a Majority White school were null (aOR = 0.99), the odds of Majority Latino schools being in the ‘Medium, Closer’ exposure class were significantly lower (aOR = 0.71) compared to Majority White schools. Yet, in rural areas, majority Latino schools demonstrated a higher likelihood of being in the high exposure category relative to majority White schools (aOR = 2.45), a pattern similar to urban areas. Schools with no racial/ethnic majority were not statistically different from majority White schools in terms of their likelihood of belonging to the various exposure classes.

School grade level was also associated with food environment category in all urbanicity classifications. In all urbanicity areas, relative to elementary schools, K-12 and high schools were significantly more likely to be in the highest exposure class. In rural areas, middle schools were also significantly more likely to be in the higher exposure classes. Notably, in suburban areas, K-12 (aOR = 1.62) and high schools (aOR = 1.94) were associated with higher likelihood of being in the ‘Medium, Closer’ exposure class, but not the ‘Medium, Farther’ class (K-12 aOR = 1.08 and high school aOR = 0.82).

The patterns of the association between enrollment and exposure classification differed by urbanicity. In urban and suburban areas, schools with more enrolled students were significantly less likely to be classified into the high exposure class (e.g., aOR: 0.80 per 500 students in urban areas). In rural areas, larger schools were more likely to be classified into higher exposure classes.

4. Discussion

The present study uses LCA to characterize food environments near California public schools according to the joint availability of six unhealthy food outlet types and the spatial distribution of the outlets, within urbanicity strata. This approach revealed that food outlets tend to cluster closer to some schools. Compared with suburban elementary schools, K-12 and high schools have greater exposure to unhealthy food outlets at closer distance to schools, a novel finding that extends prior work (Sturm, 2008) that did not consider outlet availability at different distances in the same model. The relationship between the school’s race/ethnic composition and food environment classes differed by urbanicity. Urban and rural schools attended primarily by racial/ethnic minorities are more likely to have unhealthy foods or beverages nearby compared to schools attended primarily by White students within those geographic strata; this pattern was not evident in suburban schools, except for majority Asian schools. Regardless of urbanicity, schools in low-income neighborhoods were more likely to be classified into higher exposure classes, although the gradient was steepest in urban areas. These inequities in the food environment near schools are important

Table 3
Descriptive statistics for each food environment class, based on the most likely class membership for each school.

|                | Urban          | Suburban        | Rural           |
|----------------|----------------|-----------------|-----------------|
|                | Low            | Medium          | High            | Low             | Medium, Farther | Medium, Closer | High, Closer   |
| N              | 2,446          | 1,098           | 142             | 919             | 1,040           | 533            | 694            | 286            | 858            | 247            | 485            | 178            |
| Median household income ($1,000 USD) | (±25.4) | (±21.5) | (±27.2) | (±33.4) | (±31.6) | (±28) | (±27.2) | (±28.8) | (±24.2) | (±26.2) | (±27.5) | (±17.7) |

Majority racial/ethnic group (% of column)

|                | African | 2.6 | 4.4 | 4.9* | 0.4* | 0.5* | 0.2* | 0.3* | 0.7* |
|----------------|---------|-----|-----|------|------|------|------|------|------|
| American       |         |     |     |      |      |      |      |      |      |
| Asian          | 2.9     | 4.7 | 9.2*| 1.6  | 2.8  | 1.5* | 1.3* | 1.7* |      |
| Latino         | 56.3    | 71.7| 63.4| 34.5 | 38.6 | 45.8 | 41.1 | 52.1 | 27.7 |
| No majority    | 28.5    | 15.3| 20.4| 27.2 | 28.2 | 26.8 | 27.1 | 23.1 | 15.2 |
| White          | 9.7     | 3.9 | 2.1*| 36.2 | 30.7 | 25.7 | 30.3 | 22.4 | 57.1 |

School level (% of column)

|                | Combined (K-12) | High School | Middle/Jr High | Elementary |
|----------------|-----------------|-------------|----------------|------------|
|                | 3.8             | 4.7         | 9.9            | 4.4        | 4.5        | 5.8        | 7.6        | 9.4        | 9.4        | 8.1        | 10.9       | 12.9       |
| Number of enrolled students (per 500) | (±584) | (±644) | (±545) | (±586) | (±557) | (±581) | (±609) | (±810) | (±375) | (±481) | (±385) | (±424) |

* Cell sizes ≤ 10.
considering reported associations between the school-neighborhood food environment and childhood obesity and disparities (Matsuzaki et al., 2005; da Costa Peres et al., 2020). A novel aspect of this study is its examination of relative proximity of food outlets to schools through analyses that separate the count of outlets available within the first 1/2-mile buffer. Using quantity and distance simultaneously helped reveal associations with an array of health outcomes.

