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Fast-food outlet availability and obesity: considering variation by age and methodological diversity in 22,889 Yorkshire Health Study participants

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Keywords
Fast-food; takeaway; obesity; adults; obesogenic environment.

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Abstract

This study investigated if the relationship between residential fast-food outlet availability and obesity varied due to methodological diversity or by age. Cross-sectional data (n=22,889) from the Yorkshire Health Study, England were used. Obesity was defined using self-reported height and weight (BMI≥30). Food outlets ("fast-food", "large supermarkets", and "convenience or other food retail outlets") were mapped using Ordnance Survey Points of Interest (PoI) database. Logistic regression was used for all analyses. Methodological diversity included adjustment for other food outlets as covariates and continuous count vs. quartile. The association between residential fast-food outlets and obesity was inconsistent and effects remained substantively the same when considering methodological diversity. This study contributes to evidence by proposing the use of a more comprehensive conceptual model adjusting for wider markers of the food environment. This study offers tentative evidence that the association between fast-food outlets and obesity varies by age.

What is already known on this topic?

- Despite an increase in the number of studies investigating associations between residential fast-food outlet availability and obesity, considerable methodological diversity still exists.
- Systematic reviews highlight that associations between the food environment and obesity may vary due to the diversity of methods employed.
- Despite this methodological diversity and inconsistent evidence, policymakers are increasingly engaging with the notion that the fast-food outlet availability is a contributing factor to elevated obesity prevalence.

What does this study add?

- Methodological diversity explained little variation in the association but an explicit conceptual framework is proposed.
- This study offers tentative support that the association between the residential fast-food outlet availability and change in obesity may be dependent upon age.
- This study provides tentative evidence that some populations are more susceptible to the obesogenic environment than others.

Introduction

The consequences of obesity are well documented (1-3) with obese individuals at greater risk of diabetes, cardiovascular disease, and some cancers (4-6). This is concerning given that 24% of male adults and 25% of female adults are reported to be obese in the UK (7). The subsequent health consequences remain one of the leading burdens of disease in the UK (8) with obesity related illnesses estimated to cost the NHS £5.1 billion per year (9). Due to the health burden and elevated obesity prevalence, local and national government have repeatedly attempted to address the increases in obesity prevalence in the UK (10, 11). Despite this, there have been mixed findings for public health interventions, with most only achieving short-term success in weight loss (12).

Residential fast-food outlet availability is increasingly considered a contributing factor to elevated obesity prevalence by research and policymakers (1). Despite this, recommendations to regulate fast-food outlets are based on a developing evidence base that has produced equivocal outcomes (13, 14). Evidence mainly stems from the US however, systematic reviews highlight considerable inconsistencies in study findings and suggest the variety of methods employed may impact on associations seen (15). Research is therefore beginning to explore how sources of methodological diversity such as, the use of different food outlet data sources (16), differences in accuracy of secondary datasets (17, 18), classifications of food outlets (19) and definitions of a neighbourhood (20-22) may influence both the strength and direction of any associations.

Two areas of methodological diversity which have received less attention are, the adjustment for wider markers of the food environment such as large supermarkets and convenience outlets as covariates in the same model and the use of continuous count and quartiles of food outlets as exposure variables. Treating environmental availability as relative concepts such as quartiles allows relative comparisons between levels of availability. However, as suggested by Lamb and White (23) relative measures leads to a loss of information and a lack of comparability between studies since the choice of cut-point is based on the sample distribution. The importance of adjusting for different covariates in the food environment-obesity relationship was demonstrated within a recent paper cited in many UK public health briefings. It showed evidence of an association between fast-food outlets and body mass index (BMI) (24), however, adjustment for supermarkets proved to be critical in determining study outcomes. In models that did not adjust for supermarkets, no relationship was demonstrated between fast-food outlets and obesity. Other studies have also started to adjust for supermarkets (25), however the conceptual basis for this adjustment has not been further explored or justified.

Few papers explicitly demonstrate and justify the conceptual framework for the exposure-outcome relationship and why adjustment for wider markers of the food environment in the same model is required. For instance, in the relationship between fast-food outlets and obesity, large supermarkets and convenience stores may be hypothesised to be a competing exposure or important covariate that impacts on the obesity-fast-food relationship. In some cases, the competing exposure i.e. large supermarkets and main exposure i.e. fast-food are assumed to be causally unrelated but may be correlated which is supported by recent evidence (26-28). It is also likely that there is an antecedent/latent variable (observed or unobserved) that causes both, for example, cost of land or a myriad of other factors. In this instance, inclusion of the competing exposure (large supermarkets and/or convenience or other food retail) is shown to be desirable as it is shown to improve model precision. This is represented visually in Figure 1. If authors believe there to be a sound conceptual basis for the inclusion of other food outlets then they are often included within the same model. If we trust the logic above, then large supermarkets must be included in the model as a competing exposure; the same reasoning can be applied for convenience or other food retail outlets.

INSERT FIGURE 1 HERE

The association between fast-food outlets and obesity may also differ by age due to differences in mobility patterns from younger to older adults. Large datasets present an opportunity to investigate the association between fast-food outlet availability and obesity, and any variation by individual-level factors such as age. Previous research shows how low socioeconomic status confers environmental vulnerability, exaggerating the impact of increased fast-food outlet availability, resulting in excess overall levels of, and inequalities in, BMI and obesity (29). It is also reasonable to suggest that fast-food outlet availability differentially relates to obesity according to age (30). However, little evidence internationally has considered an interaction with age (31). This study will investigate associations between residential fast-food outlet availability and obesity, explore the impact of methodological diversity on associations seen, and explore if this relationship varies by age.

Methods

Participants and settings

The sample used in this cross-sectional analysis was collected during wave I of the Yorkshire Health Study (YHS) which has been reported previously (32). Briefly, the YHS is a longitudinal

observational cohort study collecting information on the residents from the Yorkshire and Humberside region in England. It aims to inform National Health Service (NHS) and local authority health-related decision making in Yorkshire (32). Data were collected on current and long-standing health, health care usage and health-related behaviours, with a particular focus on weight and weight management.

