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**Neighbourhood typologies and associations with body mass index and obesity: a
cross-sectional study**

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Latent class analysis, food outlets, physical activity facilities, parks, body mass index, obesity

Abstract

Little research has investigated associations between a combined measure of the food and physical activity (PA) environment, BMI (body-mass-index) and obesity. Cross-sectional data (n=22,889, age 18-86 years) from the Yorkshire Health Study were used [2010-2013]. BMI was calculated using self-reported height and weight; obesity=BMI \geq 30. Neighbourhood was defined as a 2km radial buffer. Food outlets and PA facilities were sourced from Ordnance Survey Points of Interest (PoI) and categorised into 'fast-food', 'large supermarkets', 'convenience and other food retail outlets' and 'physical activity facilities'. Parks were sourced from Open Street Map. Latent class analysis was conducted on these five environmental variables and availability was defined by quartiles of exposure. Linear and logistic regression were then conducted for BMI and obesity respectively for different neighbourhood types. Models adjusted for age, gender, ethnicity, area-level deprivation, and rural/urban classification. A five-class solution demonstrated best fit and was interpretable. Neighbourhood typologies were defined as; 'low availability', 'moderate availability', 'moderate PA, limited food', 'saturated' and 'moderate PA, ample food'. Compared to low availability, one typology demonstrated lower BMI (saturated, b= -0.50, [95% CI= -0.76,-0.23]), while three showed higher BMI (moderate availability, b= 0.49 [0.27,0.72]; moderate PA, limited food, b=0.30 [0.01,0.59]; moderate PA, ample food, b=0.32 [0.08,0.57]). Furthermore, compared to the low availability, saturated neighbourhoods showed lower odds of obesity (OR=0.86 [0.75,0.99]) while moderate availability showed greater odds of obesity (OR=1.18 [1.05,1.32]). This study supports population-level approaches to tackling obesity however neighbourhoods contained features that were health-promoting and -constraining.

Introduction

One in four adults are currently obese; while recent evidence suggests that long-term trends of increasing body weight are starting to slow, the prevalence remains high (1, 2). Increasingly, research and policy are focusing on the environmental contributions for understanding these population-level patterns (3, 4). However, an extensive body of literature has shown inconsistent associations between aspects of the food environment such as supermarkets (5-10) or fast-food outlets (7, 11-14) and obesity. Furthermore, evidence demonstrating a relationship between the physical activity (PA) environment and obesity also remains equivocal (15-19).

Recent research has demonstrated that individual features of obesogenic neighbourhoods may cluster in the same locations (20). It is therefore worthy of consideration to not to treat each feature in isolation i.e. just fast-food. Developing multi-dimensional measures of both the food and physical activity (PA) environments may offer an alternative approach for representing the wider environmental influences on obesity. Previous studies have used a combined measure to delineate different urban contexts suggesting that individual experiences of neighbourhood context are multi-dimensional. However, combined measures of the environment may lack the appeal of identifying a specific availability point that can be addressed more easily through policy i.e. regulating the growth of just fast-food outlets (21). Capturing this clustering of neighbourhood features may be an opportunity to begin to more accurately reflect the wider range of environments that influence human behaviour and obesity (22).

Despite some evidence to suggest aspects of the food environment may cluster to form neighbourhood typologies, there is no clear pattern of co-occurrence when considering both PA and food environments (20). For instance, a comprehensive study that virtually audited the built environment using Google Streetview in London, Paris, Ghent and Budapest

demonstrated a complex picture (23) with four clusters of neighbourhoods existing. The typologies revealed that neighbourhoods were not always a simple linear distinction in their extent of 'obesogenic' features with some clusters containing features that were both potentially obesogenic and non-obesogenic. For example, aesthetically pleasing greener neighbourhoods which may promote PA were also those with a low presence of active transport facilities i.e. no bike lanes or foot paths. Current evidence often focuses on describing neighbourhood typologies, this study builds on existing work to investigate how different neighbourhood contexts around the home environment are associated with both body mass index (BMI) and obesity.

This study uses a large cohort that is specifically designed for informing local-level decision making on weight and weight management. The study first explores how aspects of the food and physical activity environment cluster and second, investigates the association between neighbourhood typologies, BMI, and obesity.