Examining multiple outlets within the HMB and OutR area simultaneously in one model also makes interpretation more straightforward. For example, examining 6 outlets at two distances in three urban strata would yield 36 coefficients for any one covariate, whereas our LCA analysis yields 9 coefficients. Unlike a handful of prior studies that specifically offer sweets and SSBs, especially among urban schools, given opportunities for sugary snacks and sugar sweetened beverages (SSBs). While outlets offering sweets and non-alcoholic beverages are also prevalent in suburban and rural areas, their availability is somewhat more on-par with more widely studied outlets. Beyond fast food, studies examining the food environment near schools and interventions to improve food choices among youth should consider outlets that specifically offer sweets and SSBs, especially among urban schools, given sugar/SSBs’ associations with an array of health outcomes.

Our stratification by urbanicity expands the literature on socioeconomic and race/ethnic disparities in the characteristics of the food environment surrounding schools (Neckerman et al., 2010; Sturm, 2008; Simon et al., 2008; Zenk and Powell, 2008; Kwate and Loh, 2010; Sanchez et al., 2012). Beyond established differences in availability by urbanicity (Neckerman et al., 2010; Howard et al., 2011), we found that the associations between the food environment and school-level race/ethnicity differ by urbanicity. In both urban and rural but not suburban areas, majority Latino schools are associated with highest availability of

Table 4

| Class membership | Urban | Suburban | Rural |
|------------------|-------|----------|-------|
|                  | Low   | Medium   | High  |
|                  | Low   | Medium   | High  | Low | Medium | High | Low | Medium | High |
| Median household income (in log2 scale) | 1 | 0.32 | 0.16 | 1 | 0.42 | 0.23 | 1 | 0.59 | 0.42 |
|                  | (0.27, 0.37) | (0.11, 0.23) | (0.34, 0.53) | | (0.39, 0.53) | (0.34, 0.17) | | (0.08, 0.84) | (0.70, 0.67) |
| Majority racial/ethnic group (ref: White) | | | | | | | | | |
| African American | 1 | 2.12 | 2.41 | 1 | 1.13 | 0.28 (0.01, 0.47 (0.06, 1.55 |
|                  | (1.19, 3.8) | (0.56, 10.38) | (0.27, 29.4) | | (3.84) | (0.18, 12) | | (1.53) | (0.18, 1.2) |
| Asian | 1 | 4.65 | 19.4 | 1 | 3.52 | 2.26 (0.79, 9.03 |
|                  | (2.74, 7.89) | (4.8, 78.5) | (1.61, 6.42) | | (5.45) | (2.92, 27.9) | | (1.7) | (1.2, 3.2) |
| Latino | 1 | 1.65 | 1.98 | 1 | 0.83 | 0.99 (0.7, 0.96 |
|                  | (1.11, 2.46) | (0.58, 6.79) | (0.63, 1.39) | | (0.96) | (0.61, 1.44) | | (0.61) | (0.61, 1.44) |
| No majority | 1 | 1.1 (0.72, 1.68) | 2.43 (0.67, 8.79) | 1 | 1.13 | 1.2 (0.86, 1.38) |
|                  | (1.07, 1.86) | (0.53, 3.6) | (0.67, 1.5) | | (0.76) | (0.75, 1.88) | | (0.75, 1.88) | (0.75, 1.88) |
| School level (ref: elementary) | | | | | | | | | |
| Combined (K-12) | 1 | 1.11 | 2.48 | 1 | 0.78 | 1.08 (0.61, 1.62 (1.02, 1.91 |
|                  | (0.74, 1.29) | (0.45, 4.19) | (0.45, 1.91) | | (2.59) | (1.03, 3.52) | | (1.03, 3.52) | (1.03, 3.52) |
| High School | 1 | 1.22 | 2.08 | 1 | 0.93 | 0.82 (0.54, 1.94 (1.38, 2.47 |
|                  | (0.96, 1.32) | (0.65, 2.65) | (0.65, 1.25) | | (2.72) | (1.61, 3.79) | | (1.61, 3.79) | (1.61, 3.79) |
| Intermediate/junior high | 1 | 0.87 | 1.09 | 1 | 0.78 | 1.09 (0.77, 1.94 (1.38, 1.23 |
|                  | (0.67, 1.11) | (0.56, 1.58) | (0.56, 1.58) | | (1.78) | (0.76, 2.01) | | (0.76, 2.01) | (0.76, 2.01) |
| Number of enrolled students (per 500) | 1 | 1 | 0.98 | 1 | 0.98 | 1.02 (0.89, 0.88 (0.79, 0.82 |
|                  | (0.79, 1.08) | (0.89, 1.17) | (0.89, 1.17) | | (0.98) | (0.67, 1.07) | | (0.67, 1.07) | (0.67, 1.07) |
|                  | (0.66, 1.05) | (0.89, 1.17) | (0.89, 1.17) | | (0.98) | (0.67, 1.07) | | (0.67, 1.07) | (0.67, 1.07) |