Wave I data contains records on 27,806 individuals (2010-12) from 11 boroughs within the Yorkshire and Humber region (99.1% of whom reside in South Yorkshire) (Figure 2). Participants in the cohort are older than in the total South Yorkshire population with a higher proportion of females. The majority of participants also reported being of White ethnicity (94.1%), which was over representative of the ethnic group (2011 Census; 90.5%). Adults living within the study area with a valid self-reported height, weight, postcode, ethnicity and gender were included. This resulted in 22,889 participants used for analysis. Ethical clearance was granted by the ethics committee of the Carnegie Faculty, Leeds Beckett University and informed consent to participate in the study was obtained from all participants.

Outcome variables

The height (cm), weight (kg) of each participant was self-reported. Body mass index (BMI) was calculated by the researcher as weight (kg)/height^2 (m). Participants were then split dichotomously based on their BMI into obese (BMI ≥30) or not obese (BMI <30).

Food environment availability

PoI (Point of Interest) food environment data

Data on food outlet locations was obtained from The Ordnance Survey (OS) from the Point of Interest (PoI) data source which contains the location of all commercial facilities across England. The facilities are geocoded to an address location usually within a building footprint wherever possible (79.87% of features). If not they are usually positioned to an adjacent address or location for non-addressable features (27.21%). The remaining PoIs are positioned to the road within the address or location (0.85%) or within the geographical locality (0.20%). A recent study has validated the PoI data as having good agreement with street audits of food outlets (16). PoI food outlets were obtained covering the study area (Yorkshire) at the time of the data collection (2012) and were then mapped in ArcGIS. Food outlets were extracted using proprietary classifications and then categorised by the researcher into three groups of i) fast-food outlets (comprising of the proprietary classifications “fast-food and takeaway outlets”, “fast-food delivery services” and “fish and chip shops” e.g. Domino’s) ii) large supermarkets (proprietary classifications contained “supermarket chains” e.g. Tesco, Sainsbury’s, or Waitrose superstores) and (iii) convenience and other food outlets (proprietary classifications

contained other food outlets which included but was not limited to "restaurants", "convenience stores", and "bakeries" e.g. Tesco Express) (see supplementary materials for breakdown of classifications).

Covariates

Identifying potential covariates within the built environment and health literature remains problematic (33). However, based on previous literature, we controlled for individual-level factors that may explain an individual's BMI and/or access to the food environment. Non-modifiable personal characteristics of age, gender (male or female) and ethnicity (white or non-white) were each included since they each display associations to BMI (34, 35). Area-level variables of rural or urban classification and the level of deprivation for the neighbourhood (Lower Super Output Area (LSOA)) an individual resided in (36) were also included. A LSOA is a geographical area that typically contains a minimum population of 1000 and a mean of 1500. Rural or urban classification of the LSOA was classified as either rural or urban in line with local government classifications (37). We used the Index of Multiple Deprivation (IMD) 2010 since it provides a multidimensional measure of deprivation and is commonly used by Local Governments (36). Continuous IMD scores were assigned to the LSOA of each individual, as determined by their geocoded residential postcode. Neighbourhood deprivation has been shown to be associated both to BMI and the food environment; particularly fast-food outlets (38, 39).

Neighbourhood definition

To define a neighbourhood boundary, the postcode of each participant was geocoded using the home postcode. Whilst little consensus exists at present, a neighbourhood boundary was then defined using a radial (Euclidean) buffer of 2km centred on these coordinates within ArcGIS (20). Based on use in previous research (21, 40, 41) neighbourhood was defined as a 2km radial buffer as this is hypothesised as a distance easily accessed when driving (42). We acknowledge that neighbourhoods are difficult to define as individuals are known to operate outside a radial buffer or administratively defined area (43, 44). However, sensitivity analyses (see supplementary material) also showed little difference in associations when using 1600m radial buffers which are hypothesised to better reflect walking behaviours (45). A 2km radial buffer therefore accounts for multiple forms of transport - walking and car – two forms of transport that are commonplace within the UK. The number of food outlets falling within the 2km buffer around an individual's home was represented by count of food outlets.

Statistical analyses

Participant characteristics were summarised using descriptive statistics. The food environment varied considerably between each individual. We modelled food outlet data in quartiles using dummy variables (Q1 lowest availability, Q4 highest availability). Quartiles were based on population, so each quartile contained approximately the same number of participants. A binary outcome of obese or not was then created to allow for binary logistic regression (odds ratios (OR) and 95% CI (confidence intervals)) which was used as the analysis in all the three following approaches. The OR represents the odds that an outcome (obesity) will occur given a particular exposure (food environment) (46). First, binary logistic regression estimated associations between fast-food outlets and obesity adjusting for age, gender, ethnicity, area-level deprivation, and rural or urban classification. Second, large supermarkets and convenience or other food outlets were added sequentially to adjust for wider markers of the food environment and fast-food outlets were modelled by both quartile and count. Third, an interaction between the food environment and age was then carried out to assess if the relationship between fast-food outlets and obesity varied by age (years). All statistical analyses were performed in STATA IC version 14.

Results

Sample characteristics

Descriptive statistics for the study sample (n=22,889) are shown in Table 1. Overall, slightly fewer participants were male (44.66%) and most were White British (96.45%). The average BMI was 26.56 and a large proportion of the sample were overweight (37.1%) or obese (20.0%). The food environment varied at the individual level substantially. For instance, the average individual was surrounded by 8.12 (SD=9.52) and 1.28 (SD=1.21) fast-food outlets and supermarkets respectively. Individuals with a higher fast-food outlet availability resided in areas that were more deprived, were largely urban and were less likely to have residents that were white ethnicity. The prevalence of obesity was highest in Q3 with 24.5% of individuals obese, Q4 was on average the youngest (51.78 years) while Q1 had the highest proportion of individuals aged 55 and over.