Methods

Study Sample

The sample used in this cross-sectional analysis was collected during wave one of the Yorkshire Health Study (YHS) (formerly the South Yorkshire Cohort Study) which has been reported in detail previously (24). Briefly, the YHS is an observational cohort study collecting information on the residents (aged 18-86 years) from the Yorkshire and Humber region in England. It aims to inform National Health Service (NHS) and local authority health-related decision making in Yorkshire. Data were collected on current and long-standing health, health care usage and health-related behaviours, with a focus on weight management. Wave one data collection contains records on 27,806 individuals (2010-12) from 11 boroughs within the Yorkshire and Humber region. Participants in the cohort are older than in the total South Yorkshire population with a higher proportion of females. The majority of participants were

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 height, weight, postcode, ethnicity, and gender were included resulting in 22,889 participants. Ethical clearance was granted by the ethics committee of the Carnegie Faculty, Leeds Beckett University.

Individual-level measures and covariates

Height (cm) and weight (kg) of participants was self-reported. BMI was then calculated for each participant as weight (kg)/height² (m). Participants were also split dichotomously based on their BMI into obese (BMI ≥ 30) or not obese (BMI < 30). Age, gender, ethnicity (White-British and other), deprivation score (Index of Multiple Deprivation) and rural or urban classification were included in all models as covariates. IMD provides a multidimensional measure of deprivation (based on 37 separate indicators, organised across seven distinct domains of; income deprivation; employment deprivation; health deprivation and disability; education, skills and training deprivation; crime; barriers to housing and services; and living environment deprivation) and is commonly used by Local Governments in the UK. IMD scores were assigned to the lower super-output area (LSOA) of each individual, as determined by their geocoded postcode. A higher IMD deprivation score equates to a higher level of deprivation. Rural or urban (urban areas are built up areas with $> 10,000$ people) classification of the LSOA was made in line with local government classifications (25).

Neighbourhood level measures

To define neighbourhood, the postcode of each participant was geocoded using home postcode. A neighbourhood boundary was then defined using a radial buffer of 2km centred on these coordinates within ArcGIS 10.4. Neighbourhood was defined as a 2km radial buffer as this is hypothesised as a distance easily accessible when driving (26). A 2km buffer in this case gives an approximate measure of availability within the home neighbourhood. It is

acknowledged that neighbourhoods are difficult to define as individuals are known to operate outside a radial buffer or administratively defined area (27). However, previous analyses (4) also showed little difference in associations when using 1600m radial buffers in the same study sample which are hypothesised to better reflect walking behaviours (28).

We considered a wide range of food and physical activity neighbourhood characteristics. Data on food outlet locations and physical activity facilities was obtained from The Ordnance Survey (OS), a national mapping agency in the United Kingdom which covers the island of Great Britain. Data were sourced from the Point of Interest (PoI) dataset covering the study area at the time of the data collection (2010-2012) which has been suggested as a viable source of secondary data (29) and was again mapped in ArcGIS 10.4. Classifications were defined based on a proprietary classification system within the PoI dataset. Food outlets were categorised into three groups of (i) large supermarkets, (ii) fast-food outlets and (iii) convenience or other food retail outlets. Fast-food outlets contained the PoI categories of “fast food and takeaway outlets”, “fast food delivery services” and “fish and chip shops”; large supermarket contained “supermarket chains” and convenience and other food outlets contained other food outlets which included but was not limited to “restaurants”, “convenience stores”, and “bakeries”. Physical activity (PA) facilities were included based on proprietary classification of “physical activity facilities”. Park data was obtained from Open Street Map. A park was defined as an open, green area for recreation typically open to the public that is in a town or city, national parks were not included in this dataset (30). Poles and parks falling within and intersecting with the 2km radial buffer were then identified through a point in polygon analysis in ArcGIS 10.4.

Statistical Analysis

To describe the study population and their respective neighbourhoods, means and standard deviations and percentages were calculated. Results were presented for both individual-level and area-level variables included within the analysis.

A latent class analysis (LCA) was conducted in STATA MP 14.2 using the five environmental variables (large supermarkets, fast-food outlets, convenience or other food retail, PA facilities and parks). The environment varied considerably between each individual. For instance, some individuals had no food outlets within a 2km buffer and others had 100 (Table 1). However, it is unlikely that an increase from 0-1 fast food outlets is the same as an increase from 101-102 fast food outlets. To account for this and model relative effect, we modelled food outlet data in quartiles using dummy variables (Q1 least exposed, Q4 most exposed). Quartiles were based on population so each quartile contained approximately the same number of participants. Parks were defined as tertiles due to the granularity of the data and to allow for consistency. LCA is a data driven method that identifies an unobserved or latent construct using the statistical relations among the variables (31). The goal of LCA in our study was to derive meaningful classes from a sample, assign participants to each class and then explore associations with both BMI and obesity. LCA derives mutually exclusive classes that maximize between-group variance and minimize within-group variance based on several model fit criteria.