The calculated estimates/CIs are based on cell sizes less than 10 and thus have very wide confidence intervals.

ref: elementary)
unhealthy food outlets and, in rural areas, with clustering of outlets near schools. Our findings extend prior work (Lee et al., 2006), by highlighting that socioeconomic disparities in the food environment are more pronounced in urban areas. Future studies should examine the relative effects of distance and quantity on children’s purchases, consumption of unhealthy foods and beverages, and prevalence of obesity and related disparities.

While the study has several strengths and innovations, it also has limitations. The analysis used 2010 food outlet data. Thus, the novel patterns identified regarding the relative proximity of food outlets to schools (e.g., the differentiation of the “Medium Closer” and “Medium Farther” classes, and the implication that outlets cluster near some schools but not others) warrants investigation with updated data. The study lacked non-food establishment data, which precluded adjustment for this or other markers of overall business activity near schools. However, analyses were stratified by urbanicity of school neighborhoods. Although alternate analyses that adjust for overall business activity or population density may be desirable, the actual available outlets (raw counts of outlets) are what provide children with opportunities for food or beverage purchases. In this paper, two areas were used simultaneously, the ½ mile buffer, and the outer-ring area between ½ and 1 mile. We selected 1 mile as a maximum distance because prior work has shown that associations between food outlet availability near schools and prevalence of obesity among children is negligible beyond one mile (Baek et al., 2016). A potential extension of this work is to use the proposed methods but include additional, finer-grained ‘rings-shaped areas’ simultaneously, even as granular as 0.1 mile (Currie et al., 2009). The greater granularity will come at an increased cost of model parameters and potential computational problems (e.g., non-convergence) but may be worth exploring, particularly in urban areas where greater variability in the distribution of outlets may be possible.

5. Conclusion

Intervention design and future research need to consider that the associations between food environment exposures and school characteristics differ by urbanicity, and that within urbanicity levels, there is evidence that unhealthy food outlets systematically cluster near some schools depending on characteristics of the school’s study body, including ethnicity, and school type.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgements

This research was supported in part by National Institutes of Health grant numbers R01HL136718 and R01HL131610. The funder did not have a role in the conduct of the study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.pmedr.2022.101937.

References:

Westbury, S., Ghosh, I., Jones, H.M., et al., 2021. The influence of the urban food environment on diet, nutrition and health outcomes in low-income and middle-income countries: a systematic review. BMJ Glob. Health. 6 (10).

Mah, C.L., Luongo, G., Handell, R., Taylor, N.G.A., Lo, B.K., 2019. A Systematic Review of the Effect of Retail Food Environment Interventions on Diet and Health with a Focus on the Enabling Role of Public Policies. Curr Nutr Rep. 8 (4). 411–428.