INSERT TABLE 1 HERE

Overall, 99.1% of the study population were from South Yorkshire which includes Doncaster, Sheffield, Barnsley, or Rotherham (Figure 2). While 20.0% of the sample were obese, the prevalence was highest within Doncaster, with 24.3% of individuals obese and lowest in

Sheffield with 17.3% of individuals obese. Within Barnsley and Rotherham, 22.2% and 19.7% of individuals were obese respectively.

INSERT FIGURE 2 HERE

Fast-food outlets, obesity and adjustment for wider markers of the food environment

Figure 3 demonstrates associations between fast-food outlets and obesity. Data (OR, 95% CI) from full models are presented in tabular form within supplementary material. Figure 3 shows that compared to those individuals with the lowest availability of fast-food outlets (Q1) those with the highest availability (Q4 OR=0.93 [95% CI 0.84, 1.03]) were no more likely to be obese. However, statistically significant effects were seen for those with slightly more availability (Q2 OR=1.11, 95% CI 1.02, 1.21]; and Q3 OR=1.19 [95% CI 1.08, 1.32]). Furthermore, the same overall pattern for fast-food outlets was observed regardless of the adjustment made for wider markers of the food environment (Figure 3). Compared to individuals within Q1 (0-2 fast-food outlets) those who had the highest availability of fast-food outlets (11+ fast-food outlets) were at no greater risk of obesity. However, within Q3 (6-10 fast-food outlets) an increased odds ratio was observed (relative to Q1). In contrast, this did not change in effect size or statistical significance when including wider markers of the food environment. Although, the effect within Q2 (3-5 fast-food outlets) was no longer statistically significant effect sizes remain constant. Adjustment for supermarkets and convenience or other food retail outlets did not change the magnitude or direction of relationships observed between fast-food outlets and obesity. Sensitivity analyses by different definitions of neighbourhood and by quartile or continuous measures showed substantively the same findings (supplementary material).

INSERT TABLE 2 HERE

Differences in the relationship between fast-food outlets and obesity by age

As shown below within Figure 4 there were small differences when comparing mean BMI by quartile of fast-food outlets and age group. Mean BMI increased across all quartiles as age increased with a small decrease in those aged 75+, yet there appeared to be few differences between quartiles. To assess change in the association for obesity by age, an interaction between the fast-food outlets and age (years) was added to the model. Overall, there was a significant interaction between age and fast-food outlet availability ($p<0.05$) suggesting that the association between food-outlet availability and risk of obesity was dependent on age for those with the highest availability of fast-food outlets (Q4). For an increase in age of 1 year, the effect of moving from Q1 to Q4 on the odds of obesity was 1.010 [1.004, 1.015] times

higher. Continuous count of fast-food outlets showed substantively the same small effects however, relative effects are presented for ease of interpretation and to compare relative effects.

INSERT FIGURE 4 HERE

Discussion

This study investigated if the relationship between residential fast-food outlet availability and obesity varied due to methodological diversity. Furthermore, it is one of the first studies to investigate the association between fast-food outlet availability and obesity by age. The association between fast-food outlet availability and obesity was inconsistent with methodological diversity explaining little variation in associations seen. This paper proposes the use of a more comprehensive conceptual model adjusting for wider markers of the food environment. In addition, a statistically significant interaction by age was noted which may reflect an individual's change in mobility pattern as they age. This study offers tentative evidence that the association between fast-food outlets and obesity varies by age for those with highest availability of fast-food outlets. Cross-sector policy action including Planning and Public Health and future research may benefit from moving away from considering universal environmental-level interventions to considering the impact of such interventions by population groups.

Quantifying associations between residential fast-food outlet availability and obesity remains challenging. While some studies have demonstrated positive associations (24, 47, 48) others, including several systematic reviews, longitudinal and experimental studies have shown more inconsistent associations and questioned the extent to which the physical environment may contribute to obesity (14, 15, 48, 49). Findings in this study highlight that relative to individuals with the lowest availability of fast-food outlets (Q1), individuals who had a slightly higher availability (Q2 and Q3) were more likely to be obese. Despite this, there was no evidence that individuals with the highest availability of fast-food outlets (Q4) were at any greater risk of obesity. Similarly, substantively no association was shown when modelled by continuous count of fast-food outlets. Evidence linking the fast-food environment and obesity has already been identified as inconsistent (15, 50). Whilst not disclaiming the importance of residential fast-food outlet availability, or the nutrient poor, energy dense content of fast-food, results in this study do advise caution for future policy interventions restricting residential geographical availability alone. Evidence from the US and Australia also support this claim, suggesting that environmental modifications with respect to the supply or access of the food environment may have little direct impact on diet-related behaviours (13, 51).

Despite seeming inconsistent, the protective effects of urban density or urban sprawl may offer an explanation as to why those individuals with the highest availability of fast-food outlets (Q4) were at no increased risk of obesity. In a review of 132 studies (52), a large UK based study (n=419,000 in 22 cities) (53), and other evidence (54-56), a high residential density was associated with lower risk of obesity. In a multi-country study involving 6822 adults across 14 cities, a consistent positive association between net residential density and physical activity was reported (54). Increased residential density is often related to compactness, greater access to destinations, and walkability, and thus active travel (53). Although we were not able to test this effect it could be that the built environment, through walkability or urban sprawl, may be confounding the association with obesity for those in highly populated areas who also have the highest availability of fast-food outlets (Q4). This null association is also perhaps not surprising considering the multifaceted aetiology of obesity (57, 58) and this lack of consensus could also be due to methodological diversity (59).