The expectation-maximization (EM) algorithm was used for class derivation and assignment. The LCA operates with an aim of findings participants who are similar on a combination of attributes. To identify the ideal number of classes in the sample solutions of 1 to 10 classes were tested. Models were selected based on model fit statistics of the Bayesian Information Criterion (BIC) statistic, sample sizes per class and usefulness and substantive interpretation (31). Item-response probabilities of classes were then charted for visual interpretation based on each of the five variables which were modelled in quartiles of exposure. Item-response probabilities show the probability of an affirmative response to being part of each derived class (32). Mean values close to 1 indicate a strong degree of homogeneity and classification certainty. The class prevalence and item response probabilities were presented by latent class.

Next, we estimated associations between derived latent neighbourhood patterns (classes), BMI and obesity. All models adjusted for age, gender, ethnicity, area-level deprivation and rural or urban classification of the area. Two separate models were carried out, first, to estimate associations between classes and BMI a linear regression model (b, 95% CI) was used. A binary outcome of obese or not was then created to allow for logistic regression (odds ratios (OR) and 95% CI). Due to the high statistical power in the dataset and assumption that data were missing at random (Supplementary Material) missing data were dealt with by listwise deletion. All analyses were undertaken using STATA MP 14.2.

Results

3.1 Latent class analysis

Figure 1 shows model fit criteria based on the raw Bayesian Information Criterion (BIC) score for latent class solutions. A five-class solution was deemed best fit. Any solution above this resulted in smaller gains on model fit criteria and resulted in complex interpretability. The mean maximum posterior probabilities for the 5 classes were 0.90, 0.92, 0.89, 0.93 and 0.87 for classes 1 to 5 respectively, providing evidence of homogeneity for each subgroup.

