RESEARCH ARTICLE

Associations between Food Outlets around Schools and BMI among Primary Students in England: A Cross-Classified Multi-Level Analysis

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Abstract

Introduction

Researchers and policy-makers are interested in the influence that food retailing around schools may have on child obesity risk. Most previous research comes from North America, uses data aggregated at the school-level and focuses on associations between fast food outlets and school obesity rates. This study examines associations between food retailing and BMI among a large sample of primary school students in Berkshire, England. By controlling for individual, school and home characteristics and stratifying results across the primary school years, we aimed to identify if the food environment around schools had an effect on BMI, independent of socio-economic variables.

Methods

We measured the densities of fast food outlets and food stores found within schoolchildren's home and school environments using Geographic Information Systems (GIS) and data from local councils. We linked these data to measures from the 2010/11 National Child Measurement Programme and used a cross-classified multi-level approach to examine associations between food retailing and BMI z-scores. Analyses were stratified among Reception (aged 4-5) and Year 6 (aged 10-11) students to measure associations across the primary school years.

Results

Our multilevel model had three levels to account for individual (n = 16,956), home neighbourhood (n = 664) and school (n = 268) factors. After controlling for confounders, there were no significant associations between retailing near schools and student BMI, but significant

positive associations between fast food outlets in home neighbourhood and BMI z-scores. Year 6 students living in areas with the highest density of fast food outlets had an average BMI z-score that was 0.12 (95% CI: 0.04, 0.20) higher than those living in areas with none.

Discussion

We found little evidence to suggest that food retailing around schools influences student BMI. There is some evidence to suggest that fast food outlet densities in a child's home neighbourhood may have an effect on BMI, particularly among girls, but more research is needed to inform effective policies targeting the effects of the retail environment on child obesity.

Introduction

Children in England are struggling to meet healthy diet and body weight recommendations [1,2]. According to the most recent estimates, 9.3% of English children in school Reception year (age 4–5 years) and 18.9% in Year 6 (age 10–11 years) are currently obese [3]. Obesity tends to track into adulthood [4] and is difficult to reverse [5,6], which make a strong case for prevention.

A growing body of research evidence considers how obesogenic environments [7], which promote energy intake and constrain energy expenditure, may contribute to obesity risk [8–12]. While research has traditionally focused on environmental exposures near home, there has been increased interest in non-residential environments [13]. Systematic reviews indicate that associations between food retailing and diet [14] or weight status [15] vary across settings and populations and one setting of particular interest is the retail environment around schools. Policy-makers increasingly see school neighbourhoods as a logical place for health promotion as obesity prevention begins in childhood [16–19], schools are well-controlled environments and school-based interventions provide unparalleled access to children because they spend more of their waking hours in school than any other environment outside of home [20].

A systematic review of studies examining the relationship between food retailing near schools and children's food purchases, consumption and body weight, found little evidence for an effect of retailing on purchases and consumption, but some evidence of an effect on body weight [2]. However, research in the area is still developing, meaning heterogeneous study designs, methods and measures make it difficult to draw firm conclusions about the effect that retailing near schools may have on a child's obesity risk [21,22]. The lack of evidence about environmental effects on obesity risk is complicated further by the fact that BMI is the consequence of energy balance over time, so the effect of environmental influences may not be immediately apparent. Most of the previous studies have taken place in North America, but food environments and their effects are likely to vary between countries [23], so findings may not be generalisable. Despite these research limitations, planning authorities assume the built environment's contribution to the obesity epidemic [24–26]. In the UK, local authorities have already implemented zoning or licensing restrictions related to hot food takeaway retailing around schools [27], supported by guidelines from the Academy of Medical Royal Colleges [28], Public Health England [29] and the Greater London Authority [30], among others.

While the focus in policy discussions [28] and research [31–34] has been on fast-food and takeaway outlets [35], it is important to consider other sources of convenient, energy-dense foods such as grocery stores, convenience stores or petrol stations. A study in New York found that the most frequent sources of food around public schools were small groceries selling mostly

packaged food [36]. A recent study on energy intakes of US children aged 6 to 11 years found that 63% of energy came from stores, while only 12% came from fast food outlets [37]. Another recent study examined sources of empty calories (the sum of energy from added sugar and solid fat) across retail food stores, schools and fast-food restaurants in the US found that 33% of children's empty calories came from stores [38]. In the UK, several pilot studies suggest that food stores on the journey to and from school [39] or near schools [40] may be a major source of calories for school children. Food outlets also tend to cluster around schools [41–43]. In England, longitudinal evidence suggests that numbers of food stores (grocers and convenience stores) and takeaway food outlets in close proximity to schools have increased in recent years [44].

In this study we investigated associations between the density of food outlets in both school and home environments and body weight in a large sample of primary school students in Berkshire, England. We examined if associations varied between types of food outlets. Additionally, we identified if associations were stronger for Reception (ages 4–5) or Year 6 (ages 10–11) students. We hypothesised that, given that Reception students have not been exposed to the school environment as long as Year 6 students and have less independence than year 6 pupils, the retail outlets around schools are unlikely to have as much of an impact as they would for year 6 students. For this reason, we hypothesised that if the Reception analysis showed null results but the year 6 analyses showed positive results, this may suggest that the food environment around schools has an influence.

Methods

Data

Individual student characteristics.   We used data from the 2010/2011 National Child Measurement Programme (NCMP), which works with local authorities annually to collect data on more than one million children in state-maintained primary schools in England. The NCMP includes measures from 90% of pupils reported eligible to be measured by the primary care trusts. It includes individual height and weight (measured by health professionals, usually school nurses), sex, ethnicity and month of measurement [45]. The NCMP is an anonymized dataset, based around a no consent data collection system. Ethics approval is not required for data collection or analysis. As our primary outcome measure, we used body mass index (BMI, kg/m^2) to calculate BMI z-scores relative to the International Obesity Task Force reference curves [46].

School and home characteristics.   The NCMP provides each child's school name and the lower super output area (LSOA) of the home address. LSOAs are a small geographic boundary with a mean population of 1,500 residents [47]. Using data from the Department of Education's 2010/2011 census, we ascertained school location, size (total number of pupils), percentage of students eligible for free school meals and school type (community, foundation, voluntary-controlled or voluntary-aided) [48]. There are different types of maintained or state schools in England: Community schools are controlled by local councils and are not influenced by business or religious groups; foundation schools have more independence to change the way they do things than community schools; voluntary-controlled or voluntary-aided schools are linked to a variety of organisations including faith or charitable organisations [49]. For each child's home LSOA, we identified the urban/rural classification [50] and child well-being index (CWI). The CWI is a composite score of domains including material well-being, health, education, crime, housing, environment and children in need (information about children who are in various kinds of need and served by local authorities, derived from the Children in Need Survey, from the Department for Children, Schools, and Families) [51].

Density of food outlets in school and home environments.   We requested food outlet location data from the local councils of Bracknell Forest, Reading, Slough, West Berkshire,

Windsor and Maidenhead, and Wokingham. Environmental health departments of local councils are required to provide this information under the Freedom of Information Act [52]. Food retailers are legally required to register their business with local councils and therefore, this has been found to be a reliable source of food outlet location information in the UK [53,54]. The local councils provided the names and addresses of all individuals, businesses and associations holding a food license.

The local council data included records of food outlets that were not of relevance to our research question (for example, industrial food manufacturers or bed and breakfasts), so we established a protocol for cleaning the data and categorizing the food outlet types. Food outlets were grouped into two categories: 'takeaway and fast food outlets' or 'food stores'. We defined takeaway and fast food outlets (henceforth referred to as 'fast food outlets') as those selling hot or prepared food paid for before consumption [54,55], and which may be consumed off-site, a category that included coffee shops, cafes, pizza shops, sandwich shops, bakeries, delis, kebab shops and takeaway restaurants. We defined food stores as other retail outlets selling food that may be consumed off-site such as supermarkets, convenience stores, off-license stores or newsagents. Researchers consulted local business directories and Google Street View (Mountain View, California, USA) to confirm food outlet types. One researcher completed the initial processing. To test the reliability of our food outlet definitions, three researchers independently classified a 10% sample of the food outlets and there was agreement for all three raters on 88% of occasions, which gave a kappa score of 0.84.

