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Food environment and obesity: a systematic review and meta-analysis

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ABSTRACT

Background Obesity is influenced by a complex, multifaceted system of determinants, including the food environment. Governments need evidence to act on improving the food environment. The aim of this study was to review the evidence from spatial environmental analyses and to conduct the first series of meta-analyses to assess the impact of the retail food environment on obesity.

Methods We performed a systematic review and random-effects meta-analyses, focusing on geographical–statistical methods to assess the associations between food outlet availability and obesity. We searched OvidSP-Medline, Scielo, Scopus and Google Scholar databases up to January 2022. The search terms included spatial analysis, obesity and the retail food environment. Effect sizes were pooled by random-effects meta-analyses separately according to food outlet type and geographical and statistical measures.

Findings Of the 4118 retrieved papers, we included 103 studies. Density (n=52, 50%) and linear and logistic regressions (n=68, 66%) were the main measures used to assess the association of the food environment with obesity. Multilevel or autocorrelation analyses were used in 35 (34%) studies. Fast-food outlet proximity was positively and significantly associated with obesity (OR: 1.15, 95% CI: 1.02 to 1.30, p=0.02). Fresh fruit and vegetable outlet density and supermarket proximity were inversely associated with obesity (OR: 0.93, 95% CI: 0.90 to 0.96, p<0.001; OR: 0.90, 95% CI: 0.82 to 0.98, p=0.02). No significant associations were found for restaurants, convenience stores or any of the body mass index measures.

Conclusions Food outlets which sell mostly unhealthy and ultra-processed foods were associated with higher levels of obesity, while fruit and vegetable availability and supermarket accessibility, which enable healthier food access, were related to lower levels of obesity. The regulation of food outlets through zoning laws may not be enough to tackle the burden of obesity. Regulations that focus on increasing the availability of healthy food within stores and ensure overall healthy food environments require further attention.

PROSPERO registration number CRD42018111652.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The food environment is a recognised key determinant for the prevention of obesity and other diet-related non-communicable diseases (NCDs). Multiple studies have identified inconsistent findings regarding the association between elements of the retail food environment and obesity. Variability in geographical and analytical methods has been pointed out as a potential cause for these discrepancies.

WHAT THIS STUDY ADDS

⇒ This systematic literature review and meta-analyses consolidates all the evidence and effect sizes to determine which elements of the retail food environment have the greatest impact on obesity. It stratigically considers elements of the retail food environment, along with geographical and statistical methods to provide increased statistical power, accuracy, and a comprehensive summary of findings regarding the association of the food environment with obesity.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The evidence generated from this systematic review and meta-analyses can serve as a foundational tool for policymakers and researchers in developing programmes and interventions for the prevention of obesity and other diet-related NCDs. This study offers a quantitative and visual guide for identifying the retail food environment elements that require greater focus in strategies aimed at tackling obesity.

INTRODUCTION

The retail food environment and obesity

Obesity, a critical risk factor for non-communicable diseases (NCDs), is prevalent in countries across all income levels, including low-, middle- and high-income nations.[1 2] Its prevalence is shaped by a complex array of determinants, notably the retail food environment and advertising landscapes.[3] Modern food environments are marked by the widespread availability and promotion of energy-dense, nutrient-poor foods.[4] For instance, the increase in food retailers has contributed to a significant rise in calorie availability, facilitating greater access to a wide array of food choices.[5] To combat structural overconsumption and curb the obesity epidemic, policy interventions must be enacted, even in the face of commercial interests. However, the specific influence of food environments on obesity, as distinct from individual behaviour, remains poorly defined.[6 7] There is a scarcity of evidence identifying the exact elements of food environments that contribute to obesity and could be targeted for change.[3 4 8] This review aims to enhance understanding of the analytical methods required to dissect the various components of the modern retail food environment in relation to obesity and to assess the impact of retail food environments on obesity levels.

Analysing the retail food environment

Spatial analysis, leveraging Geographic Information Systems (GIS), has become instrumental in exploring the interplay between the environment and health outcomes. It particularly aids in investigating the food environment by mapping the locations of food stores, examining their spatial distribution and assessing their impact on obesity and population health. This approach enables the study of how the proximity and density of food outlets relative to residential areas influence access to healthy versus unhealthy food options, thereby identifying key environmental factors and protective measures against obesity through spatial patterns.[9–12]

Previous literature reviews

Previous literature reviews on the relationship between the retail food environment and obesity have underscored methodological issues that may affect the analysis and interpretation of how food environments influence health and dietary outcomes. There is a recognised need for precise, comprehensive evaluations, including standardised and validated measurement techniques and diverse approaches to assessing the retail food environment, as current methods exhibit considerable variability.[12–14] Essential aspects of retail food environment research involve confirming the location and type of food outlets through store audits (ground truthing),[13] considering the confounding effects of socioeconomic status[14 15] and using longitudinal studies to observe changes in the retail food environment and dietary choices over time.[15 16]

Despite numerous studies investigating the retail food environment's impact on obesity, systematic reviews and meta-analyses are scarce.[17–20] Previous analyses have often been restricted to specific regions or populations, with limited attention to the methodologies for measuring the retail food environment.[17–20] This paper undertakes a systematic review and meta-analyses to synthesise available evidence on the retail food environment's role in obesity and diet-related NCDs, aiming to pinpoint elements that could be targeted by policy interventions. Furthermore, it critically assesses the methodological strategies used to study the global impact of the retail food environment on obesity.