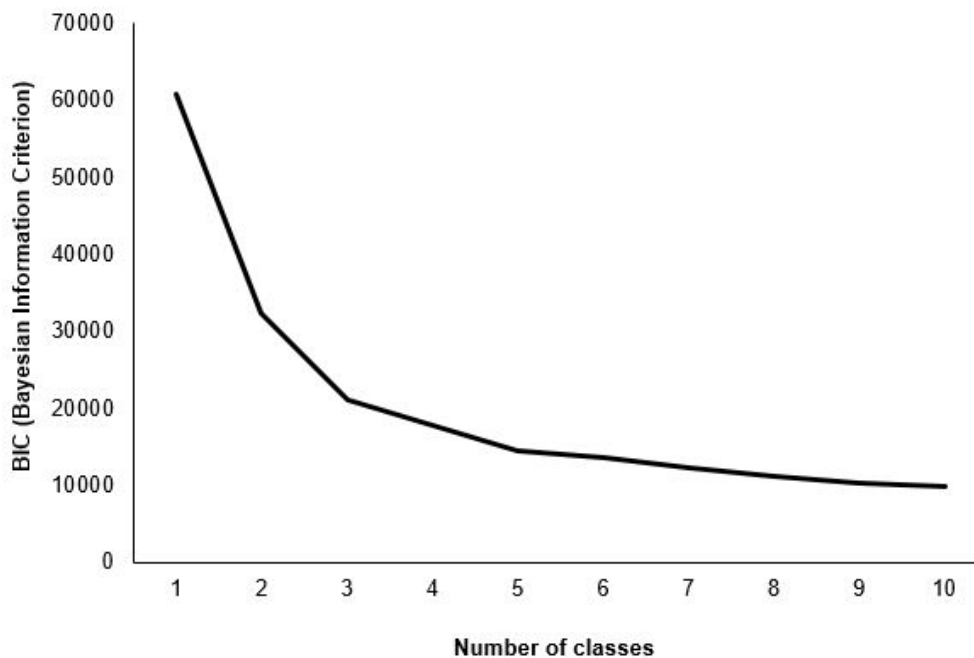


Figure 1 – Bayesian Information Criterion by number of classes

Five neighbourhood typologies were identified (Table 1). Class 1 (18.98% of participants) was labelled as 'low availability' and contained the lowest proportion of all types of neighbourhood amenities. Class 2 (33.32%) was defined as 'moderate availability' as it contained a moderate amount of both food outlets, PA facilities and parks. Class 3 (12.15%) was labelled as 'moderate PA, limited food' although PA environment availability was moderate, it had lower availability of convenience/other food outlets and large supermarkets and the lowest availability of all classes to fast-food outlets. Class 4 (13.57%) was defined as 'saturated availability', with high availability to all types of amenities across the food (particularly fast-food and other food or convenience outlets) and PA environment. Finally, class 5 (21.99%) was defined as 'moderate PA, ample food' with moderate access to PA environment and high availability to all food outlets (particularly fast-food and other food or convenience outlets). Neighbourhood typologies are shown visually on a map with the supplementary material. From this point forward neighbourhood typology name will be referred to rather than class number.

Table 1 - Item-response probabilities of classes

	(count)	Low access (n=4344, 18.98%)	Moderate access (n=7626, 33.32%)	Moderate PA, limited food access (n=2780, 12.15%)	Saturated access (n=3106, 13.57%)	Moderate PA, ample food access (n=5033, 21.99%)
Parks	T1 (0-1)	0.82	0.63	0.47	0.00	0.42
	T2 (2-3)	0.14	0.25	0.27	0.09	0.41
	T3 (4+)	0.04	0.12	0.26	0.91	0.17
Physical activity facilities	Q1 (0-4)	0.81	0.21	0.12	0.00	0.20
	Q2 (5-7)	0.15	0.30	0.38	0.05	0.30
	Q3 (8-10)	0.03	0.23	0.36	0.22	0.29
	Q4 (11+)	0.01	0.25	0.14	0.73	0.20
Fast-food	Q1 (0-2)	0.80	0.03	0.93	0.00	0.00
	Q2 (3-5)	0.14	0.82	0.06	0.02	0.00
	Q3 (6-10)	0.06	0.14	0.01	0.00	0.52
	Q4 (11+)	0.00	0.00	0.00	0.98	0.48
Large supermarket	Q1 (0-0)	0.78	0.22	0.32	0.04	0.15
	Q2 (1-1)	0.20	0.38	0.66	0.15	0.41
	Q3 (2-2)	0.02	0.27	0.02	0.31	0.20
	Q4 (3+)	0.00	0.12	0.00	0.50	0.24
Convenience and other food outlets	Q1 (0-7)	0.97	0.11	0.34	0.00	0.00
	Q2 (8-13)	0.03	0.43	0.65	0.00	0.07
	Q3 (14-22)	0.00	0.45	0.00	0.05	0.40
	Q4 (23+)	0.00	0.01	0.00	0.95	0.52

3.2 Composition differences across classes

Table 2 demonstrates that demographic characteristics differed by neighbourhood typology. The percentage of males and females remained consistent however, 'moderate PA, limited food' had the oldest population (mean 56.75 years) and 'saturated' had the youngest (mean 49.49 years). Ethnicity did vary by neighbourhood type, with the smallest percentage (1.2%) of non-white participants residing with the 'low availability', and the largest proportion within

the 'saturated' typology (10.24%). In terms of rurality, 'low availability' was mainly rural (34.28%) and 'saturated' were mostly within the urban areas (99.97%). Deprivation varied by neighbourhood typology; neighbourhoods with low availability to food ('low availability and moderate PA', 'limited food') were typically the least deprived. Typically, as availability to food increases across neighbourhood typologies, deprivation increases, the only exemption is the 'saturated' typology which has segments of low deprivation.