Schools and food outlets were geocoded according to their postcode using a geographic information system (ArcGIS 10, ESRI, Redlands, CA, USA). Postcodes in the UK contain only 15 addresses on average, and therefore allow for relatively precise geocoding. Postcodes, transportation networks and LSOA boundary data were obtained from Ordnance Survey via UK Digimap (University of Edinburgh, Scotland, UK). We calculated the density of fast food outlets and food stores located within an 800 metre (m) street network buffer of school centroids and within home LSOA boundaries. Precedent for the use of an 800m buffer to represent a 'neighbourhood' has been set in the literature, and approximately corresponds to a 10 minute walk [2].

To test the validity of local council food outlet data, two researchers selected a random 10% sample of schools and identified the food outlets falling within an 800m street network buffer using Google Street View for comparison using percentage agreement statistics. We found that 85% (157 out of 184) of the local council-provided food outlets were also found in Google Street View. However, we also found 22 food outlets in Google Street View that were not included in the local council dataset, so when we compared agreement between the full dataset (using both sources), there was a 76% agreement.

Statistical analysis

Using a cross-classified multi-level model, which allowed us to account for the nested structure of the data (i.e. children within school and home neighbourhoods), we examined the association between pupil BMI z-score and density of fast food and food stores in both home and school areas while controlling for confounding factors at the individual student, school and home environment levels. We categorised food outlet densities into '0 outlets' (the reference category) and divided the remaining densities into tertiles. The individual-level student variables were sex, age, ethnicity and month of measurement. Home neighbourhood-level variables were urbanicity and residential child well-being index. School neighbourhood-level variables were school size, type and percentage of students on free meals.

The results for BMI are reported as z-scores in comparison to the International Obesity Task Force standard [56].

Three-level cross-classified random effects models were run using Markov chain Monte Carlo methods. Four models were calculated for each year group: Model 1 (the null model) was run for each exposure variable only (fast food near schools, food stores near schools, fast food in home neighbourhood and food stores in home neighbourhood) and controlled for no covariates, this allowed us to examine any associations between BMI z-score and food density at schools and home in univariable models. Model 2 included home and school neighbourhood covariates, and were run for each outcome variable separately, allowing us to study if any associations in Model 1 were due to confounding factors at the school or home neighbourhood level. Model 3 was also run for each outcome variable and controlled for all covariates including those at the school, home and individual levels, to investigate if any significant associations could be explained by differences between schools and home neighbourhoods in terms of pupil composition. The full model 4 included the school, home and individual level covariates, and all outcome variables together; this final model investigated whether food store densities around schools and homes had independent associations with BMI z-score. Ninety five percent confidence intervals (CIs) were used to determine significant differences between tertiles of outlet density and BMI z-score. We also used Wald tests to determine whether the non-reference categories were significantly different to each other in their association with the outcome variable. All analyses were conducted using MLwiN version 2.28 (Centre for Multilevel Modelling, University of Bristol, UK).

Results

Descriptive Statistics

We analysed anonymised data from 16,956 individual children attending 268 schools, and living in 664 different home neighbourhoods in Berkshire. Descriptive statistics for the study sample are shown in Table 1. The mean BMI z-score for Reception students (n = 8,745) was 0.38 (SD = 1.00) and for Year 6 students (n = 8,211) was 0.51 (SD = 1.04); these are both lower than the mean BMI z-score found for the national sample in the same calendar year (Reception = 0.46, Year 6 = 0.56). Descriptive statistics for home and school neighbourhood factors, as well as BMI z-scores by home and school neighbourhood characteristics are shown in Table 2. The majority of home neighbourhoods (80.3%) were classified as 'urban city and town', and more than half (57.1%) of the participating schools were community schools. Pupils attending schools with a greater proportion of students eligible for free school meals had higher mean BMI z-scores.

Food outlet frequencies within home and school neighbourhoods are shown in Table 3. The number of fast food outlets found within home neighbourhoods ranged from 0 to 35, with a mean of 1.14 (SD = 3.05). The number of food stores ranged from 0 to 35, with a mean of 1.40 (SD = 3.03). There were more fast food outlets and food stores in the most deprived home neighbourhoods (i.e. those falling within the highest quartiles of the Child Well Being Index). The number of fast food outlets found within an 800 metre street network of schools ranged from 0 to 30 outlets, with a mean of 2.67 (SD = 4.47). The number of food stores ranged from 0 to 33, with a mean of 3.34 (SD = 4.57). There were more fast food outlets and food stores located near larger schools and those with the highest proportion of students eligible for free school meals (Table 3).

A description of participant BMI z-scores by home and school neighbourhoods is shown in Table 4. Reception students living in LSOAs with no fast food outlets had a mean BMI z-score of 0.36 (SD = 0.33), while those living in LSOAs with 30–35 fast food outlets had a BMI z score of 0.90 (SD = 0.63). Among Year 6 students, there was relatively less of a difference between pupils living in areas with no food outlets compared to those living in areas with the highest density of outlets, with BMI z scores of 0.51 (SD = 0.45) and 0.45 (SD = 0.43), respectively.

Table 1. Frequencies and mean BMI z-scores for individual-level factors.

Descriptive statistics	Reception	Year 6	Total	BMI z-score	Reception Mean (SD)	Year 6 Mean (SD)
Individual- n	8,745	8,211	16,956	All	0.38 (1.00)	0.51 (1.04)
Sex—(%)				Sex		
Male	4,501 (51.5)	4,265 (51.9)	8,766 (51.7)	Male	0.34 (1.00)	0.49 (1.05)
Female	4,244 (48.5)	3,946 (48.1)	8,190 (48.3)	Female	0.42 (1.00)	0.52 (1.04)
Age in months				Age quartiles		
Mean (SD)	63.0 (5.3)	133.4 (3.8)	97.1 (35.5)	1st Quartile	0.43 (0.98)	0.51 (1.04)
Min-Max	48.9–77.6	124.5–142.3	48.9–142.3	2nd Quartile	0.42 (0.98)	0.49 (1.03)
				3rd Quartile	0.34 (0.99)	0.52 (1.06)
				4th Quartile	0.32 (1.03)	0.51 (1.04)
Ethnicity—(%)				Ethnicity		
Bangladeshi	14 (0.2)	42 (0.5)	56 (0.3)	Bangladeshi	0.02 (1.16)	1.01 (1.24)
Black African	90 (1.0)	228 (2.8)	318 (1.9)	Black African	0.39 (1.19)	0.76 (1.04)
Black Caribbean	25 (0.3)	75 (0.9)	100 (0.6)	Black Caribbean	-0.26 (0.84)	0.66 (1.24)
Chinese	10 (0.1)	49 (0.6)	59 (0.3)	Chinese	0.21 (0.55)	0.22 (1.12)
Indian	195 (2.2)	410 (5.0)	605 (3.6)	Indian	0.10 (1.16)	0.58 (1.15)
Pakistani	363 (4.2)	591 (7.2)	954 (5.6)	Pakistani	0.08 (1.16)	0.57 (1.27)
White British	1,789 (20.5)	5,520 (67.2)	7,309 (43.1)	White British	0.39 (0.89)	0.46 (0.99)
White Irish	19 (0.2)	44 (0.5)	63 (0.4)	White Irish	0.58 (0.94)	0.67 (0.88)
Other	398 (4.6)	1,169 (14.2)	1,567 (9.2)	Other	0.35 (1.11)	0.62 (1.07)
Not stated	5,842 (66.8)	83 (1.0)	5,925 (34.9)	Not stated	0.41 (0.99)	0.39 (1.09)
Month measured—n (%)				Month measured		
Sept—Dec	2,532 (29.0)	0 (0)	2,532 (14.9)	Sept—Dec	0.40 (1.02)	-
Jan—April	4,313 (49.3)	4,851 (59.1)	9,164 (54.0)	Jan—April	0.38 (0.98)	0.49 (1.03)
May—Aug	1,900 (21.7)	3,360 (40.9)	5,260 (31.0)	May—Aug	0.34 (0.99)	0.54 (1.06)

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Reception and Year 6 students attending schools with no fast food or no food stores within 800 metres had lower mean BMI z-scores than those attending schools with the highest densities of food outlets.