There has been little progress in developing or transparently reporting robust conceptual frameworks. Consequently, researchers often adjust for different covariates when investigating associations between fast-food environment outlets and obesity (60, 61). There seems to be a sound conceptual basis for the adjustment of other food outlets such as large supermarkets within statistical models to account for the impact of the wider food environment. Previous research has shown this adjustment to be highly important in detecting associations (24). However, in this study, adjustment for large supermarkets and convenience or other food retail outlets, did not substantially change conclusions. Nevertheless, careful consideration must be given to the approach to statistical analysis and the development of statistical models as this has shown in previous research to change conclusions significantly.

While this study provides novel contributions by examining areas of methodological diversity in a large cohort of UK adults, it also acknowledges that this association may change by age. Although effects were small, this study confirms such theory. This is plausible as first, body weight is known to increase as individual's age (62-64). Furthermore, other research has shown that mobility trajectories of older men and women increased during young adulthood and declined in early adulthood through to older adulthood (31, 65-67). Importantly, associations for mobility in this previous research changed across the life course by gender (31). It is reasonable to suggest that the residential neighbourhood environment may therefore play a more important role in shaping daily life to a greater extent in individuals who remain closer to home such as older adults with reduced mobility or those who live within close amenity to many facilities in city centres.

This study has direct practical relevance for public health and policymakers such as town planners as it questions the rigour of current methods used. Moreover, it is among the first to explicitly define and justify the exposure-outcome relationship. Methodological diversity currently presents two significant practical challenges. First, for researchers it is difficult to compare between studies; second, it is then difficult for policymakers to translate this diverse research into evidence-based policy. Future research should better justify the adjustment for different covariates such as large supermarkets and convenience stores. Moreover, researchers should be encouraged to report their methodological choices in detail. Policymakers should also pay attention to the methodological approach used by the researcher as this may change outcomes seen. At the very least care should be exercised when collating study findings that have employed different methodological approaches. Finally, rather than applying universal rules across population groups, it may be that some populations, for instance, younger adults are more susceptible or resolute to the effect of the obesogenic environment than others. Consequently, it may be useful for policymakers to consider the impact of any planned fast-food outlet interventions by age.

Strengths and limitations

The findings within this study should be considered within its limitations. Relying on cross-sectional data limits our ability to draw causal conclusions. Furthermore, obesity within this study was defined by self-reported height and weight which can produce biased estimates of BMI (68). Moreover, we had no evidence of actual food consumption behaviours, therefore, it remains unconfirmed that greater availability drives use. Importantly, classifying types of food outlets was also arbitrary and may have contributed to the inconsistent associations. For example, many studies classify food outlets differently where a simplified classification of healthy (supermarkets and grocery) and unhealthy (fast-food, and convenience) is used. It is important to note that unhealthy foods may indeed be bought in a supermarket or grocery store whilst healthy items may be bought in a convenience store.

Neighbourhood was defined using a 2km radial buffer. Although this buffer was based on the best available evidence, how to define a neighbourhood remains a limitation across the evidence base as it is known individuals may operate beyond a radial buffer. Future research should capture actual purchasing behaviours to determine where and what participants actually consume. US studies have demonstrated that objectively measured distance to food outlets may not be a key predictor of obesity risk but other factors such as price of foods are important factors to consider (69, 70). It is also worth considering that PoI data was geocoded using provided coordinates for precise location. There is therefore, the potential for spatial

misclassification of participant fast-food outlet access when compared to different secondary datasets.

This study offers one of the largest (n=22,889) local level analyses of associations between the food environment and obesity. It makes use of a large cohort population specifically designed for informing NHS and local authority health-related decision making in relation to weight and weight management (32). Furthermore, findings were confirmed across different statistical models using a variety of measures of the food environment. Future research should explore if these findings hold for a different study area or contexts and develop a clear consensus for the adjustment of covariates. A final suggestion for future research is to further investigate the importance of including a walkability measure as a covariate in models too, particularly as this may explain some of the associations seen in those environments which are very urban and highly walkable neighbourhoods.

Conclusions

The study investigates the association between fast-food outlet availability and obesity as well as exploring the impact of methodological diversity on outcomes which limits the comparability of evidence in this research domain. The key finding was despite being in theory a more precise model, by adjusting for large supermarkets and convenience stores in the same model, associations between fast-food and obesity remained substantively the same. Finally, although effects were small, this study is one of the first internationally to offer tentative evidence that the association between fast-food outlets and obesity varies by age. This supports the notion that some populations are more susceptible to an obesogenic environment than others.

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Tables

Table 1 – Descriptive characteristics for dependent and independent variables by quartile of fast-food outlet availability and overall

	Q1 (n=6,471)	Q2 (n=7,234)	Q3 (n=3,865)	Q4 (n=5,319)	Overall (n=22,889)
Dependent variables					
BMI	26.32 (4.68)	26.69 (5.08)	27.21 (5.39)	26.18 (5.00)	26.56 (5.02)
Overweight (%)	38.0	37.9	37.6	34.5	37.1
Obese (%)	18.3	20.2	24.5	18.5	20.0
Individual level covariates					
Age	56.88 (16.05)	55.42 (16.26)	55.09 (16.80)	51.78 (17.01)	54.93 (16.58)
Age group (%)					
18-25	286 (4.4)	356 (4.9)	260 (6.7)	373 (7.0)	1275 (5.6)
26-35	504 (7.8)	643 (8.9)	341 (8.8)	815 (15.3)	2303 (10.1)
36-45	822 (12.7)	1005 (13.9)	504 (13.0)	796 (15.0)	3127 (13.7)
46-55	1086 (16.8)	1349 (18.6)	659 (17.1)	867 (16.3)	3961 (17.3)
56-65	1574 (24.3)	1669 (23.1)	909 (23.5)	1109 (20.8)	5261 (23.0)
66-75	1450 (22.4)	1468 (20.3)	794 (20.5)	1015 (19.1)	4727 (20.7)
75+	749 (11.6)	744 (10.3)	398 (10.3)	344 (6.5)	2235 (9.8)
Gender					
Female (%)	55.9	55.2	54.7	55.3	55.34
Ethnicity					
White (%)	98.5	97.2	96.4	92.9	96.45
Area level covariates					
IMD score	18.23 (12.91)	21.54 (15.18)	31.71 (15.34)	28.16 (18.49)	23.86 (16.27)
Rural (%)	20.01	2.62	13.81	0.00	11.35
Food environment					
Fast-food	0.92 (0.83)	4.59 (1.15)	7.91 (1.06)	21.80 (10.92)	8.12 (9.52)
Supermarkets	0.46 (0.58)	1.20 (1.04)	1.53 (1.16)	2.19 (1.32)	1.28 (1.21)
Convenience or other food	5.71 (3.63)	12.69 (5.24)	18.04 (8.37)	47.32 (33.43)	19.67 (23.08)