Obesity and the food environment

The food environment encompasses physical, economic, political and sociocultural factors affecting dietary choices.[21] Glanz *et al.*'s[22] model suggests that dietary intake is shaped by policy, environment, individual and behavioural factors. This includes the community nutrition environment (types of food stores, locations, and availability), which in this study we refer to as the 'retail food environment'; organisational settings (neighbourhood, school, workplace); and consumer aspects (food availability, placement, pricing, promotions, nutrition labelling). Key attributes defining the food environment are geographical access, availability, affordability and advertising.[23–25] While various factors contribute to obesity, environmental and policy measures can significantly improve the food environment, leading to widespread dietary changes and reduced obesity and disease rates.[26]

METHODS

We performed a systematic review and meta-analyses to assess the association of the retail food environment with adult obesity and to evaluate the geographical and statistical methods used. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed (online supplemental figure S1). Search results were screened by two reviewers for eligibility. The review was registered in PROSPERO as CRD42018111652.

Literature search strategy

We conducted a literature search on 31 January 2022, spanning papers published from 1946 onwards, to identify studies focusing on the impact of the retail food environment on obesity through spatial analysis. Using OvidSP-Medline, Scopus and Google Scholar databases, we structured the search around three primary themes: the retail food environment, obesity and spatial analysis. Initially, each theme was explored individually, and subsequently, we employed the 'AND' operator to search them concurrently. Using the Population, Intervention, Control, Outcome (PICO) framework (online supplemental table S1) for eligibility assessment,[27] we considered publications examining the influence of the retail food environment on adult obesity or body mass index (BMI) for inclusion in our systematic literature review and meta-analyses.

Our literature search strategy involved MeSH words, Boolean search terms and proximity searching characters ($, *, W, #) on Medline (OvidSP, 1946–current: 31 January 2022). The terms covered diverse aspects such as buffer, chain, convenience, density variations (denoted by densit*), desert, distance, eating habits (indicated by eat$), environmental factors, farmers' markets, fast food, geography, geolocation, geospatial analysis, GIS (geographic information systems), global, grocery stores, increase, index, location, markets, access, provision, proximity, restaurants, retail, spatial considerations, stores, supermarkets, supply, BMI (body mass index), body mass, nutrition, obesity, overweight, positional factors, weight gain and overeating. Additionally, the search extended to Scopus and Google Scholar using the query "(ALL (obesity) AND ALL (food environment OR convenience store OR food retail) AND ALL (GIS OR spatial analysis OR geographic information systems))" as of 31 January 2022.

Risk of bias and quality assessment criteria

Risk of bias and quality were evaluated using a weighted quality score derived from the Cochrane risk-of-bias tool, the systematic review data collection procedures from The Guide to Community Preventive Services[28] and the food environment quality assessment by Williams *et al*.[29] Nine criteria were assessed: population representativeness, outcome validity, exposure representativeness, exposure source, retail food environment assessment method, physical activity assessment, study design, statistical methods and data temporality. Studies received one point for each criterion met (online supplemental table S2).

Spatial and statistical methods and study design appraisal

Study design, statistical methods and models were explored and assessed according to their consideration of spatial clustering,[30] and according to their inclusion of confounders.

Meta-analysis

We performed random-effect meta-analyses to explore the link between the retail food environment and obesity, analysing data from various outlets including fast-food restaurants, convenience stores, supermarkets and farmers' markets. We evaluated the retail food environment using density, proximity and the Retail Food Environment Index (RFEI)—the ratio of unhealthy to healthy food outlets. Our analyses focused on ORs for categorical outcomes and beta-coefficients (β) for continuous variables, combining similar measures for meta-analyses. We assessed the impact of the retail food environment on adult BMI (β) and obesity prevalence (ORs), selecting the most relevant estimate from studies providing multiple results to ensure observations remained independent. Only models adjusted for confounders were included. For comparability, we considered data within 1 mile buffers or equivalent, representing walkable distances. In longitudinal studies, the most recent data were used. When results were stratified by sex and socioeconomic position (SEP), we chose observations based on the largest sample size or prioritised women and low-income groups if sizes were equal. We reported effect sizes and 95% CIs for each study, using Stata V.16.0 for all statistical analyses.[31]

RESULTS

We retrieved 4118 studies, and after applying inclusion and exclusion criteria, retained 103 articles yielding 526 data points (online supplemental figure S1). These were categorised by statistical measure, geographical measure and food outlet type, with 437 data points used in meta-analyses and meta-regression. The analysis covered 16 countries, with 90% of the studies from high-income countries: 1 from Africa, 5 each from Asia, Latin America and Australia, 14 from Europe and 74 from North America, spanning from 2004 to 2021, predominantly between 2011 and 2017 (n=54, 52%) (online supplemental table S3).

In terms of retail food environment measures, 52 (50%) studies evaluated density, 21 (20%) proximity, 3 (3%) both, 4 (4%) the RFEI or variants and 15 (15%) other measures like ratio and diversity. Most studies (n=77, 75%) assessed one geographical measure, 20 (19%) evaluated two and six (6%) assessed up to three. From the 526 data points that were extracted from all studies, fast-food outlets were the most examined (n=166, 32%), followed by supermarkets (n=102, 19%), restaurants (n=101, 19%) and convenience stores (n=61, 12%), fresh fruit and vegetable stores (n=17, 3%), grocery stores (n=14, 3%), specialty stores (n=8, 2%), supercentres (n=5, 1%), and farmers' markets (n=4, 1%). A majority of the studies, 61% (n=63), accounted for walkability or physical activity as a confounder (online supplemental table S4).

Associations varied by geographical area, underscoring the need for representative geographical selection. For example, Fan *et al*[32] found different associations between restaurants and obesity for men at the census tract level and for women at the block level. However, 64% (n=66) of studies did not perform ground truthing or verify retail food environment data (online supplemental table S4).