Associations between the density of food outlets and BMI z-scores

School neighbourhoods. Results from the cross-classified multilevel analysis are shown in Tables 5 and 6. For Reception students overall, there were no significant associations between school fast food or food store densities and BMI (Table 5). For Year 6 students, initial models showed a significant positive relationship between school fast food and food store densities and BMI z-score, however these associations were null when adjusting for school, home or individual-level covariates (Table 6).

Home neighbourhoods. In model 4, Reception students living in home neighbourhoods with the highest densities of fast food had a mean BMI z-score 0.08 (95% CI: 0.00, 0.17) higher than those living in home neighbourhoods with no fast food stores. When we stratified the analyses by sex, we found that this relationship was significant for Reception girls (mean BMI z-score = 0.13, 95% CI 0.00, 0.24), but not boys. However, evidence of a dose-response effect in this relationship was not observed. Reception students whose home neighbourhoods had the highest density of food stores had a mean BMI z-score that was 0.09 (95% CI: -0.16, -0.01) lower than students living in home neighbourhoods with no food stores, however associations with other densities of home neighbourhood food store exposure were null. When we stratified

Table 2. Frequencies and mean BMI z-scores for home- and school-level factors.

Home Lower Super Output Area (LSOA) Factors						
Descriptive Statistics	Reception	Year 6	Total	BMI z-score	Reception	Year 6
LSOA—n	614	628	664		Mean (SD)	Mean (SD)
Urban/rural—(%)				Urban/rural		
Rural town and fringe	52 (8.5)	52 (8.3)	57 (8.6)	Rural town and fringe	0.42 (0.33)	0.54 (0.56)
Rural village and dispersed	43 (7.0)	45 (7.2)	51 (7.7)	Rural village and dispersed	0.37 (0.36)	0.22 (0.57)
Urban city and town	509 (82.9)	516 (82.2)	533 (80.3)	Urban city and town	0.36 (0.33)	0.53 (0.41)
Urban major conurbation	10 (1.6)	15 (2.4)	23 (3.5)	Urban major conurbation	0.72 (0.89)	0.64 (1.03)
Child Well Being Index				Child Well Being Index		
Mean (SD)	100.4 (73.5)	99.5 (73.3)	99.5 (72.79)	1st Quartile	0.33 (0.36)	0.45 (0.48)
Min-Max	9.2–400.8	9.2–400.8	9.2–400.8	2nd Quartile	0.30 (0.33)	0.46 (0.47)
				3rd Quartile	0.44 (0.36)	0.50 (0.49)
				4th Quartile	0.43 (0.32)	0.61 (0.47)
School-level factors						
Descriptive Statistics	Reception	Year 6	Total	BMI z-score	Reception	Year 6
School-n	238	221	268		Mean (SD)	Mean (SD)
School type—(%)				School type		
Community	135 (56.7)	125 (56.6)	153 (57.1)	Community	0.38 (0.21)	0.51 (0.22)
Foundation	6 (2.5)	6 (2.7)	6 (2.2)	Foundation	0.38 (0.32)	0.72 (0.28)
Voluntary aided	55 (23.1)	54 (24.4)	62 (23.1)	Voluntary aided	0.36 (0.23)	0.47 (0.28)
Voluntary controlled	42 (17.6)	36 (16.3)	47 (17.5)	Voluntary controlled	0.41 (0.23)	0.50 (0.31)
Total no. Pupils—(%)				Total no. Pupils		
Mean (SD)	268.9 (150.0)	285.4 (150.6)	276.8 (144.3)	1st Quartile	0.38 (0.27)	0.44 (0.31)
Min-Max	29.0–763.0	29.0–763.0	29.0–763.0	2nd Quartile	0.38 (0.22)	0.49 (0.24)
				3rd Quartile	0.41 (0.21)	0.56 (0.20)
				4th Quartile	0.37 (0.21)	0.53 (0.23)
Free School Meals—n (%)				Free School Meals		
Mean (SD)	10.1 (8.8)	10.5 (9.4)	10.1 (9.0)	1st Quartile	0.30 (0.20)	0.37 (0.21)
Min-Max	0.0–46.7	0.0–48.2	0.0–48.2	2nd Quartile	0.40 (0.21)	0.47 (0.22)
				3rd Quartile	0.41 (0.24)	0.57 (0.26)
				4th Quartile	0.42 (0.23)	0.61 (0.24)

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the analyses by sex, we found that the negative relationship between food store densities and BMI was significant for boys but not girls (mean BMI z-score = -0.09, 95% CI: -0.18, -0.01).

There was a positive relationship between BMI z-scores and home fast food outlet density for Year 6 students. Those who were exposed to the highest densities of fast food outlets in the home neighbourhood had BMI z-scores 0.10 (95% CI: 0.01, 0.18) and 0.12 (95% CI: 0.04, 0.20) greater than those least exposed. When we stratified the analyses by sex, we found that the relationship between fast food outlets near homes and BMI z-score was significant for girls, but not for boys. Year 6 girls living areas with the highest densities of fast food had a mean BMI z-score that was 0.19 (95% CI: 0.07, 0.3) greater than those living in areas with none. Adjusted associations between BMI z-scores and school neighbourhood fast food or food store densities were null for Year 6 students.

Discussion

This analysis did not support an independent effect of food stores or fast food outlets around schools on body weight in a sample of UK Reception or Year 6 students. However, there was

Table 3. Food outlet frequencies by home and school neighbourhoods.

Food outlets within home Lower Super Output Area (LSOA)		
Store Frequency	Fast food (n = 630)	Food stores (n = 630)
	Mean (SD)	Mean (SD)
	1.14 (3.05)	1.40 (3.03)
Child Well Being Index		
1st Quartile	0.74 (2.95)	1.05 (2.74)
2nd Quartile	0.88 (2.17)	1.14 (2.20)
3rd Quartile	1.50 (4.03)	1.72 (2.67)
4th Quartile	1.49 (2.72)	1.72 (2.66)
Urban/rural		
Rural town and fringe	0.70 (1.60)	1.09 (1.71)
Rural village and dispersed	0.57 (1.41)	0.88 (1.61)
Urban city and town	1.27 (3.30)	1.52 (3.26)
Urban major conurbation	0 (0)	0 (0)
Food outlets near schools (within 800 metres)		
Store Frequency	Fast food (n = 712)	Food stores (n = 892)
	Mean (SD)	Mean (SD)
	2.67 (4.47)	3.34 (4.57)
School type		
Community	2.8 (4.4)	3.5 (4.8)
Foundation	3.8 (3.4)	5.7 (5.1)
Voluntary aided	2.8 (5.2)	3.4 (4.8)
Voluntary controlled	1.8 (3.6)	2.5 (3.1)
Total no. Pupils		
1st Quartile	1.0 (2.9)	1.7 (3.4)
2nd Quartile	2.0 (3.0)	2.8 (3.2)
3rd Quartile	4.3 (6.0)	4.8 (6.2)
4th Quartile	3.5 (2.7)	4.1 (4.2)
Free Meals		
1st Quartile	1.5 (3.6)	2.0 (3.8)
2nd Quartile	1.6 (2.6)	2.2 (3.0)
3rd Quartile	3.2 (4.9)	3.9 (4.3)
4th Quartile	4.3 (5.6)	5.2 (5.9)

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evidence of a weak positive association between fast food outlet exposure around the home and body weight for older girls in this sample, which remained after adjustment for individual-level and school-level covariates, and exposure to other types of food stores.