Data is mean (standard deviation) unless stated otherwise. Max., maximum; Min., minimum; s.d. standard deviation. IMD = Index of Multiple Deprivation.

Table 2 – Exploring the interaction between age and the availability of fast-food outlets without and with adjustment for wider markers of the food environment.

	Without adjustment	With adjustment
Fast-food outlets*Age		
Q1	REF	REF
Q2	0.996 [0.991, 1.002]	0.996 [0.991, 1.002]
Q3	1.001 [0.995, 1.007]	1.001 [0.995, 1.007]
Q4	1.010 [1.004, 1.015]*	1.009 [1.003, 1.015]*
Fast-food outlets		
Q1 (0-2)	REF	REF
Q2 (3-5)	1.34 [0.97, 1.84]	1.29 [0.93, 1.79]
Q3 (6-10)	1.08 [0.75, 1.54]	1.06 [0.74, 1.53]
Q4 (11+)	0.56 [0.40, 0.81]*	0.62 [0.43, 0.90]*
Age	1.01 [1.01, 1.02]*	1.01 [1.01, 1.02]*
Gender		
Female	1.09 [1.02, 1.17]*	1.09 [1.02, 1.17]*
Ethnicity		
White	0.93 [0.78, 1.12]	0.95 [0.78, 1.14]
Area-level deprivation		
Q1	REF	REF
Q2	1.37 [1.23, 1.52]*	1.36 [1.22, 1.50]*
Q3	1.74 [1.57, 1.92]*	1.75 [1.58, 1.94]*
Q4	2.22 [2.00, 2.45]*	2.20 [1.99, 2.44]*
Rural/urban classification		
Rural	0.89 [0.79, 1.01]	0.89 [0.78, 1.01]
Large supermarkets		
Q1 (0-0)	REF	REF
Q2 (1)	-	1.10 [1.01, 1.20]*
Q3 (2)	-	1.16 [1.04, 1.30]*
Q4 (3+)	-	0.97 [0.86, 1.09]
Convenience or other food		
Q1 (0-7)	REF	REF
Q2 (8-13)	-	1.08 [0.97, 1.20]
Q3 (14-22)	-	1.04 [0.92, 1.18]
Q4 (23+)	-	0.93 [0.80, 1.09]

Reference category = Male, rural, and white. Value = OR [95% CI]; * = p<0.05.

Figures

Figure 1A) Commonly employed exposure – outcome model but with the addition of large supermarkets

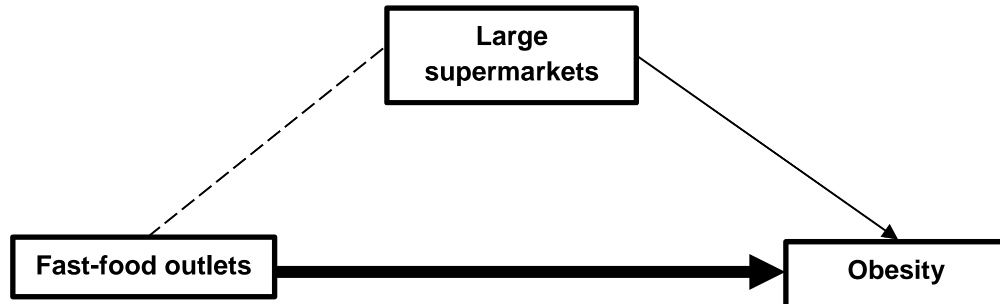
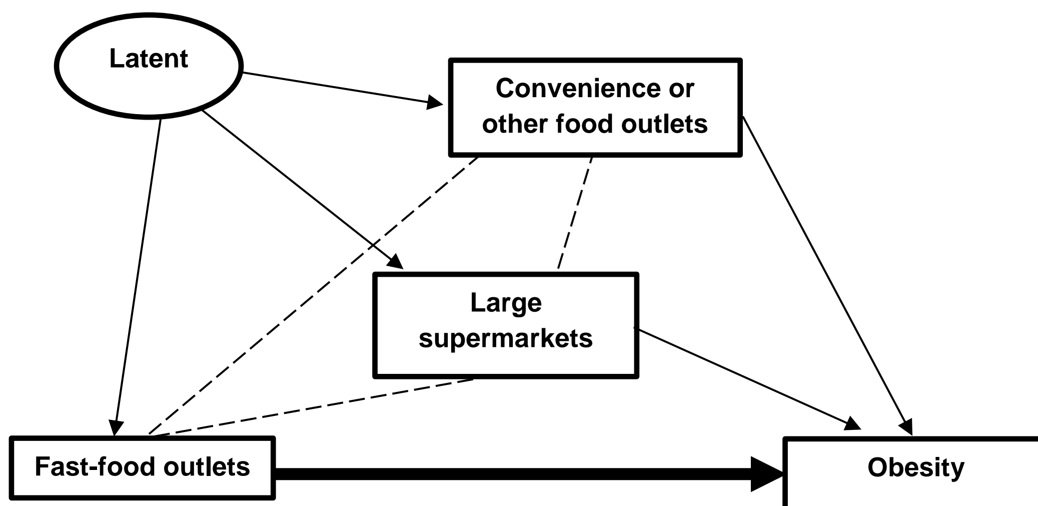


Figure 1B) Exposure outcome relationship with addition of large supermarkets and convenience or other food retail outlets, most likely correlated with each other and latent variable



Key
- - - - - - Causally not related but correlated
➡ Exposure – outcome relationship
→ Pathway

Note: adjustment for covariates such as education or area-level deprivation are not included for visual ease of exposure – outcome relationship and addition of wider markers of the food environment.