Statistical and geographical methods

Of the studies analysed, 68 (66%) applied linear or logistic regression, while 35 (34%) used multilevel modelling or methods accounting for spatial factors and clustering (online supplemental table S3). In terms of data sources for food outlet locations, 39 (38%) used government databases, 27 (26%) commercial databases, 14 (14%) conducted ground truthing, 23 (22%) employed various methods and 1 (1%) did not disclose their source. Among the studies employing multilevel modelling or spatial considerations, 26 (74%) identified positive correlations between the presence of food retailers selling foods high in fat, sugar and salt (HFSS) and obesity rates (online supplemental table S3).

Study design

Of the 89 cross-sectional studies analysed, 59 (66%) discovered a correlation between obesity and food retailers specialising in unhealthy foods and beverages, such as convenience stores and fast-food outlets. Among the 14 longitudinal studies, half revealed a significant link between the presence of unhealthy food outlets and obesity (refer to online supplemental tables S3 and S4 for detailed findings).

Quality and bias assessment of studies

The mean quality score of the studies was low, at 4 out of 9 points, with the highest being 7.[33 34] Key limitations

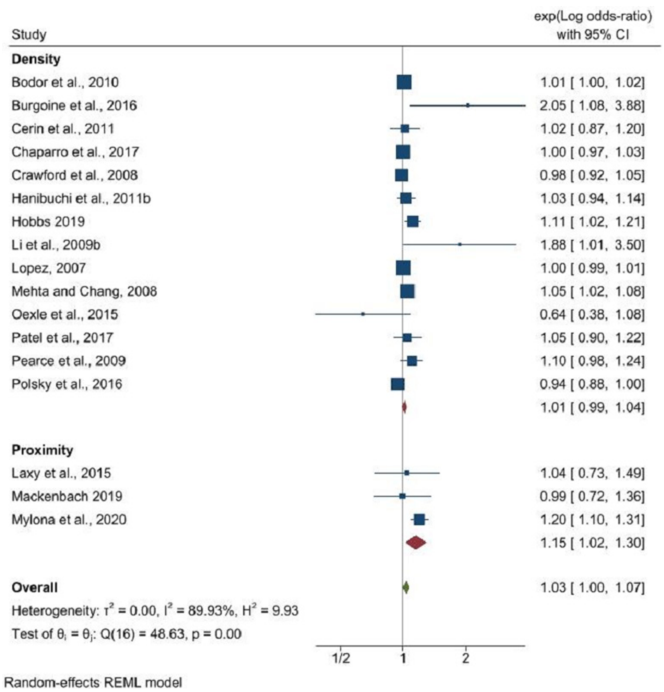

Figure 1 Fast-food outlet density and proximity and its association with obesity. REML, Restricted Maximum Likelihood.

included the reliance on cross-sectional designs, the failure to account for clustering or to apply spatial methods in 30 (29%) studies, reliance on self-reported height and weight data in 34 (33%) studies and the use of inappropriate statistical methods in 43 (42%) studies (online supplemental table S5). Studies deemed to have a high risk of bias were excluded from the meta-analyses.

Meta-analysis

In the meta-analyses conducted, significant heterogeneity was observed across the studies, stemming from variations in statistical methods, study designs, stratification by gender and ethnicity, geographical measures of the retail food environment, classifications of food outlets and the definitions used to measure or define obesity, thereby limiting the robustness of the pooled analyses. Despite these variances, the majority of the studies used BMI, derived from measured height and weight, as a primary indicator, reporting it either as a continuous variable (kg/m^2) or in categorical terms (overweight or obesity). However, there was a notable scarcity of studies disaggregating outcome data by critical demographic factors such as age group, gender, ethnicity or SEP, which is pivotal considering the diverse exposure to retail food environments experienced by these groups.[35] Results of the meta-analyses are presented below by measure of the retail food environment (ie, density and proximity) and statistical measures (ORs and Beta-coefficients—in the supplemental material).

The findings revealed that the density of fast-food outlets did not significantly influence obesity rates (OR: 1.01, 95% CI: 0.99 to 1.04, p=0.18), in contrast to proximity to fast-food outlets, which showed a significant association with obesity (OR: 1.15, 95% CI: 1.02 to 1.30, p=0.02) (figure 1). Restaurant density's correlation with obesity was marginally significant (OR: 0.92, 95% CI: 0.85 to 1.00, p=0.05), yet the literature lacked sufficient data to evaluate the impact of restaurant proximity (figure 2). No significant relationship was identified between the density of convenience stores and obesity (OR: 1.02, 95% CI: 0.95 to 1.10, p=0.64), and a similar non-significant trend was observed for proximity to convenience stores (OR: 1.04, 95% CI: 0.97 to 1.11, p=0.31) (figure 3).

Furthermore, supermarket density did not show a significant relationship with obesity (OR: 0.98, 95% CI: 0.92 to 1.05, p=0.53), whereas a significant inverse relationship was evident between supermarket proximity and obesity (OR: 0.90, 95% CI: 0.82 to 0.98, p=0.02) (figure 4). An inverse association was also noted between the density of fresh fruit and vegetable stores and obesity (OR: 0.93, 95% CI: 0.90 to 0.96, p<0.001) (figure 5), though data were insufficient to assess the impact of proximity to these outlets. The RFEI did not reveal any significant associations with obesity (OR: 1.00, 95% CI: 0.99 to 1.01, p=0.99) (figure 6), and BMI as a continuous variable showed no association with any type of food outlet, indicating a nuanced and complex relationship between the retail food environment and obesity (online supplemental figures S2–S7).