There are a number of strengths and limitations to this paper. One of the main strengths was our use of school, home and individual-level measures, which enabled us to identify multi-level determinants of body weight while accounting for the cross-classified structure of the data [57]. The importance of accounting for individual characteristics and exposures from multiple locations is highlighted by Kestens *et al*, who found that estimates of food environment exposures accounting for both residential and non-residential settings were significantly and more strongly associated with overweight than estimates based on one exposure setting only [58]. This relationship differed between men and women, highlighting the importance of multiple estimates

Table 4. BMI z-scores by home and school neighbourhoods.

Food outlets within home Lower Super Output Areas (LSOAs)									
			BMI z-score					**BMI z-score**	
			Reception	Year 6				Reception	Year 6
	N-LSOAs	%	Mean (SD)	Mean (SD)		N-LSOAs	%	Mean (SD)	Mean (SD)
Fast food			**0.37 (0.33)**	**0.51 (0.45)**	**Food stores**			**0.37 (0.34)**	**0.51 (0.45)**
0	404	64.1	0.36 (0.37)	0.49 (0.50)	0	320	50.8	0.37 (0.39)	0.51 (0.54)
1	88	14	0.37 (0.28)	0.47 (0.340	1	131	20.8	0.36 (0.28)	0.48 (0.36)
2	52	8.3	0.44 (0.29)	0.61 (0.32)	2	75	11.9	0.39 (0.28)	0.56 (0.34)
3	32	5.1	0.38 (0.28)	0.55 (0.42)	3	37	5.9	0.34 (0.30)	0.48 (0.35)
4	16	2.5	0.32 (0.30)	0.63 (0.37)	4	26	4.1	0.39 (0.30)	0.60 (0.36)
5	14	2.2	0.33 (0.18)	0.62 (0.38)	5	16	2.5	0.30 (0.29)	0.60 (0.50)
6–9	15	2.4	0.54 (0.20)	0.69 (0.31)	6–9	16	2.5	0.45 (0.28)	0.53 (0.35)
10–19	6	1	0.43 (0.22)	0.49 (0.19)	10–19	4	0.6	0.45 (0.28)	0.38 (0.16)
20–29	0	0	-	-	20–29	3	0.5	0.36 (0.22)	0.52 (0.7)
30–35	2	0.3	0.90 (0.63)	0.45 (0.43)	30–35	2	0.3	0.42 (0.07)	0.39 (0.60)
Food outlets near schools (within 800 metres)									
			BMI z-score					**BMI z-score**	
			Reception	Year 6				Reception	Year 6
	N-schools	%	Mean (SD)	Mean (SD)		N-schools	%	Mean (SD)	Mean (SD)
Fast food			**0.38 (0.23)**	**0.51 (0.25)**	**Food stores**			**0.38 (0.23)**	**0.51 (0.25)**
0	119	44.6	0.38 (0.24)	0.45 (0.25)	0	74	27.7	0.35 (0.23)	0.40 (0.20)
1	34	12.7	0.36 (0.24)	0.52 (0.29)	1	46	17.2	0.39 (0.22)	0.52 (0.30)
2	35	13.1	0.36 (0.18)	0.56 (0.20)	2	40	15	0.42 (0.26)	0.54 (0.24)
3	20	7.5	0.32 (0.21)	0.50 (0.25)	3	25	9.4	0.39 (0.19)	0.50 (0.18)
4	12	4.5	0.45 (0.27)	0.59 (0.19)	4	21	7.9	0.45 (0.20)	0.65 (0.27)
5	5	1.9	0.33 (0.18)	0.62 (0.08)	5	10	3.7	0.26 (0.14)	0.46 (0.25)
6–9	19	7.1	0.42 (0.15)	0.47 (0.22)	6–9	26	9.7	0.42 (0.22)	0.62 (0.23)
10–19	19	7.1	0.50 (0.24)	0.73 (0.23)	10–19	22	8.2	0.37 (0.26)	0.55 (0.24)
20–29	3	1.1	0.41 (0.09)	0.68 (0.27)	20–29	2	0.7	0.47 (0.05)	0.57 (-)
30			-	0.19 (-)	30–35	1	0.4	0.38 (-)	0.98 (-)

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of environmental exposure based around key daily anchor points such as homes and schools, as well as the potential moderating influence of individual-level characteristics such as gender.

Few studies have reported on the reliability or validity of their methods to characterize food environments. We conducted inter-rater reliability tests for our food outlet inclusion criteria and categorization, finding 88% agreement, which gave a kappa score of 0.84. We also validated the data provided from the local councils against Google Street View, a virtual street audit method that has been identified as a potentially promising alternative to ground-truthing [59]. We found a low level of agreement between the two sources, which may have been due to temporal mismatch between local council records and Google's images. Earlier attempts to validate local council food outlet data with Google Street View found similarly low levels of agreement [60].

The acceptability and validity of secondary food outlet data sources, including data from local councils in the United Kingdom, has been tested previously against field observations and has been found to be the most accurate publicly available source of food environment data compared to the 'gold standard' of field testing[52]. Lake et al compared three sources of food environment data (Yellow Pages, Yell.com and Council Data) to a 'gold standard' of observations made in the field and found that the council data had a positive predictive value of 91.5%

Table 5. Associations between food outlets in home Lower Super Output Area (LSOA) and within 800 metres of schools and BMI z-score among Reception students in Berkshire, England.

Food Outlets[a]	Reception Students Overall								Boys		Girls	
	Model 1		Model 2		Model 3		Model 4		Model 4		Model 4	
ref = 0	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
	Fast food around schools (ref = 0)											
1	-0.011	-0.08, 0.058	-0.01	-0.08, 0.061	0.005	-0.064, 0.073	-0.01	-0.086, 0.065	0.004	-0.094, 0.103	-0.028	-0.127, 0.071
2	0.019	-0.068, 0.107	0.025	-0.063, 0.113	0.041	-0.046, 0.128	0.046	-0.056, 0.147	0.055	-0.071, 0.182	0.037	-0.088, 0.163
3	0.059	-0.015, 0.133	0.048	-0.032, 0.128	0.058	-0.019, 0.135	0.113	0,0.226	0.121	-0.020, 0.263	0.087	-0.056, 0.231
Wald	2.949	(p = 0.229)	1.957	(p = 0.376)	1.854	(p = 0.396)	5.405	(p = 0.067)	2.979	0.226	2.974	0.226
	Food stores around schools (ref = 0)											
1	0.04	-0.034, 0.114	0.038	-0.039, 0.115	0.043	-0.031, 0.118	0.045	-0.034, 0.125	0.025	-0.077, 0.128	0.064	-0.037, 0.166
2	0.077	-0.008, 0.162	0.058	-0.028, 0.144	0.055	-0.03, 0.141	0.032	-0.07, 0.135	0.038	-0.093, 0.168	0.034	-0.098, 0.167
3	0.022	-0.056, 0.1	-0.006	-0.094, 0.083	0.029	-0.056, 0.113	-0.05	-0.173, 0.074	-0.069	-0.223, 0.086	-0.020	-0.179, 0.139
Wald	3.392	(p = 0.335	2.333	(p = 0.311)	0.411	(p = 0.814)	3.453	(p = 0.178)	3.056	0.217	1.538	0.464
	Fast food in home Lower Super Output Area (ref = 0)											
1	-0.012	-0.075, 0.051	-0.011	-0.073, 0.051	-0.006	-0.068, 0.056	0.015	-0.05, 0.08	0.005	-0.087, 0.097	0.022	-0.073, 0.117
2	0.067	-0.011, 0.145	0.06	-0.016, 0.135	0.058	-0.019, 0.134	**0.084***	**0.001, 0.167**	0.043	-0.074, 0.161	**0.125***	**0.006, 0.244***
3	0.008	-0.051, 0.067	-0.005	-0.065, 0.055	-0.001	-0.058, 0.056	0.042	-0.031, 0.115	0.045	-0.062, 0.152	0.047	-0.057, 0.151
Wald	3.367	(p = 0.339)	2.777	(p = 0.249)	2.289	(p = 0.318)	2.286	(p = 0.319)	0.568	0.753	2.530	0.282
	Food stores in home Lower Super Output Area (ref = 0)											
1	-0.02	-0.079, 0.038	-0.03	-0.088, 0.028	-0.027	-0.085, 0.031	-0.045	-0.105, 0.014	**-0.092**	**-0.176, -0.007***	-0.002	-0.087, 0.083
2	-0.006	-0.073, 0.062	-0.008	-0.073, 0.058	-0.006	-0.073, 0.06	-0.037	-0.11, 0.036	-0.012	-0.112, 0.089	-0.057	-0.161, 0.048
3	-0.034	-0.094, 0.025	-0.055	-0.115, 0.006	-0.048	-0.106, 0.01	**-0.086***	**-0.162,-0.011**	-0.096	-0.202, 0.011	-0.082	-0.189, 0.026
Wald	0.588	(p = 0.745)	1.601	(p = 0.449)	1.280	(p = 0.527)	1.689	(p = 0.43)	3.034	0.219	2.384	0.304