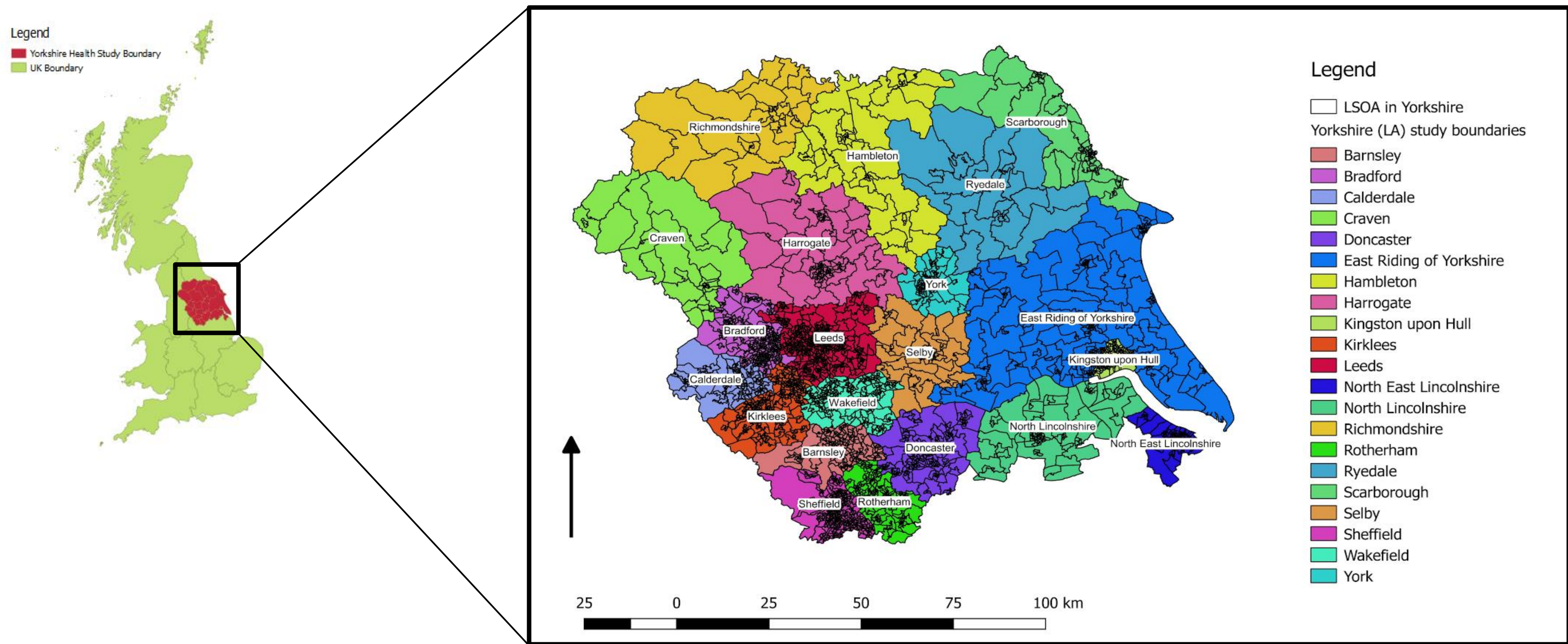


Figure 2 – The Yorkshire and Humber region within the United Kingdom where Yorkshire Health Study participants were recruited from (99.1% of study participants within wave one were from Sheffield, Barnsley, Doncaster or Rotherham).