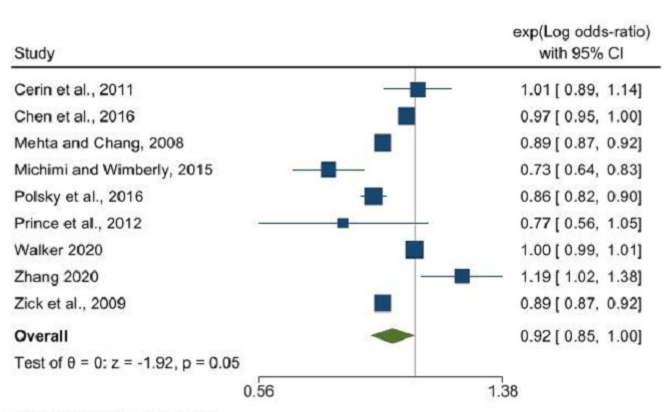

Figure 2 Restaurant density and its association with obesity. REML, Restricted Maximum Likelihood.

DISCUSSION

The results of our systematic review and meta-analyses indicate a nuanced relationship between the retail food environment and obesity. Results for the association between the retail food environment and obesity varied significantly by type of food outlet, statistical measure and geographical measure. However, the pooled effect sizes show that proximity of fast-food outlets was associated with a higher risk of obesity, while proximity of supermarkets and fresh fruit and vegetable stores was associated with a lower risk of obesity.

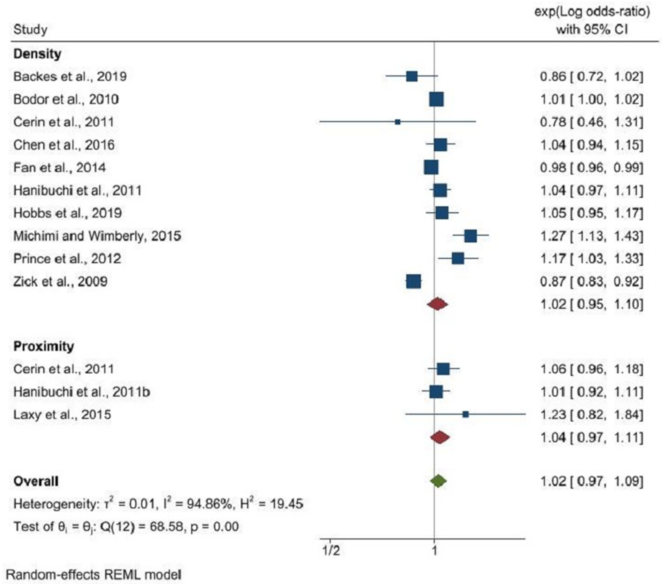

Figure 3 Convenience store density and proximity and its association with obesity. REML, Restricted Maximum Likelihood.

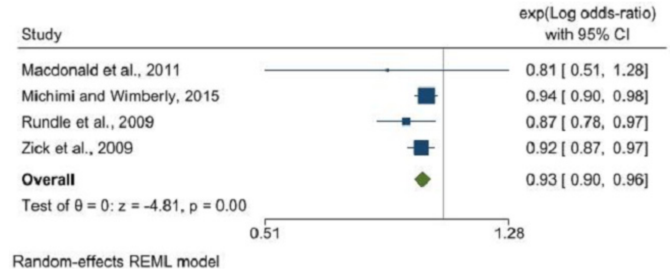

Figure 5 Fruit and vegetable store density and its association with obesity. REML, Restricted Maximum Likelihood.

Previous research highlights the crucial role of fruit and vegetable availability and affordability in fostering healthy eating habits and preventing obesity and chronic diseases.[36] Conversely, fast-food outlets predominantly offer ultra-processed foods—industrially processed items rich in fat, salt and/or sugar—whose consumption is associated with increased risks of obesity and chronic conditions.[37]

The observed phenomenon can be attributed to the ease of access to different types of food outlets and their impact on dietary choices. Fast-food outlets, often closer to residential areas or on the pathways from school or the office to home, provide convenient access to high-calorie, processed foods, which can contribute to higher obesity rates among nearby residents.[14] Conversely, supermarkets, which are sometimes located further from residential areas, offer a broader range of healthier food options. When supermarkets are closer, it encourages the purchase and consumption of healthier foods, potentially reducing obesity risk.[38] This highlights the significant role of the retail food environment accessibility in influencing dietary behaviours and obesity prevalence.

In addition, socioeconomic area level may play a critical role in this context by influencing both access to and choices within the retail food environment.[39] Individuals living in lower socioeconomic areas may have more limited access to supermarkets offering a variety of healthy options due to cost or proximity, leading to a reliance on closer, often less expensive fast-food outlets.[39] This disparity can result in dietary patterns that contribute to higher obesity rates in these populations, underscoring the need for targeted interventions to improve access to healthy food options across all socioeconomic groups.

Importantly, while geographical measures such as proximity and density provide insights into the retail food environment or built food environment, they do not capture the complexities *within* food outlets that influence consumer choices. The 'in-store food environment', encompassing product placement, promotion strategies

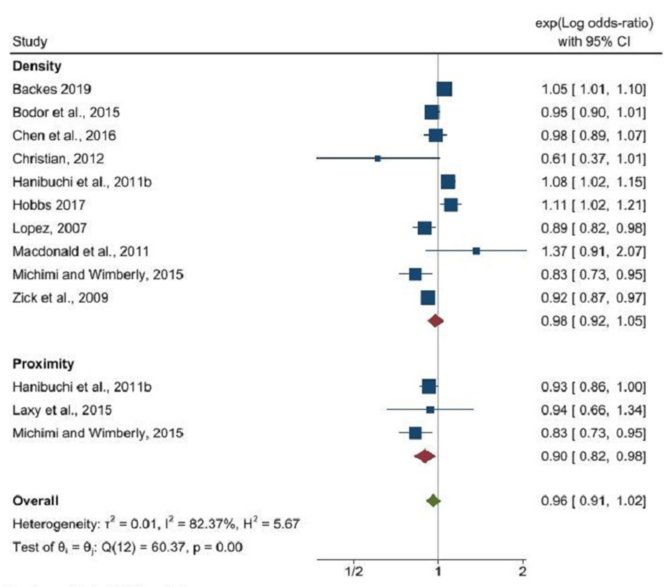

Figure 4 Supermarket density and proximity and its association with obesity. REML, Restricted Maximum Likelihood.