Model 1 Univariable models for each exposure variable, **Model 2** Univariable exposure variables with controls for school (number of pupils, percentage eligible for free meals, school type, school urbanicity) and LSOA (urbanicity and IMD), **Model 3** Multivariable- Univariable exposure with all controls (school, LSOA and pupil: sex age, month of measurement, ethnicity), **Model 4** Multivariable exposure with all controls.
[a]Food outlet densities were categorised into zero outlets (the reference group) and the remaining densities were divided into tertiles.
*Indicates significant associations (p <0.05)

[54]. Similarly, Cummins et al [53] found reasonable, but imperfect agreement between a publicly available directory of food retail premises and field-validated reality. However, while council data is likely to be in the upper bounds of validity compared to commercial listings (because it is collected for regulatory purposes), researchers should acknowledge the imperfect nature of such data [53].

Our study was limited by its cross-sectional design, which precluded us from establishing a causal relationship between food outlet exposure and body weight. While the NCMP data

Table 6. Associations between food outlets in home Lower Super Output Area (LSOA) and within 800 metres of schools and BMI z-score among Year 6 students in Berkshire, England.

Food Outlets[a]	Year 6 Students Overall								Boys		Girls	
	Model 1		Model 2		Model 3		Model 4		Model 4		Model 4	
ref = 0	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI	β	95% CI
	Fast food around schools (ref = 0)											
1	0.064	-0.012, 0.14	0.016	-0.058, 0.09	0.029	-0.05, 0.108	-0.008	-0.089, 0.073	0.002	-0.096, 0.100	-0.001	-0.110, 0.108
2	0.059	-0.039, 0.157	0.009	-0.083, 0.101	-0.002	-0.096, 0.092	-0.033	-0.142, 0.077	-0.002	-0.133, 0.129	-0.019	-0.165, 0.126
3	**0.121***	**0.037, 0.205**	0.039	-0.041, 0.119	0.028	-0.059, 0.116	0.038	-0.094, 0.17	0.101	-0.052, 0.254	0.018	-0.152, 0.187
Wald	1.780	(p = 0.411)	0.440	(p = 0.803)	0.485	(p = 0.785)	1.546	(p = 0.462)	2.511	p = -0.285	0.241	p = -0.886
	Food stores around schools (ref = 0)											
1	0.121*	0.041, 0.201	0.059	-0.019, 0.137	0.073	-0.01, 0.155	0.085	-0.003, 0.174	0.034	-0.070, 0.138	0.113	0.000, 0.227
2	0.148*	0.052, 0.244	0.064	-0.032, 0.16	0.075	-0.021, 0.172	0.096	-0.017, 0.21	0.056	-0.077, 0.189	0.106	-0.043, 0.254
3	0.161*	0.077, 0.245	0.037	-0.045, 0.119	0.036	-0.051, 0.123	0.018	-0.124, 0.159	-0.053	-0.212, 0.106	0.070	-0.110, 0.250
Wald	1.109*	(p = 0.574)	0.486	(p = 0.784)	1.128	(p = 0.569)	2.288	(p = 0.319)	2.744	p = -0.254	0.297	p = -0.862
	Fast food in home Lower Super Output Area (ref = 0)											
1	0.009	-0.062, 0.08	0.013	-0.054, 0.08	0.013	-0.057, 0.084	0.024	-0.044, 0.092	-0.029	-0.127, 0.069	0.058	-0.044, 0.160
2	**0.106***	**0.018, 0.194**	0.089	0.003, 0.175	0.079	-0.008, 0.166	**0.096***	**0.011, 0.181**	-0.046	-0.171, 0.079	**0.246***	**0.115, 0.377**
3	**0.117***	**0.052, 0.182**	0.086	0.017, 0.155	**0.083***	**0.018, 0.147**	**0.120***	**0.042, 0.198**	0.041	-0.071, 0.153	**0.185***	**0.067, 0.303**
Wald	**6.879***	**(p = 0.032)**	3.519	(p = 0.172)	3.072	(p = 0.215)	4.448	(p = 0.108)	2.024	p = -0.363	**6.119***	**p = -0.047**
	Food stores in home Lower Super Output Area (ref = 0)											
1	-0.014	-0.083, 0.055	-0.028	-0.091, 0.035	-0.028	-0.088, 0.032	-0.046	-0.108, 0.017	-0.025	-0.111, 0.061	-0.085	-0.174, 0.005
2	**0.087***	**0.005, 0.169**	**0.084***	**0.01, 0.158***	**0.079***	**0.008, 0.151**	0.032	-0.05, 0.114	0.107	-0.007, 0.221	-0.073	-0.191, 0.044
3	0.049	-0.02, 0.118	0.012	-0.053, 0.077	0.004	-0.062, 0.069	-0.073	-0.154, 0.008	0.013	-0.101, 0.127	-0.165	-0.283,-0.046
Wald	5.888	(p = 0.527)	**7.731***	**(p = 0.021)**	**6.517***	**(p = 0.038)**	5.331	(p = 0.070)	5.361	p = -0.069	2.238	p = -0.327

Model 1 Univariable models for each exposure variable, **Model 2** Univariable exposure variables with controls for school (number of pupils, percentage eligible for free meals, school type, school urbanicity) and LSOA (urbanicity and IMD), **Model 3** Multivariable- Univariable exposure with all controls (school, LSOA and pupil: sex age, month of measurement, ethnicity), **Model 4** Multivariable exposure with all controls.

[a]Food outlet densities were categorised into zero outlets (the reference group) and the remaining densities were divided into tertiles.

*Indicates significant associations (p <0.05)

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provided BMI measures for a large number of children, it did not include other data on physical activity or dietary behaviours, which may be more strongly related to the exposures examined here. We characterized food retailing in home and school neighbourhoods, but we did not capture exposures along the journey between home and school, or in wider activity space environments, which may be important [61–63]. We used 800m buffers around schools and home LSOA boundaries as a proxy for neighbourhoods, but this may not be an accurate reflection of a child's neighborhood [63].

Questions remain about defining and classifying food outlets. In this study, we drew upon studies by Lake et al[54] and Burgoine et al [55] in forming our definitions of fast food outlets and food stores. However, definitions vary widely between studies. A review on fast food access by Fleischacker et al [64] found that close to half of the studies (n = 16, 40%) used a proprietary fast food outlet definition. Given this variation, it is important for future research to be clear about their criteria for classifying food outlets.