Table 2 - Individual- and area-level participant characteristics

	Low access (n=4344, 18.98%)	Moderate access (n=7626, 33.32%)	Moderate PA, limited food access (n=2780, 12.15%)	Saturated access (n=3106, 13.57%)	Moderate PA, ample food access (n=5033, 21.99%)	Overall (n=22,889)
Age	56.80 (16.02)	55.39 (16.33)	56.75 (16.24)	49.49 (16.72)	54.98 (16.81)	54.93 (16.58)
Gender						
Male	1938 (44.61)	3418 (44.82)	1221 (43.92)	1402 (45.14)	2244 (44.59)	10,223 (44.70)
Female	2406 (55.39)	4208 (55.18)	1559 (56.08)	1704 (54.86)	2789 (55.41)	12,666 (55.30)
Ethnicity						
White	4292 (98.80)	7419 (97.29)	2734 (98.35)	2788 (89.76)	4844 (96.24)	22,077 (96.50)
Non-white	52 (1.20)	207 (2.71)	46 (1.65)	318 (10.24)	189 (3.76)	812 (3.50)
Area-level deprivation						
Quartile 1 (Least deprived)	1157 (26.63)	2233 (29.28)	855 (30.76)	1002 (32.26)	478 (9.50)	5725 (25.00)
Quartile 2	1370 (31.54)	1603 (21.02)	1175 (42.27)	538 (17.32)	1077 (21.40)	5763 (25.20)
Quartile 3	1310 (30.16)	1950 (25.57)	390 (14.03)	517 (16.65)	1609 (31.97)	5776 (25.20)
Quartile 4 (Most deprived)	507 (11.67)	1840 (24.13)	360 (12.95)	1049 (33.77)	1869 (37.13)	5625 (24.60)
Urbanicity						
Rural	1489 (34.28)	351 (4.60)	59 (2.12)	1 (0.03)	116 (2.30)	2016 (11.40)
Urban	2855 (65.72)	7275 (95.40)	2721 (97.88)	3105 (99.97)	4917 (97.70)	20,873 (88.60)
Weight Status						
Underweight	53 (1.22)	98 (1.29)	40 (1.44)	63 (2.03)	72 (1.43)	326 (1.42)
Healthy weight	1818 (41.85)	3066 (40.20)	1145 (41.19)	1530 (49.26)	1933 (38.41)	9492 (41.47)
Overweight	1654 (38.08)	2880 (37.77)	1061 (38.17)	994 (32.00)	1905 (37.85)	8494 (37.11)
Obese	819 (18.85)	1582 (20.74)	534 (19.21)	519 (16.71)	1123 (22.31)	4577 (20.00)

3.2 Associations between the combined environment and BMI

Table 3 presents the association between the combined environment and BMI, relative to 'low availability' after adjusting for individual- and area-level covariates. Those within 'low availability' neighbourhoods (class 1) were chosen as a reference category. In theory, they would have lower availability to the physical activity environment and although more debatable, poorer availability to all aspects of the food environment which may result in lower physical activity levels and poorer dietary intake due to the lack of availability of all types of food outlets. Individuals who resided within 'saturated' neighbourhoods had statistically significant lower BMIs ($b = -0.50$, 95% CI [-0.76, -0.23]) compared to individuals within 'low availability' neighbourhoods. The other three latent classes of 'moderate availability' ($b = 0.49$, 95% CI [0.27, 0.71]), 'moderate PA, limited food' ($b = 0.30$, 95% CI [0.01, 0.59]) and 'moderate PA, ample food' ($b = 0.23$, 95% CI [0.08, 0.57]) were each found to have significantly higher BMI values compared to 'low availability' neighbourhoods.

Table 3 – Associations between neighbourhood clusters and BMI (n=22,889)

	b [95% CI], B
Neighbourhood typology	
Low access	REF
Moderate access	0.49 [0.27, 0.71], 0.04
Moderate PA, limited food	0.30 [0.01, 0.59], 0.02
Saturated	-0.50 [-0.76, -0.23], -0.03
Moderate PA, ample food	0.32 [0.08, 0.57], 0.02
Age	0.04 [0.03, 0.04], 0.12
Gender (Female)	-0.48 [-0.61, -0.35], -0.05
Ethnicity (non-white)	-0.25 [-0.70, 0.12], -0.01
Area-level deprivation	0.04 [0.04, 0.04], 0.13
Rural or urban (urban)	-0.36 [-0.61, -0.10], -0.02

3.3 Associations between the combined environment and obesity

Table 4 presents the results of the logistic regression model that examined the association between the combined environment and obesity for each of the environments relative to 'low availability' after adjusting for individual- and area-level covariates. Individuals who resided in

neighbourhoods with ‘moderate availability’ typology were 18% more likely to be obese (OR=1.18 95% CI [1.05,1.32]). Individuals who resided within ‘saturated’ neighbourhoods were 14% less likely to be obese (OR=0.86 95% CI [0.75,0.99]). The results for residing in the ‘moderate PA, limited food’ and ‘moderate PA, ample food’ were not statistically significant for obesity but were in the same direction as associations with body mass index.