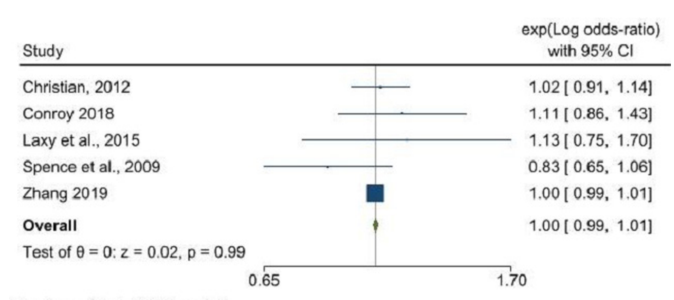

Figure 6 Retail Food Environment Index (RFEI) and its association with obesity. REML, Restricted Maximum Likelihood.

and food layout, plays a pivotal role in shaping dietary habits. Studies have demonstrated that strategic placement of healthy food options at eye level or in prominent store locations can significantly influence consumer purchases towards healthier choices.[40–43]

A comprehensive approach, addressing both the proximity of various food outlet types and the intricate details of the in-store food environment, is essential for devising effective public health interventions aimed at reducing obesity. Future research and policy efforts should consider these dimensions of the food environment to develop more nuanced and impactful strategies for obesity prevention.

The UK is a pioneer in regulating the food environment, having introduced legislation to restrict the promotion and placement of HFSS foods within retail settings, both online and physical.[44] This legislation targets the influence of food retailers on consumer choices, particularly aiming to reduce the impact of price promotions on children's food preferences by limiting promotions and strategic placement of HFSS products. This is a crucial step in promoting healthier eating habits and combating obesity and related health issues.

Additionally, in high-income countries, zoning powers allow local authorities to regulate food outlets' location, and healthy food carts have been effectively deployed in urban areas to increase access to nutritious food.[18]

Studies on the food environment can inform the creation of improved land use and public health policies, mitigating the negative effects of local food and nutrition environments on population health[45] Effective obesity reduction efforts should include policies or regulations to limit the availability of low-quality food in neighbourhoods, schools and other sensitive areas. However, the relationship between food outlets and obesity has shown inconsistent results, underscoring the need for solid evidence to guide government actions on enhancing the food environment.

This research significantly advances the evidence[18–20] by integrating a systematic review with meta-analyses to explore the retail food environment's influence on obesity and BMI. This dual approach, not previously used for this topic, integrates geographical and statistical analyses and offers a comprehensive analysis of the relationship between food outlet types, BMI and obesity. Furthermore, this study is distinct as it includes analyses that employ spatial methodologies to explore the retail food environment's components and their correlation with obesity, providing a comprehensive evidence base for policy formulation aimed at enhancing public health.

Implications for policymakers and urban planners

The observed association between fast-food outlet proximity and increased obesity risk emphasises the need for zoning regulations to manage their density in residential areas, schools and communal spaces. This strategic intervention becomes crucial in mitigating the obesity crisis. Our study discerns variations in associations among different food outlet types. While proximity of fast-food outlets correlates positively with obesity, proximity of supermarkets and fresh produce stores demonstrates an inverse relationship. Urban planners can influence health outcomes by strategically placing health-promoting outlets in residential areas, aligning with the concept of fostering a 'healthy food environment'.

Beyond reaffirming existing knowledge, our study introduces novel insights into nuanced relationships between specific food outlets and obesity risk. Policymakers and urban planners can leverage this information to refine existing zoning laws based on prevalent food outlet types.

Our analysis also reveals a gap in the assessment of in-store food environments. Policymakers should focus on internal dynamics, implementing regulations targeting the arrangement and promotion of food items within stores to encourage healthier choices. Moreover, they should engage with town planners, health professionals and community representatives to develop comprehensive strategies. Collaborative efforts can lead to urban spaces that limit the impact of detrimental food outlets and food choices while promoting health and well-being. This aligns with the broader goal of fostering healthier communities, emphasising the importance of continued research and dialogue between academia and policymakers.

Strengths and limitations

This study's primary strength lies in its comprehensive systematic search strategy, which involved querying multiple databases, imposing no publication date restrictions and conducting searches in two languages. Additionally, it uniquely explored and assessed geographical measures and statistical methods within a systematic literature review context and conducted a risk-of-bias assessment to objectively evaluate the reviewed literature.

By incorporating spatial analysis, this study addressed gaps in previous literature by elucidating the impact of food outlets' geographical distribution on obesity rates. This approach enabled the identification of spatial patterns and correlations potentially overlooked in traditional epidemiological studies, thereby providing insight into the obesogenic environment.

Spatial analysis also enhanced the meta-analyses by facilitating the integration and comparison of findings from studies across different geographical scales and settings, thereby bolstering the robustness of our conclusions. This rigour in methodology supported evidence synthesis, offering a detailed overview of the retail food environment's role in obesity.

Through a detailed spatial analysis, our study not only corroborates the significance of geographical factors in obesity prevalence but also underscores the need for targeted public health interventions. By pinpointing areas with high concentrations of unhealthy food outlets relative to healthy ones, policymakers and urban planners can devise more effective strategies aimed at improving the food environment and, subsequently, public health.

However, the study has limitations. The review focused on obesity in the adult population because of the diverse reviews already focused on children, and because of the important role that adults play in food outlet selection within a family setting. Focusing on adult populations is critical for chronic disease prevention and successful ageing. Only studies based on neighbourhood, rural or urban environments were considered. Studies that did not include an objective measure of obesity such as BMI via measured height and weight were excluded. However, many studies that used BMI and other measures of diet and obesity were considered. The identified exposures, measures and outcomes included in this study were the most reported in the literature. Although this may exclude other important obesity-related outcomes (eg, adiposity, fat mass, diet), focusing on BMI and obesity allowed a wider comparison between studies and could facilitate translation into policies and actions to regulate and improve the food environment.