Food access includes many components [14] which were beyond the scope of this study to measure. Our measures of food availability (density of fast food outlets and food stores) may not reflect the foods actually available within stores. Categorizing food outlets as 'healthy' (e.g. grocery stores) and 'unhealthy' (e.g. takeaway shops) is problematic [65] because both healthy and unhealthy food options are often found within the same venue. Future research needs to integrate detailed information on what is sold within stores, alongside measures of access to the stores themselves [22]. However, it is possible that use of food stores varies as a function of age such that young children make less healthy choices than older children and adults. This hypothesis is yet to be explored in the published literature.

This study did not consider the food environments within schools, which have broad potential to impact pupil's food choices [66–68]. School meal standards in the United Kingdom have been described as amongst some of the most detailed and comprehensive in the world[69] and recent reforms from the Department of Education have introduced a new set of standards for all food served in schools [70]. In contexts where the within-school food environment is less regulated (or where standards are non-existent), future research should consider both the within-school and out-of-school availability of food when considering environmental influences on diet quality.

The NCMP data allowed us to control for individual-level characteristics such as sex, age, and ethnicity, but it did not include other potentially important factors, such as cognitions, psychological and psychosocial factors [71]. Our school data set would have been strengthened by additional measures on socio-cultural and political environments [72].

Previous research studies on associations between food outlets around schools and obesity or diet outcomes among children have varied widely in their exposure and outcome measures [2], and have found mixed results. To the best of our knowledge, of those studies examining neighbourhood environment effects on body weight, only two have been conducted in England [73,74]. Like our study, Harrison *et al* considered food retail exposures in both school and home environments and found retailing around homes was more strongly associated with Fat Mass Index (FMI) than retailing around schools [63]. Among girls, access to unhealthy food outlets (takeaways and convenience stores) near home was associated with FMI and access to healthy outlets (supermarkets and greengrocers) near home was associated with a lower FMI. Similarly, we found high access to fast food in the home neighbourhoods of Year 6 students was associated with a higher BMI z-score and high access to food stores in the home of Reception students was associated with a lower BMI z-score. Harrison *et al* also measured the child's mode of travel to school and found associations varied between active- and non-active travellers, with some evidence that environmental exposures may have more of an influence on the former. This has important implications for our study because children who are driven to and from school may have little chance to interact with the school neighbourhood.

Our study builds upon earlier work examining associations between food environments, deprivation and childhood overweight and obesity using NCMP data [73]. Unlike our study, which was limited to one region in England, this study included schools across England and had data from three time points (2007–2010). Our main contribution to this work is the inclusion of individual-level measures (rather than aggregate school-level measures). Also, while their study focused on takeaways, we considered takeaways and other types of retailers.

Cetateanu *et al* observed associations between takeaways around schools and obesity rates among older (Year 6) students, but not the younger (Reception) students. Similarly, we found stronger evidence of associations between food retailing and BMI among older students (Year 6) compared to younger students (Reception). One possible explanation is that older children have increased autonomy, spending power and capacity to travel independently to and from school. However, Sanchez *et al* [75] found that the presence of convenience stores near schools was significantly associated with the overweight prevalence ratio of fifth grade students (around age 10), but not ninth grade students (about 14 years). The reasons behind this discrepancy are currently unclear.

We do not know why associations between fast food outlets near homes and mean BMI z scores were stronger for girls than they were for boys. Previous research has also shown sex differences in associations between the environment and weight-related outcomes [74,76–78], but further work is needed to understand what lies behind these differences.

There are many reasons why we may not have seen an association between food retailing around schools and BMI. Perhaps an association would have been observed if we had looked at more proximal outcomes like diet or physical activity. It could be that students near schools with a high density of outlets eat more fast food, but compensate for it with higher levels of physical activity or eat less food at home. Another possibility is that the cumulative effects have not yet appeared among primary school children. Unfortunately, the NCMP doesn't measure secondary school pupils, who may be more affected by food outlets around schools than younger students. Future research on associations between food retailing and weight among secondary schoolchildren would benefit from considering whether or not schools have stay-on-site lunch policies. While this is the norm among primary schools, many secondary schools allow older students to leave campus for meals.

Future work may benefit from the collection and analysis of data over a wide range of spatial and temporal scales [13,79,80] while accounting for individual-level characteristics. Research in this area will also would benefit from using a national sample at various time points, as done by Cetateanu *et al* [73], while also controlling for individual-level and home-environment characteristics.

Additional work is needed to find ways to more accurately characterize environmental exposures at home and school [81]. Accounting for individual mobility patterns such as activity spaces [82] or GPS routes [83] will enable researchers to assess the various environments beyond home and school. One recent example in the UK found that exposure to takeaway food outlets in home, work, and commuting environments combined was associated with higher consumption of takeaway food, greater body mass index, and greater odds of obesity among adults [55].

Obesity is the consequence of a complex web of influences; its underlying systems that are non-linear and ill-suited to dichotomous hypothesis testing [84]. The scientific evidence about the effects of food outlets on child BMI is not conclusive. However, in the face of this uncertainty, proponents of the precautionary principal would argue that if plausible risk [16] to health has been identified, preventive measures are warranted.

Supporting Information

S1 Table. Food Outlets in West Berkshire: Names, Postcodes, Categories and Addresses from Local Councils.
(XLSX)

Acknowledgments

Author Contributions

Conceived and designed the experiments: JW PS AM NT TB MR. Performed the experiments: JW PS AM NT LM TB. Analyzed the data: JW PS AM NT LM TB. Wrote the paper: JW PS AM NT LM TB MR.

References

1. Townsend N, Bhatnagar P, Wickramasinghe K, Williams J, Vujcich D, Rayner M (2013) Children and Young People Statistics; Weissberg P, editor. London: British Heart Foundation.

2. Williams J, Scarborough P, Matthews A, Cowburn G, Foster C, Roberts N, et al. (2014) A systematic review of the influence of the retail food environment around schools on obesity-related outcomes. Obes Rev 15: 359–374. doi: 10.1111/obr.12142 PMID: 24417984

3. Health and Social Care Information Centre (2013) National Child Measurement Programme, England, 2012–13 school year.

4. Maffeis C, Tato L (2004) Long-term effects of childhood obesity on morbidity and mortality. Hormone Research in Paediatrics 55: 42–45.

5. Waters E, de Silva Sanigorski A, Hall B, Brown T, Campbell K, Gao Y, et al. (2011) Interventions for preventing obesity in children (Review). Cochrane collaboration: 1–212.

6. Oude Luttikhuis H, Baur L, Jansen H, Shrewsbury VA, O'Malley C, Stolk RP, et al. (2009) Interventions for treating obesity in children. Cochrane Database Syst Rev 1.

7. Egger G, Swinburn B (1997) An" ecological" approach to the obesity pandemic. BMJ: British Medical Journal 315: 477. PMID: 9284671

8. Lytle LA (2009) Measuring the food environment: state of the science. American journal of preventive medicine 36: S134–S144. doi: 10.1016/j.amepre.2009.01.018 PMID: 19285204

9. McKinnon RA, Reedy J, Morrissette MA, Lytle LA, Yaroch AL (2009) Measures of the food environment: a compilation of the literature, 1990–2007. American Journal of Preventive Medicine 36: S124–S133. doi: 10.1016/j.amepre.2009.01.012 PMID: 19285203

10. Larson N, Story M (2009) A review of environmental influences on food choices. Annals of Behavioral Medicine 38: 56–73.

11. Drewnowski A (2004) Obesity and the food environment: dietary energy density and diet costs. American journal of preventive medicine 27: 154–162. PMID: 15450626

12. Swinburn BA, Sacks G, Hall KD, McPherson K, Finegood DT, Moodie ML, et al. (2011) The global obesity pandemic: shaped by global drivers and local environments. The Lancet 378: 804–814.