Caspi, C.E., Sorensen, G., Subramanian, S.V., Kawachi, I., 2012. The local food environment and diet: a systematic review. Health Place. 18 (5). 1172–1187.

Salisz, J.F., Glanz, K., 2006. The role of built environments in physical activity, eating, and obesity in childhood. Future Child. 16 (1). 89–108.

Story, M., Kaphingst, K.M., French, S., 2006. The role of schools in obesity prevention. Future Child. 16 (1). 109–142.

Story, M., Nannya, M.S., Schwartz, M.B., 2009. Schools and obesity prevention: creating school environments and policies to promote healthy eating and physical activity. Milbank Q. 87 (1). 71–100.

Clark, E.M., Quighe, R., Wong, J.E., Richards, R., Black, K.E., Skidmore, P.M., 2014. Is the food environment surrounding schools associated with the diet quality of adolescents in Otago, New Zealand? Health Place. 30. 78–85.

Smith, D., Cammins, S., Clark, C., Stansfield, S., 2013. Does the local food environment around schools affect diet? Longitudinal associations in adolescents attending secondary schools in East London. BMC Public Health. 13. 70.

Goncalves, V.S.S., Figueredo, A., Silva, S.A., et al., 2021. The food environment in schools and their immediate vicinities associated with excess weight in adolescence: A systematic review and meta-analysis. Health Place. 71. 102664.

da Costa Peres, C.M., Gardone, D.S., Costa, B.V.L., Duarte, C.K., Pessoa, M.C., Mendes, L.L., 2020. Retail food environment around schools and overweight: a systematic review. Nutr Rev. 78 (10). 841–856.

Williams, J., Scarborough, P., Matthews, A., et al., 2014. A systematic review of the influence of the retail food environment around schools on obesity-related outcomes. Obes Rev. 15 (5). 359–374.

Matsuzaki, M., Sanchez, B.N., Acosta, M.E., Botkin, J., Sanchez-Vaznaugh, E.V., 2020. Food environment near schools and body weight-A systematic review of associations by race/ethnicity, gender, grade, and socio-economic factors. Obes Rev. 21 (4). 129979.

Neckerman, K., Bader, M., Richards, C., et al., 2010. Disparities in the food environments of New York City public schools. Am J Prev Med. 39 (3). 195–202.

Borradaile, K.E., Sherman, S., Vander Veer, S.S., et al., 2009. Snacking in children: the role of urban corner stores. Pediatrics. 124 (5). 1293–1298.

Austin, S.B., Melly, S.J., Sanchez-Brun, N., Patel, A., Buka, S., Gottmacher, S.L., 2005. Clustering of fast-food restaurants around schools: a novel application of spatial statistics to the study of food environments. American journal of public health. 95 (9). 1575–1581.

Howard, P.H., Fitzpatrick, M., Fulfrost, B., 2011. Proximity of fast food retailers to schools and rates of overweight ninth grade students: an ecological study in California. BMC Public Health. 11, 68.

Sturm, R., 2008. Disparities in the food environment surrounding US middle and high schools. Public Health. 122 (7). 681–690.

Simon, P.A., Kwan, D., Anglecén, A., Shih, M., Fielding, J.E., 2008. Proximity of fast food restaurants to schools: do neighborhood income and type of school matter? Prev Med. 47 (3). 284–288.

Zenk, S., Powell, L., 2008. US secondary schools and food outlets. Health Place. 14 (2). 326–336.

Kwate, N., Loh, J., 2010. Separate and unequal: the influence of neighborhood and school characteristics on spatial proximity between fast food and schools. Prev Med. 51 (2). 153–156.

Sanchez, B.N., Sanchez-Vaznaugh, E.V., Uscilka, A., Baek, J., Zhang, L.D., 2012. Differential Associations Between the Food Environment Near Schools and Childhood Overweight Across Race/Ethnicity, Gender, and Grade. Am J Epidemiol. 175 (12). 1284–1293.

Davis, B., Carpenter, C., 2009. Proximity of fast-food restaurants to schools and adolescent obesity. American journal of public health. 99 (3). 505–510.