CONCLUSION

Despite significant methodological diversity among the studies reviewed, the literature consistently identifies the food environment as a crucial factor in preventing obesity. Regions characterised by abundant fast-food outlets, limited supermarket access and scarce fresh fruit and vegetable stores tend to have higher obesity rates. While regulating access to healthier food options is necessary, it may not suffice to combat obesity on its own. Comprehensive strategies are also needed, including regulation of the in-store availability of unhealthy foods and the promotion of a food environment that supports healthy and affordable diets.

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Contributors EP designed the study, collected and analysed the data, drafted the manuscript, and was responsible for the overall content as the guarantor. JS, SS, CL and JSM drafted and revised the draft and provided statistical advice.

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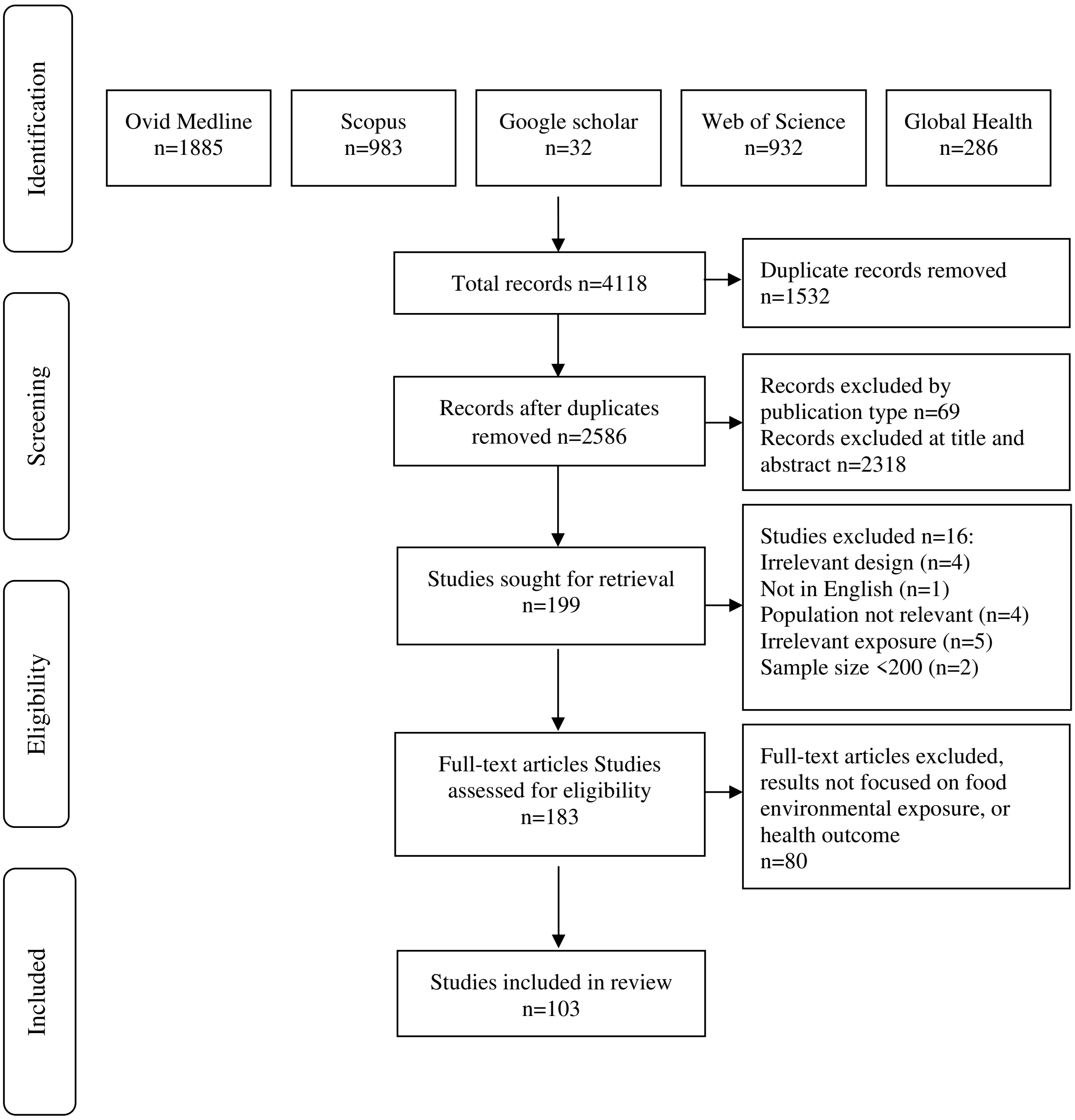
The Food Environment and Obesity:
A Systematic Review and Meta-analysis

Supplementary Material

Contents

1. PRISMA Flow Diagram

Figure S1. PRISMA Flow Diagram



2. Eligibility criteria

Table S1. Eligibility criteria for publications relevant to the review using PICO

Population	General adult population, excluding populations with comorbidities.
Intervention/ exposure	Assessment of the retail food environments at any geographical level (e.g., census tract area, postal code, county, city, etc)
Control	Not applicable/areas with no food environment
Primary Outcomes	Obesity related outcomes (e.g., BMI, obesity prevalence, adiposity, etc.)