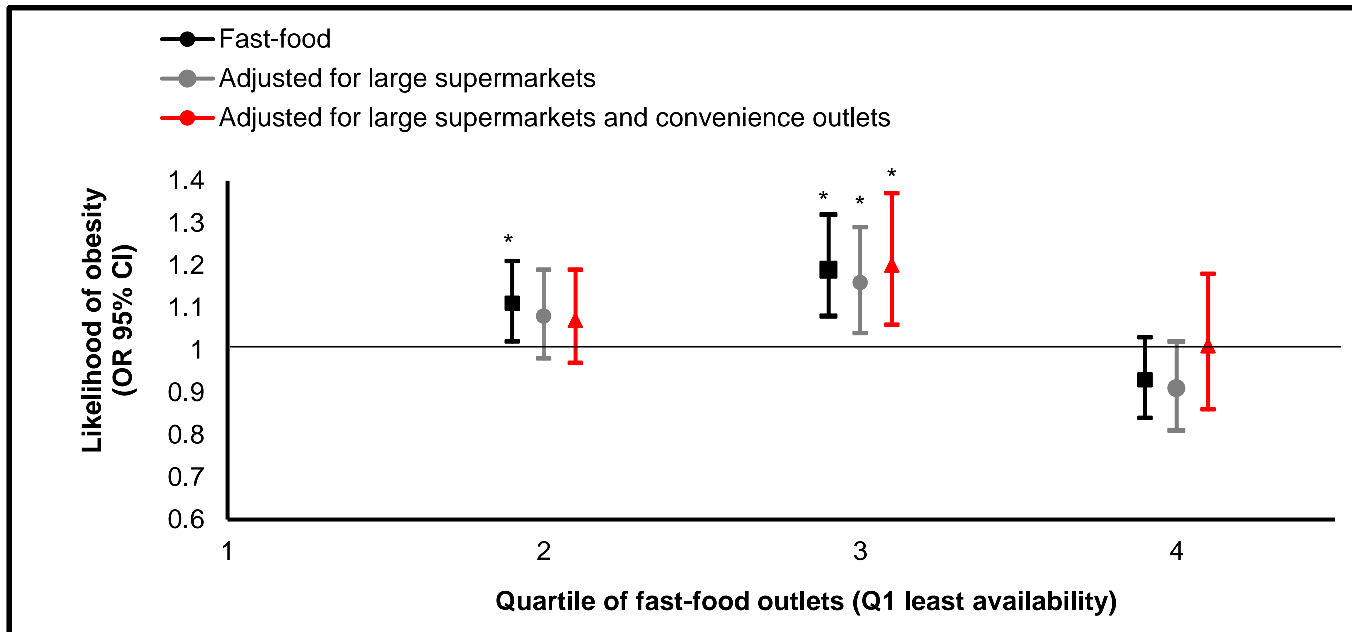


Figure 3 – The relationship between fast-food outlets and obesity (black), adjusted for large supermarkets (grey) and adjusted for large supermarkets and convenience or other food retail outlets (red).

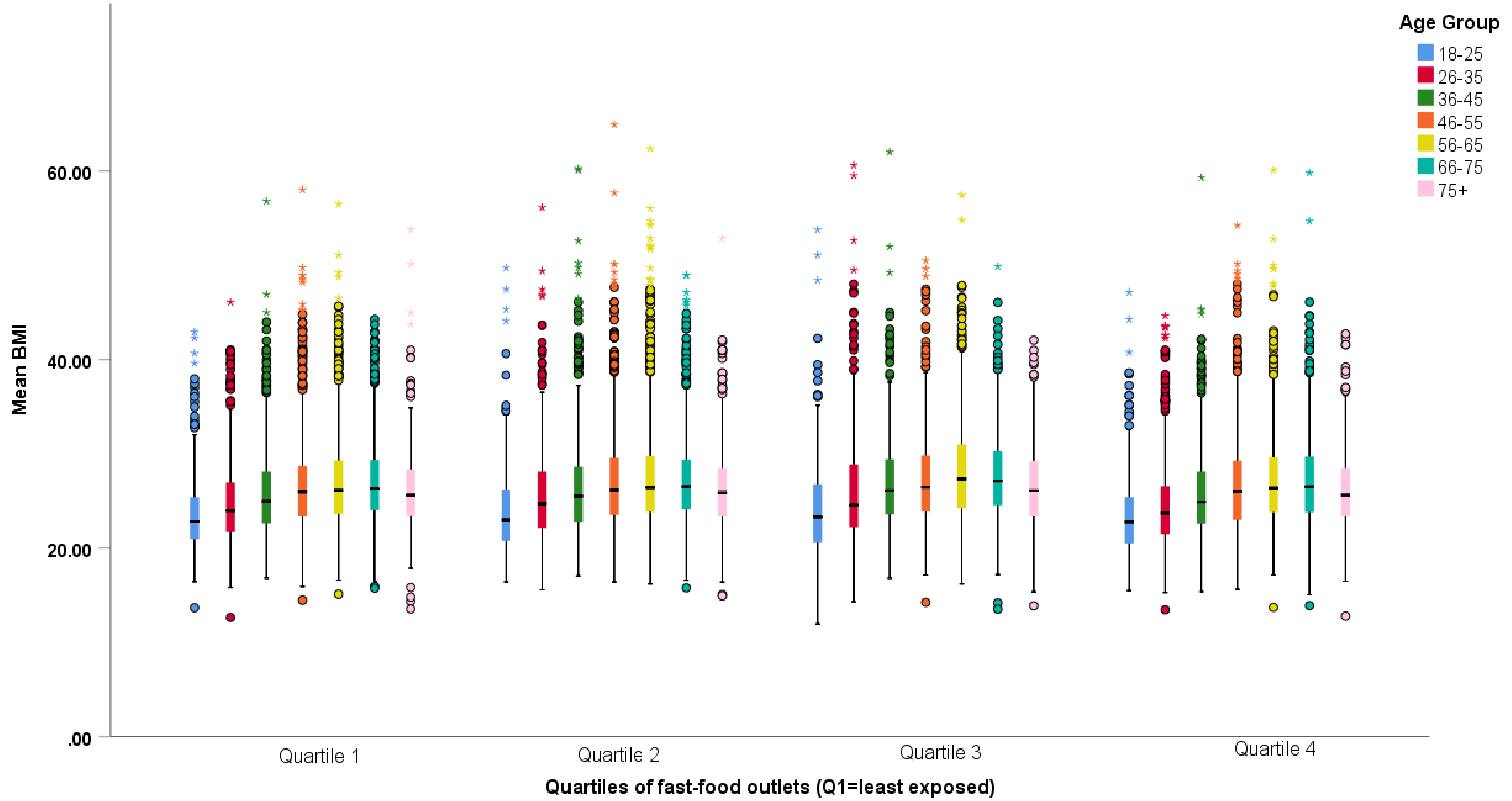


Figure 4 – A box plot of mean BMI by quartile of fast-food outlets and age group (data that is an outlier is a circle or star).