13. Cummins S (2007) Commentary: investigating neighbourhood effects on health—avoiding the 'local trap'. International Journal of Epidemiology 36: 355–357. PMID: 17376797

14. Caspi CE, Sorensen G, Subramanian SV, Kawachi I (2012) The local food environment and diet: a systematic review. Health Place 18: 1172–1187. doi: 10.1016/j.healthplace.2012.05.006 PMID: 22717379

15. Feng J, Glass TA, Curriero FC, Stewart WF, Schwartz BS (2010) The built environment and obesity: a systematic review of the epidemiologic evidence. Health Place 16: 175–190. doi: 10.1016/j.healthplace.2009.09.008 PMID: 19880341

16. Crawford PB, Gosliner W, Kayman H (2011) Peer Reviewed: The Ethical Basis for Promoting Nutritional Health in Public Schools in the United States. Preventing chronic disease 8.

17. Khambalia A, Dickinson S, Hardy L, Gill T, Baur L (2012) A synthesis of existing systematic reviews and meta-analyses of school-based behavioural interventions for controlling and preventing obesity. Obesity Reviews 13: 214–233. doi: 10.1111/j.1467-789X.2011.00947.x PMID: 22070186

18. Katz D, O'connell M, Njike VY, Yeh M, Nawaz H (2008) Strategies for the prevention and control of obesity in the school setting: systematic review and meta-analysis. International Journal of Obesity 32: 1780–1789. doi: 10.1038/ijo.2008.158 PMID: 19079319

19. Nestle M (2010) Strategies to Prevent Childhood Obesity Must Extend Beyond School Environments. American Journal of Preventive Medicine 39: 280–281. doi: 10.1016/j.amepre.2010.06.001 PMID: 20709261

20. Kaphingst KM, French S (2006) The role of schools in obesity prevention. The Future of Children 16: 109–142. PMID: 16532661

21. Oakes JM, Masse LC, Messer LC (2009) Work group III: Methodologic issues in research on the food and physical activity environments: addressing data complexity. Am J Prev Med 36: S177–181. doi: 10.1016/j.amepre.2009.01.015 PMID: 19285211

22. Ni Mhurchu C, Vandevijvere S, Waterlander W, Thornton LE, Kelly B, Cameron AJ, et al. (2013) Monitoring the availability of healthy and unhealthy foods and non-alcoholic beverages in community and consumer retail food environments globally. obesity reviews 14: 108–119. doi: 10.1111/obr.12080 PMID: 24074215

23. Cummins S, Macintyre S (2006) Food environments and obesity—neighbourhood or nation? Int J Epidemiol 35: 100–104. PMID: 16338945

24. Public Health England (2013) Obesity and the environment: regulating the growth of fast food outlets. London.

25. Wooten H, McLaughlin I, Chen L, Fry C, Mongeon C, Graff S. Zoning and Licensing to Regulate the Retail Environment and Achieve Public Health Goals; 2012. Duke University Law School. All Rights Reserved. Duke Forum for Law & Social ChangeDuke Forum for Law & Social Change. pp. 65–129.

26. Diller PA, Graff S (2011) Regulating Food Retail for Obesity Prevention: How Far Can Cities Go? The Journal of Law, Medicine & Ethics 39: 89–93.

27. Mitchell C, Cowburn G, Foster C (2011) Assessing the options for local government to use legal approaches to combat obesity in the UK: putting theory into practice. Obesity Reviews 12: 660–667. doi: 10.1111/j.1467-789X.2011.00872.x PMID: 21426480

28. Academy of Royal Medical Colleges (2013) Measuring up. The medical profession's prescription for the nation's obesity crisis. London.

29. Cavill N, Rutter H (2013) Healthy people, healthy places briefing: obesity and the environment: regulating the growth of fast food outlets. Public Health England.

30. Greater London Authority (2012) Takeaways toolkit: tools, interventions and case studies to help local authorities develop a response to the health impacts of fast food takeaways.

31. Currie J, DellaVigna S, Moretti E, Pathania V (2010) The Effect of Fast Food Restaurants on Obesity and Weight Gain. American Economic Journal-Economic Policy 2: 32–63.

32. Grier S, Davis B (2013) Are All Proximity Effects Created Equal? Fast Food Near Schools and Body Weight Among Diverse Adolescents. Journal of Public Policy & Marketing 32: 116–128.

33. Nixon H, Doud L (2011) Do fast food restaurants cluster around high schools? A geospatial analysis of proximity of fast food restaurants to high schools and the connection to childhood obesity rates. Journal of Agriculture, Food Systems, and Community Development 2: 181–194.

34. Forsyth A, Wall M, Larson N, Story M, Neumark-Sztainer D (2012) Do adolescents who live or go to school near fast-food restaurants eat more frequently from fast-food restaurants? Health & place 18: 1261–1269.

35. Neckerman KM (2014) Takeaway food and health. BMJ 348: g1817. doi: 10.1136/bmj.g1817 PMID: 24625461

36. Neckerman KM, Bader MD, Richards CA, Purciel M, Quinn JW, Thomas JS, et al. (2010) Disparities in the food environments of New York City public schools. American journal of preventive medicine 39: 195–202. doi: 10.1016/j.amepre.2010.05.004 PMID: 20709250

37. Drewnowski A, Rehm CD (2013) Energy intakes of US children and adults by food purchase location and by specific food source. Nutrition journal 12: 59. doi: 10.1186/1475-2891-12-59 PMID: 23656639

38. Poti JM, Slining MM, Popkin BM (2014) Where Are Kids Getting Their Empty Calories? Stores, Schools, and Fast-Food Restaurants Each Played an Important Role in Empty Calorie Intake among US Children During 2009–2010. Journal of the Academy of Nutrition and Dietetics 114: 908–917. doi: 10.1016/j.jand.2013.08.012 PMID: 24200654

39. Matthews A, Cowburn G, Foster C, Pearce J, Nelson M (2011) Food purchases and consumption on the journey to and from school: a pilot study. School Food Trust.

40. Sinclair S, Winkler J (2008) The School Fringe: What pupils buy and eat from shops surrounding secondary schools. Nutrition Policy Unit, London Metropolitan University.

41. Austin SB, Melly SJ, Sanchez BN, Patel A, Buka S, Gortmaker SL (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: 1575. PMID: 16118369

42. Day PL, Pearce J (2011) Obesity-promoting food environments and the spatial clustering of food outlets around schools. American journal of preventive medicine 40: 113–121. doi: 10.1016/j.amepre.2010.10.018 PMID: 21238858

43. Ellaway A, Macdonald L, Lamb K, Thornton L, Day P, Pearce J (2012) Do obesity-promoting food environments cluster around socially disadvantaged schools in Glasgow, Scotland? Health & place 18: 1335–1340.

44. Smith D, Cummins S, Clark C, Stansfeld 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. doi: 10.1186/1471-2458-13-70 PMID: 23347757

45. Public Health England (2013) National Child Measurement Programme Local Authority Profile.

46. Cole TJ, Flegal KM, Nicholls D, Jackson AA (2007) Body mass index cut offs to define thinness in children and adolescents: international survey. Bmj 335: 194. PMID: 17591624

47. United Kingdom Office for National Statistics Super output areas. A Beginner's Guide to UK Geography.

48. Department for Education (2011) The School Census England.

49. United Kingdom Government (2014) Types of school.

50. Office for National Statistics (2014) Rural and Urban Classifications.

51. United Kingdom Government (2010) Department for Communities and Local Government, Child Wellbeing Index.

52. Burgoine T (2010) Collecting accurate secondary foodscape data. A reflection on the trials and tribulations. Appetite 55: 522–527. doi: 10.1016/j.appet.2010.08.020 PMID: 20832436

53. Cummins S, Macintyre S (2009) Are secondary data sources on the neighbourhood food environment accurate? Case-study in Glasgow, UK. Preventive medicine 49: 527–528. doi: 10.1016/j.ypmed.2009.10.007 PMID: 19850072

54. Lake AA, Burgoine T, Greenhalgh F, Stamp E, Tyrrell R (2010) The foodscape: Classification and field validation of secondary data sources. Health & Place 16: 666–673.