3. Risk of bias

Table S2. Risk of bias and quality criteria assessment for reviewed studies

Criterion	Meeting criteria (Score 1)	Not meeting criteria (Score 0)
Population	Population was randomly selected, and proper sampling methods were undertaken to select a representative population according to the study's aims.	Population was selected using telephone surveys.
Outcome (BMI)	Measured weight and height or validated data.	Self-reported or non-validated data used.
Exposure (food environment)	> 2 types of food establishments were studied.	≤ 2 types of food establishments were studied
Food outlet data source	Validated or trustworthy source (e.g., up-to-date government database) used or ground truthing was undertaken).	Data were not validated.
Spatial analysis method	≥ 2 methods were employed.	Only one method.
Physical activity (PA)	PA or walkability was considered in the model.	Neither PA nor walkability considered.
Study design	Longitudinal studies.	Cross-sectional or ecological design
Statistical method	Use of Moran's I, multilevel analysis, geographic weighted regression analysis or any other method that considered space or clustering as an important variable of influence.	Linear regression methods which do not consider space or clustering.
Data temporality	Health and food outlet data were from same year.	Health and food outlet data varied in collection time.

4. General characteristics of reviewed studies

Table S3. General characteristics and descriptive summary of reviewed studies

Reference	Country	Sample population	Physical activity consideration	Statistical Method	Significant findings
		Cross-sectional studies			
Abbott et al., 2014	Australia	1,819	Yes	Linear regression model	Yes
Adachi-Mejia 2017	USA	2,025	Yes	Multiple regression models	Mixed
Ahern et al., 2011	USA	USA population	Yes	Linear regression	Yes
Albalawi et al., 2020	UK	456,079	No	Multiple linear regressions	No
Backes et al., 2019	Brazil	1,096	No	Multilevel Poisson regression models (with robust standard error)	No
Bodor et al., 2010	USA	3,925	Yes	Hierarchical linear models	Yes
Burgoine 2017	UK	9,702	Yes	Multiple linear regression	Yes
Burgoine 2018	UK	51,361	Yes	Multivariable linear and binomial logistic regression	Yes
Cerin et al., 2011	USA	274	Yes	GLM with binomial variance and logit link functions	Yes
Chaparro et al., 2017	USA	1,041	No	Multilevel logistic regression	No
Chen et al., 2010	USA	844,187	No	OLS spatial diagnostic test on regression residual of non-spatial model	Yes
Chen et al., 2013	USA	3,550	Yes	OLS	Yes
Chen et al., 2016	USA	25,023	No	Multilevel	Yes
Chen et al., 2019	USA	20,897	Yes	Ordinary least squares linear regression (evaluated by Moran's I index) global ordinary least squares regression local geographically weighted regression	Yes
Chen et al., 2020	USA	20,897	No	Path analysis	Yes

Reference	Country	Sample population	Physical activity consideration	Statistical Method	Significant findings
Christian et al., 2012	USA	121	Yes	Multivariate logistic regression	No
Conroy et al., 2018	USA	102,906	Yes	multivariable linear regression multivariable multinomial logistic regression	No
Cooksey-Stowers et al., 2017	USA	3,108	Yes	OLS	Yes
Crawford et al., 2008	Canada	684	Yes	Bivariate logistic regression	No
Dake et al., 2016	Ghana	657	Yes	Multilevel	Yes
Drewnowski et al., 2012	USA	1,304	No	Modified Poisson regression	No
Drewnowski et al., 2014a	USA-France	9,291	No	Modified Poisson regression w/ robust error variance	No
Dunn et al., 2012	USA	1,019	No	Probit regression	Yes
Fan et al., 2014	USA	403,305	No	Multilevel regression models	Yes
Frankenfeld et al., 2015	USA	USA population	No	Linear regression	Yes
Fuller et al., 2013	USA	1,440	Yes	Bivariate linear regression	No
Gartin 2012	Paraguay	126	No	Linear regression no GIS analysis	No
Ghosh-Dastidar et al., 2014	USA	1,214	No	Multivariate logistic regression	Yes
Hanibuchi et al., 2011	Japan	39,765	No	Multiple linear regression logistic regression	Yes
Hattori et al., 2013	USA	97,678	Yes	Negative binomial regression OLS and logistic regression	Yes
Hobbs 2017	UK	4,723	No	Single-level linear regression linear multilevel	No
Hobbs et al., 2019	UK	22,889	No	Binary logistic regression	No
Hobbs et al., 2019	UK	7,544	No	Structural equation modelling	No
Hollands et al., 2013	Canada	1,269 geographic areas	Yes	OLS and spatial auto-regressive error	Yes

Reference	Country	Sample population	Physical activity consideration	Statistical Method	Significant findings
Hollands et al., 2014	Canada	84,341	Yes	Multivariable regression analyses	Yes
Hosler et al., 2009	USA	Columbia and Greene counties in NY	No	Bivariate correlations	No
Inagami et al., 2009	USA	2,156	No	Multilevel modelling	Yes
Jeffery et al., 2006	USA	1,033	Yes	Logistic regression	No
Jilcott et al., 2011	USA	USA population	Yes	Multilevel linear models	Yes
Kruger et al., 2014	USA	1,345	No	Stepwise linear regressions	Yes
Laxy et al., 2015	USA	1,570	Yes	Multivariate linear and logistic regression	No
Li et al., 2008	USA	1,221	Yes	Linear and logistic regression	No
Li et al., 2009b	USA	1,145	Yes	Multilevel Poisson regression	Yes
Li et al., 2009c	USA	1,145	Yes	Multilevel	Yes
Liese 2017	USA	459	Yes	Multivariable/hierarchical linear regression	Yes
Lopez 2007	USA	15,358	No	Multilevel logistic regression	Yes
Macdonald et al., 2011	Scotland	991	No	Multilevel	Yes
Mackenbach 2019	Belgium France Hungary Netherlands and the United Kingdom.	5,076	No	Logistic and linear regressions	No
Mackenbach 2019	Netherlands	2,812	No	Linear and multinomial logistic regression	Yes
Maddock 2004	USA	USA population	Yes	Logistic regression and multinomial regression	Yes
Mason 2018	UK	40,1435	Yes	Multilevel linear regression	Yes