Supplementary file

Table S1 – Comparing change in associations between the built environment and obesity across different buffer sizes and types

	2km buffer		1600m buffer		LSOA density (km^2)
	OR [95% CI]		OR [95% CI]		OR [95% CI]
Fast-food					
Q1 (0-2)	REF	Q1 (0-1)	REF	T1 (0-0)	REF
Q2 (3-5)	**1.11 [1.02-1.21]**	Q2 (2-3)	**1.15 [1.03-1.28]**	T2 (0.1-2.2)	1.09 [0.98-1.22]
Q3 (6-10)	**1.19 [1.08 -1.32]**	Q3 (4-7)	**1.21 [1.10-1.34]**	T3 (2.3+)	0.96 [0.87-1.06]
Q4 (11+)	0.93 [0.84-1.03]	Q4 (8+)	0.98 [0.87-1.10]		

Reference category = Male, rural area and white
Value = OR [95% CI]; all models adjust for IMD, gender, LSOA rural/urban classification, ethnicity and age

Table S2 *- Definitions of food outlets within PoI databases*

PoI database classifications

Group	Category	Class	Description	Category
01	01	0006	Hotels, motels, country houses and inns	Convenience and other food retail
01	02	0013	Cafes, snack bars and tea rooms	Convenience and other food retail
01	02	0018	Fast food and takeaway outlets	Fast-food
01	02	0019	Fast food delivery services	Fast-food
01	02	0020	Fish and chip shops	Fast-food
01	02	0034	Pubs, bars, and inns	Convenience and other food retail
01	02	0043	Restaurants	Convenience and other food retail
09	47	0661	Bakeries	Convenience and other food retail
09	47	0662	Butchers	Convenience and other food retail
09	47	0663	Confectioners	Convenience and other food retail
09	47	0699	Convenience stores and independent supermarkets	Convenience and other food retail
09	47	0665	Delicatessens	Convenience and other food retail
09	47	0666	Fishmongers	Convenience and other food retail
09	47	0667	Frozen foods	Convenience and other food retail
09	47	0668	Green and new age goods	Convenience and other food retail
09	47	0669	Grocers, farm shops and pick your own	Convenience and other food retail
09	47	0670	Herbs and spices	Convenience and other food retail
09	47	0671	Alcoholic drinks including off licences and wholesalers	Convenience and other food retail
09	47	0768	Cash and carry	Convenience and other food retail
09	47	0672	Organic, health, gourmet and kosher foods	Convenience and other food retail
09	47	0819	Supermarket chains	Large supermarket
09	47	0798	Tea and coffee merchants	Convenience and other food retail

Table S3 *– Odds ratios (95% CI) from associations between fast-food outlets and obesity as well as adjustment for wider markers (large supermarkets, convenience and other food retail outlets)*

	OR [95%CI]		
Fast-food outlets			
Q1 (0-2)	REF	REF	REF
Q2 (3-5)	1.11 [1.02, 1.21]*	1.08 [0.98, 1.19]	1.07 [0.97, 1.19]
Q3 (6-10)	1.19 [1.08, 1.32]*	1.16 [1.04, 1.29]*	1.20 [1.06, 1.37]*
Q4 (11+)	0.93 [0.84, 1.03]	0.91 [0.81, 1.02]	1.01 [0.86, 1.18]
Age	1.01 [1.01, 1.01]*	1.01 [1.01, 1.01]*	1.01 [1.01, 1.01]*
Gender			
Female	1.10 [1.03, 1.17]*	1.10 [1.04, 1.29]*	1.10 [1.03, 1.17]*
Ethnicity			
White	0.88 [0.73, 1.06]	0.87 [0.74, 1.07]	0.90 [0.74, 1.08]
Area-level deprivation	1.02 [1.01, 1.02]*	1.02 [1.01, 1.02]*	1.02 [1.01, 1.02]*
Rural/urban classification			
Rural	0.86 [0.76, 0.96]*	0.85 [0.76, 0.96]*	0.86 [0.76, 0.97]*
Large supermarkets	REF	REF	REF
Q1 (0-0)	-	1.11 [1.02, 1.21]*	1.10 [1.01, 1.20]*
Q2 (1)	-	1.16 [1.04, 1.29]*	1.15 [1.03, 1.28]*
Q3 (2)	-	1.00 [0.88, 1.12]	1.00 [0.88, 1.12]
Q4 (2+)			
Convenience or other food			
Q1 (0-7)	REF	REF	REF
Q2 (8-13)	-	-	1.05 [0.95, 1.17]
Q3 (14-22)	-	-	1.01 [0.90, 1.14]
Q4 (22+)	-	-	0.90 [0.78, 1.06]

Reference category = Male, rural, and white.. Value = OR [95% CI]; * = p<0.05.

***Table S4 –** Sensitivity analyses for continuous count of food outlets*

The arbitrary categorisation of quartiles of exposure leads to a loss of information and a lack of comparability between studies since the choice of cut-point is based on the sample distribution. Sensitivity analyses were therefore carried out to explore methodological diversity in terms of comparing quartiles of exposure with count of fast-food outlets as the exposure. We anticipated issues raised by Lamb et al. (2015) however, results showed substantively same effects when using obesity and continuous count of food outlets. We follow these procedures to utilise all the available information available in the data, avoiding a loss of power as experienced when categorisation is adopted. We retained all available information by using the continuous exposure, however substantively the same small effects were noted below and there were few differences by neighbourhood buffer.

	2km radial buffer	1.6km radial buffer
Fast-food outlets		
Count	0.99 [0.99, 0.99]*	1.00 [0.99, 1.01]
Age	1.01 [1.01, 1.01]*	1.01 [1.01, 1.01]*
Gender		
Female	1.09 [1.02, 1.17]*	1.10 [1.03, 1.18]*
Ethnicity		
Non-white	0.88 [0.79, 0.99]*	0.86 [0.78, 1.01]
Area-level deprivation		
Q1	REF	REF
Q2	1.31 [1.18, 1.45]*	1.31 [1.18, 1.46]*
Q3	1.65 [1.50, 1.83]*	1.65 [1.51, 1.84]*
Q4	2.06 [1.87, 2.29]*	2.05 [1.86, 2.29]*
Rural/urban classification		
Urban	0.89 [0.79, 0.99]*	0.90 [0.80,1.01]
Large supermarkets		
Count	0.99 [0.95, 1.03]	0.98 [0.96, 1.02]
Convenience or other food		
Count	1.00 [0.99, 1.02]	0.99 [0.98, 1.01]

Reference category = Male, rural, and white. Value = OR [95% CI]; * = $p<0.05$.