Table 4 – Adjusted odds ratios for associations between neighbourhood clusters and obesity (n=22,889)

	OR [95% CI]
Neighbourhood typology	
Low access	REF
Moderate access	1.18 [1.05, 1.32]
Moderate PA, limited food	1.12 [0.96, 1.30]
Saturated	0.86 [0.75, 0.99]
Moderate PA, ample food	1.12 [0.98, 1.27]
Age	1.01 [1.01, 1.01]
Gender (Female)	1.09 [1.02, 1.17]
Ethnicity (non-white)	0.90 [0.74, 1.09]
Area-level deprivation	1.02 [1.01, 1.02]
Rural or urban (urban)	0.82 [0.72, 0.93]

Discussion

Our study used latent class analysis to develop a combined measure of the food and PA environment. To our knowledge, this is one of the first studies to investigate the association between typologies of neighbourhood contexts and BMI and obesity. We add to the literature by presenting a multidimensional picture of contextual neighbourhood factors and their contribution to BMI and obesity. Neighbourhood typologies contained features that may be considered protective of obesity such as, greater availability to PA facilities but also features that may be considered more obesogenic such as increased availability to fast food outlets. It suggests that previous analyses utilising perhaps more simple measures of neighbourhood context (or treating factors in isolation) may fail to correctly understand the role of

neighbourhood context. Research should explicitly acknowledge that neighbourhoods have availability to multiple features i.e. fast-food outlets, convenience stores and parks that may be both health-promoting and -constraining, rather than focusing on singular aspects such as only fast-food outlets. This confirms prior work (33) which suggests that accounting for multiple environmental influences, may represent a more accurate reflection of the wider influences of an environmental influence on human behaviour and health (22).

'Saturated' neighbourhoods, characterised by greater availability to the PA and food environment (particularly fast-food and other food or convenience outlets), were associated with reduced BMI and obesity compared to low exposure neighbourhoods. Although several studies have demonstrated the high calorie and nutrient poor content of fast-food (34, 35), this counterintuitive result demonstrates the multi-dimensional nature of an individual's availability within an environment and associations with weight related outcomes. Alternatively, it may be that another important aspect of neighbourhood, not captured within this study, such as the social or built environment may exhibiting important associations with BMI and obesity. Nevertheless, this importance of moving beyond assessing singular aspects of the environment i.e. just fast food was highlighted by a study which showed that the amount of energy consumed within full service restaurants was equivalent to those who ate at fast food outlets (36). We provide evidence that neighbourhoods are not healthy or unhealthy, but are characterized by neighbourhood features that are both health-promoting and health-constraining (20). We add to the evidence by exploring multiple aspects of both the food and PA environments.

'Moderate availability' neighbourhoods were associated with greater odds of obesity and BMI with a meaningful effect despite the relatively wide confidence intervals (18% greater odds of obesity). Research from the UK (20) and internationally (37) have demonstrated the multi-dimensional nature of neighbourhoods, however few have extended their analyses to show associations with BMI and obesity. Compared to 'low availability' neighbourhoods, 'moderate

PA, limited food' and 'moderate PA, ample food' also showed a statistically significant higher BMI however, this association did not persist for obesity. Neighbourhood typologies which were related by some type of 'moderate availability' may not be neighbourhoods commonly hypothesised to be at greater risk of both higher BMI and/or obesity. However, it is worth noting that residential neighbourhood context captured within this study may only have a small effect on BMI or obesity and individuals may also have availability outside of their immediate context for instance, at work or when commuting (38).

Neighbourhoods also contain other influential contextual factors not captured within this study such as the quality of the PA environment or prices within supermarkets which may have exhibited an effect BMI and obesity. For instance, research (39, 40) has demonstrated the importance of the quality of PA spaces in determining PA behaviours. Similarly, other studies have demonstrated that economic i.e. the affordability of supermarkets were important factors in detecting associations with BMI (41, 42). However, this was not captured within this study predominantly due to the difficulty of conducting such research over such a large area on a variety of different environmental variables. Such differences in the quality of environment in terms of aesthetics, safety, features, price, or choice may be important in determining usage or purchasing behaviours and are important considerations for future research. Although a park may be near a home, it may be unsafe which inhibits its use (43). Without more detailed measures of the food and PA environment, such nuances will continue to reduce the accuracy of statistical models employed and may go some way to explaining the associations seen within this study. Leveraging our approach allows researchers to capture the variety in neighbourhood circumstances, which itself may be an important factor in influencing behaviours.