55. Burgoine T, Forouhi NG, Griffin SJ, Wareham NJ, Monsivais P (2014) Associations between exposure to takeaway food outlets, takeaway food consumption, and body weight in Cambridgeshire, UK: population based, cross sectional study. BMJ: British Medical Journal 348.

56. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH (2000) Establishing a standard definition for child overweight and obesity worldwide: international survey. Bmj 320: 1240. PMID: 10797032

57. Townsend N, Rutter H, Foster C (2011) Age differences in the association of childhood obesity with area-level and school-level deprivation: cross-classified multilevel analysis of cross-sectional data. International journal of obesity 36: 45–52. doi: 10.1038/ijo.2011.191 PMID: 22005718

58. Kestens Y, Lebel A, Chaix B, Clary C, Daniel M, Pampalon R, et al. (2012) Association between activity space exposure to food establishments and individual risk of overweight. PloS one 7: e41418. doi: 10.1371/journal.pone.0041418 PMID: 22936974

59. Charreire H, Mackenbach JD, Ouasti M, Lakerveld J, Compernolle S, Ben-Rebah M, et al. (2014) Using remote sensing to define environmental characteristics related to physical activity and dietary behaviours: A systematic review (the SPOTLIGHT project). Health & Place 25: 1–9.

60. Rossen LM, Pollack KM, Curriero FC (2012) Verification of retail food outlet location data from a local health department using ground-truthing and remote-sensing technology: Assessing differences by neighborhood characteristics. Health & Place 18: 956–962.

61. Rossen LM, Curriero FC, Cooley-Strickland M, Pollack KM (2013) Food availability en route to school and anthropometric change in urban children. Journal of Urban Health 90: 653–666. doi: 10.1007/s11524-012-9785-4 PMID: 23392564

62. Timperio A, Ball K, Roberts R, Campbell K, Andrianopoulos N, Crawford D (2008) Children's fruit and vegetable intake: Associations with the neighbourhood food environment. Prev Med 46: 331–335. doi: 10.1016/j.ypmed.2007.11.011 PMID: 18164753

63. Harrison F, Jones AP, van Sluijs EM, Cassidy A, Bentham G, Griffin SJ (2011) Environmental correlates of adiposity in 9–10 year old children: Considering home and school neighbourhoods and routes to school. Social science & medicine 72: 1411–1419.

64. Fleischhacker S, Evenson K, Rodriguez D, Ammerman A (2011) A systematic review of fast food access studies. Obesity Reviews 12: e460–e471. doi: 10.1111/j.1467-789X.2010.00715.x PMID: 20149118

65. Vernez Moudon A, Drewnowski A, Duncan GE, Hurvitz PM, Saelens BE, Scharnhorst E (2013) Characterizing the food environment: pitfalls and future directions. Public health nutrition 16: 1238–1243. doi: 10.1017/S1368980013000773 PMID: 23570695

66. Jaime PC, Lock K (2009) Do school based food and nutrition policies improve diet and reduce obesity? Preventive medicine 48: 45–53. doi: 10.1016/j.ypmed.2008.10.018 PMID: 19026676

67. Story M (1999) School-based approaches for preventing and treating obesity. International Journal of Obesity 23: S43–S51.

68. Kubik MY, Lytle LA, Hannan PJ, Perry CL, Story M (2003) The association of the school food environment with dietary behaviors of young adolescents. American journal of public health 93: 1168–1173. PMID: 12835204

69. Evans C, Harper C (2009) A history and review of school meal standards in the UK. Journal of Human Nutrition and Dietetics 22: 89–99. doi: 10.1111/j.1365-277X.2008.00941.x PMID: 19302115

70. Schabas L (2014) The School Food Plan: putting food at the heart of the school day. Nutrition Bulletin 39: 99–104.

71. van der Horst K, Timperio A, Crawford D, Roberts R, Brug J, Oenema A (2008) The school food environment associations with adolescent soft drink and snack consumption. American Journal of Preventive Medicine 35: 217–223. doi: 10.1016/j.amepre.2008.05.022 PMID: 18617354

72. Gebremariam MK, Andersen LF, Bjelland M, Klepp K-I, Totland TH, Bergh IH, et al. (2012) Does the school food environment influence the dietary behaviours of Norwegian 11-year-olds? The HEIA study. Scandinavian Journal of Public Health 40: 491–497. doi: 10.1177/1403494812454948 PMID: 22833556

73. Cetateanu A, Jones A (2014) Understanding the relationship between food environments, deprivation and childhood overweight and obesity: Evidence from a cross sectional England-wide study. Health & place 27: 68–76.

74. Harrison F, Bentham G, Jones AP, Cassidy A, van Sluijs EMF, Griffin SJ (2011) School level correlates with adiposity in 9–10 year old children. Health & Place 17: 710–716.

75. Sánchez BN, Sanchez-Vaznaugh EV, Uscilka A, Baek J, Zhang L (2012) Differential Associations Between the Food Environment Near Schools and Childhood Overweight Across Race/Ethnicity, Gender, and Grade. American Journal of Epidemiology 175: 1284–1293. doi: 10.1093/aje/kwr454 PMID: 22510276

76. Chiang P-H, Wahlqvist ML, Lee M-S, Huang L-Y, Chen H-H, Huang ST-Y (2011) Fast-food outlets and walkability in school neighbourhoods predict fatness in boys and height in girls: a Taiwanese population study. Public Health Nutrition 14: 1601–1609. doi: 10.1017/S1368980011001042 PMID: 21729476

77. He M, Tucker P, Gilliland J, Irwin JD, Larsen K, Hess P (2012) The influence of local food environments on adolescents' food purchasing behaviors. International Journal of Environmental Research & Public Health [Electronic Resource] 9: 1458–1471.

78. Park S, Choi BY, Wang Y, Colantuoni E, Gittelsohn J (2013) School and neighborhood nutrition environment and their association with students' nutrition behaviors and weight status in seoul, South Korea. Journal of Adolescent Health 53: 655–662. e612. doi: 10.1016/j.jadohealth.2013.06.002 PMID: 23891243

79. Holsten JE (2009) Obesity and the community food environment: a systematic review. Public health nutrition 12: 397–405. doi: 10.1017/S1368980008002267 PMID: 18477414

80. Matthews SA (2012) Thinking about place, spatial behavior, and spatial processes in childhood obesity. American journal of preventive medicine 42: 516. doi: 10.1016/j.amepre.2012.02.004 PMID: 22516493

81. Gilliland JA, Rangel CY, Healy MA, Tucker P, Loebach JE, Hess PM, et al. (2012) Linking childhood obesity to the built environment: a multi-level analysis of home and school neighbourhood factors associated with body mass index. Canadian Journal of Public Health Revue Canadienne de Sante Publique 103: eS15–21.

82. Zenk SN, Schulz AJ, Matthews SA, Odoms-Young A, Wilbur J, Wegrzyn L, et al. (2011) Activity space environment and dietary and physical activity behaviors: a pilot study. Health & place 17: 1150–1161.

83. Harrison F, Burgoine T, Corder K, van Sluijs EM, Jones A (2014) How well do modelled routes to school record the environments children are exposed to?: a cross-sectional comparison of GIS-modelled and GPS-measured routes to school. International journal of health geographics 13: 5. doi: 10.1186/1476-072X-13-5 PMID: 24529075

84. Rutter H (2012) The single most important intervention to tackle obesity. International journal of public health: 1–2.