Currie, J., DeMaggio, I., Mortensen, E., Pathania, V., 2009. National Bureau of Economic Research. The Effect of Fast Food Restaurants on Obesity and Weight Gain. In: Cambridge, Mass.: National Bureau of Economic Research. http://www.nber.org/papers/w14721.

Wilkins, E., Radley, D., Morris, M., et al., 2019. A systematic review employing the GeoFERN framework to examine methods, reporting quality and associations between the retail food environment and obesity. Food Places. 57. 186–199.

Health CDIO. Modified retail food environment index. https://data.chhs.ca.gov/dataset/modified-retail-food-environment-index. Published 2020. Accessed 05/05/2022,

Jennings, A., Welch, A., Jones, A.P., et al., 2011. Local Food Outlets, Weight Status, and Dietary Intake Associations in Children Aged 9–10 Years. American Journal of Preventive Medicine. 40 (4). 405–410.

Spence, J.C., Cutumisu, N., Edwards, J., Raine, K.D., Smoyer-Tomic, K., 2009. Relation between the retail food environment and obesity among adolescents. BMJ Public Health. 50. 120–126.

Morland, K., Roux, A.V.D., Wing, S., 2006. Supermarkets, other food stores, and obesity – The atherosclerosis risk in communities study. American Journal of Preventive Medicine. 30 (4). 333–339.

Baek, J., Sanchez, B.N., Berrouch, V.J., Sanchez-Vaznaugh, E.V., 2016. Distributed Lag Models: Examining Associations Between the Built Environment and Health. Epidemiology. 27 (1). 116–124.

California Department of Education. Public Schools and Districts Data Files. https://www.cde.ca.gov/ds/sd/fliesenr.asp. In: Education Cdio, ed2014.
ArcGIS Desktop: Release 10.3 [computer program]. Redlands, CA: Environmental Systems Research Institute; 2014.
US Census Bureau. Selected Economic Characteristics. 2006-2010 American Community Survey 5-Year Estimates. In: Bureau UC, ed2010.
The Nielsen Company, 2013. Selected Prizm Segment Distributions Data (Census Tract Level). In: The Nielsen Company, New York.
Walls, D., 2007. National establishment time-series Database© data overview. In: Kauffman Symposium on Entrepreneurship and Innovation Data. https://doi.org/10.2139/asm.1022962.
Auchincloss, A.H., Moore, K.A., Moore, L.V., Diez Roux, A.V., 2012. Improving retrospective characterization of the food environment for a large region in the United States during a historic time period. Health Place. 18 (6), 1341-1347.
Powell, L.M., Bao, Y.J., 2009. Food prices, access to food outlets and child weight. Econ Hum Biol. 7 (1), 64-72.
Asparouhov, T., Muthén, B., 2014. Auxiliary variables in mixture modeling: Three-step approaches using Mplus. Structural Equation Modeling: A Multidisciplinary Journal. 21 (3), 329–341.

Hallquist, M.N., Wiley, J.F., 2018. MplusAutomation: An R Package for Facilitating Large-Scale Latent Variable Analyses in Mplus. Struct Equ Modeling. 25 (4), 621-638.
Schuster, M.A., Elliott, M.N., Kanouse, D.E., et al., 2012. Racial and ethnic health disparities among fifth-graders in three cities. New England Journal of Medicine. 367 (8), 735-745.
Meyer, K.A., Boone-Heinonen, J., Duffey, K.J., et al., 2015. Combined measure of neighborhood food and physical activity environments and weight-related outcomes: The CARDIA study. Health & Place. 33, 9-18.
McDonald, K., Heiss, M., Farbakhsh, K., et al., 2012. Adolescent physical activity and the built environment: A latent class analysis approach. Health & Place. 18 (2), 191-198.
Norman, G.J., Adams, M.A., Kerr, J., Ryan, S., Frank, I.D., Roesch, S.C., 2010. A Latent Profile Analysis of Neighborhood Recreation Environments in Relation to Adolescent Physical Activity, Sedentary Time, and Obesity. J Public Health Man. 16 (5), 411-419.
Lee, N.E., De, A.K., Simon, P.A., 2006. School-based physical fitness testing identifies large disparities in childhood overweight in Los Angeles. J Am Diet Assoc. 106 (1), 118-121.