The low exposure neighbourhood typology was used as the reference category (low availability to parks, PA facilities and all types of food outlets). Conceptually, participants would be restricted in their ability to expend energy within parks or PA facilities and the food they can

purchase in their immediate residential neighbourhood. Overall, 19.0% of participants resided within low availability neighbourhoods which were also home to slightly older participants relative to other neighbourhood typologies. This neighbourhood typology may be consistent with a design that has been planned around the use of the car. Such designs are conducive to lower PA and higher obesity rates (44).

Implications for policy and practice

Our study adds important local-level analyses which are required to inform local policy on environmental level prevention efforts. The results identified within this study begin to highlight the multi-dimensional nature of neighbourhoods that local authorities must account for with making health-related decision making. Neighbourhoods were not wholly unhealthy or healthy but contained a range of features that had varied associations with BMI and obesity. Based on these neighbourhood profiles, population-based interventions to reduce BMI and obesity that are targeted towards specific neighbourhoods show promise. This is also particularly important for this study given the size of the effects seen. For instance, an 18% greater likelihood of obesity in moderate availability neighbourhoods could be argued as a meaningful effect size for a contextual factor and may be suggestive of an importance for policy moving forward. However, policy should be designed to account for the variety of neighbourhood environments through strategies targeting the multidimensional aspects of neighbourhood context.

Limitations

Our study design was cross-sectional restricting our ability to draw out causal effects. The YHS is a self-reported survey and our outcome variable, BMI, may be biased. Furthermore, although we used PoI data which has been suggested as a valid alternative to UK local authority data this was only validated within one local authority (29). As consistent with many other studies within this area, neighbourhood was defined on the best available evidence but based on the home environment only. It is acknowledged that individuals will inevitably operate

beyond their 'neighbourhood buffer' which in this case was only defined based on home postcode (45). We also acknowledge that the placement of food outlets, and PA facilities are not random, determined most likely by property value, land costs, land use and potential customers (population density) to support the service in question (46). Furthermore, the movement of people between neighbourhoods is not random, most likely determined by factors such as income or the affordability of housing in certain areas. We only consider one aspect (availability within the environment) for how environments may be 'healthy' or not, and expanding on future approaches to include factors such as the social environment which may influence risk of obesity will be important for future research. Furthermore, other factors within the built environment that may promote active transport or reflect a diversity of destinations may also be important to consider moving forward. Finally, although a range of factors were used to develop the combined environment latent class analysis, perceptual or economic (affordability) based measures could have helped strengthen the notion of a more comprehensive measure of neighbourhood. Future research may consider the relative contribution of each type of food outlet or type of PA facility included to associations seen and benefit from capturing availability beyond the residential environment and by including, actual geocoded measures of dietary and physical activity behaviours. This is a particularly important consideration when investigating associations with the combined environment as it is unreasonable to continue to assume that fast food outlets for instance are a proxy for unhealthy foods without doing in-store audits or measuring actual purchasing and consumption behaviours of individuals.

Conclusion

Our study found evidence of distinct neighbourhood typologies of the food and physical activity environment surrounding individuals that were associated with BMI and obesity. Policymakers, town planners and local authorities are increasingly engaged with population-based strategies to reduce the prevalence of obesity through improved urban design, regulation of food outlets and increased availability to physical activity facilities or parks. These

population-level approaches are supported within this study, in that specific neighbourhood typologies were associated with BMI and obesity. However, these findings also reinforce the notion that neighbourhoods are not wholly unhealthy or healthy, they are characterised by a variety of neighbourhood features that are both health-promoting and -constraining. Given the progress in availability to secondary data on the environment it is now imperative that researchers consider wider environmental influences that include a broad range of environmental factors which include other food outlets, PA facilities, and parks. These findings have international relevance and highlight the need for research and policy to embrace the multidimensional nature of neighbourhoods in designing interventions to promote 'healthy' places.

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Conflict of Interest

All authors declare no conflicts of interest.

Authorship

Author	Contribution
Matthew Hobbs	Concept of idea, data analysis, lead on writing of manuscript
Claire Griffiths	Concept of idea, refinement of manuscript
Mark Green	Concept of idea, data analysis, refined manuscript
Hannah Jordan	Critical review of paper
Joanna Saunders	Refinement of manuscript
Jim McKenna	Concept of idea, refinement of manuscript

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