Reference	Country	Sample population	Physical activity consideration	Statistical Method	Significant findings
Mazidi and Speakman 2017	USA	2,996 counties. 3,138 counties USA population~ 170 million adults	Yes	Linear regression	No
Mehta and Chang 2008	USA	876,091	Yes	Bivariate correlation hierarchical multiple regression	Yes
Mejia et al., 2015	USA	5,185	Yes	Multilevel analysis Two-level hierarchic regression models	Yes
Mendes et al., 2013	Brazil	3,404	No	Negative binomial	Yes
Michimi and Wimberly 2010	USA	1,477,828	No	Poisson regression model in a single level	No
Michimi and Wimberly 2015	USA	300,933	No	Latent class analysis	Yes
Morland et al., 2006	USA	10,763	Yes	Multilevel logistic regression	Yes
Murphy 2017	Australia	3,218	No	Generalised estimating equations	Yes
Murphy 2018	Australia	3,141	Yes	Generalized estimating equations models	Yes
Mylona 2020	USA	20,927	Yes	Multivariate logistic regression	Yes
Oexle et al., 2015	USA	838	No	Multilevel logistic regression	Yes
Oka et al., 2013	USA	5,485	Yes	Multilevel modelling binomial regression	Yes
Patel et al., 2017	India	1,782	Yes	Logistic regression	Yes
Pearce et al., 2009	New Zealand	12,529	No	Multinomial Logistic regression	No
Pineda et al., 2021	Mexico	37,969	Yes	Multilevel linear regression	Yes
Polsky et al., 2016	Canada	10,199	Yes	logistic regression stratified linear regression	Yes
Polsky et al., 2016	Canada	10,199	Yes	Multilevel modelling	No

Reference	Country	Sample population	Physical activity consideration	Statistical Method	Significant findings
Pouliou and Elliott 2010	Canada	115,548	Yes	Two-level logistic regression multilevel	Yes
Prince et al., 2012	Canada	4,727	Yes	Logistic and linear regression	Yes
Pruchno et al., 2014	USA	5,688	No	Multivariate analysis	No
Richardson et al., 2015	USA	5,114	Yes	Binomial multivariate multilevel model	Yes
Rundle et al., 2009	USA	13,102	Yes	Multilevel structural equation	Yes
Salois 2012	USA	3,051 counties	Yes	Structural equation model	Yes
Singleton et al., 2016	USA	3,135	No	Linear regression	Yes
Slack et al., 2014	USA	3,109 counties	Yes	Multilevel analysis	Yes
Spence et al., 2009	Canada	2,900	No	Robust regression MM estimator regression	Yes
Stark et al., 2013	USA	48,482	Yes	OLS spatial regression	No
Tung et al., 2016	USA	267	Yes	Linear regression	No
Viola et al., 2013	USA	48,014	Yes	Weighted logistic regression models	Yes
Walker 2020	Canada	8,076	Yes	Logistic regression	Yes
Wang et al., 2007	USA	7,595	Yes	Multilevel Pearson correlation coefficients	Yes
Xu and Wang 2015	USA	328,156	Yes	Bayesian ecologic approach for spatial prediction	Yes
Yan et al., 2015	USA	3,041	No	Multilevel	No
Yenerall 2017	USA	784	No	Logistic regression model	No
Zhang 2019	USA	8,365	No	Generalised linear regression and logistic regression	No
Zhang 2020	China	170,872	Yes	Five-level logistic regression models	Yes
Zick et al., 2009	USA	898,387	Yes	Multilevel Logistic model	Yes
Jaime et al., 2011	Brazil	2,122	Yes	Correlation analyses Pearson	No

Reference	Country	Sample population	Physical activity consideration	Statistical Method	Significant findings
				correlation coefficient	
Longitudinal studies					
Block et al., 2011a	USA	3,113	No	Cross-classified multilevel model	No
Boone-Heinonen et al., 2013	USA	4,092	Yes	Regression with fixed effects for individuals	Yes
Burgoine et al., 2011	England	893	Yes	Correlation ANOVA and Chi-square analysis	No
Burgoine et al., 2016	UK	2,039	Yes	Linear and logistic regression	Yes
Carroll 2020	Australia	2,253	Yes	Spearman rank correlation latent variable growth models	Yes
Du et al., 2014	China	24,396	Yes	Random intercept-slope growth model	Yes
Dubowitz et al., 2012	USA	60,775	Yes	Logistic regression multivariate regression models with random effects	Yes
Gibson et al., 2011	USA	27,825	Yes	OLS	Yes
Hobbs 2019	UK	8,864	No	Multilevel linear regression	No
Jilcott Pitts et al., 2015	USA	205	No	Multiple linear and logistic regression	No
Meyer et al., 2015	USA	14,397	Yes	OLS logistic regression	No
Rummo 2017	USA	12,174	Yes	Instrumental-variables regression	No
Xu et al., 2013	China	28,063	Yes	Bayesian hierarchical regressions multilevel	Yes
Zenk 2017	USA	219	No	Hierarchical linear regression	No

GLM: General linear model, OLS: ordinary least squares regression, ANOVA: analysis of variance

Table S4. Food environment characteristics and methods of the reviewed studies

Reference	Geographic unit of observation	Store type	Spatial food store measure	Buffer size	Food outlet source
Abbott et al., 2014	Suburbs	Green grocers, supermarkets, FF	Density	NA	NA
Adachi-Mejia 2017	Neighbourhood	FF, restaurant, GS, supermarket	Density and proximity	1 km street-network	Government and commercial
Ahern et al., 2011	County	Direct-to-consumer farms, GS, restaurants, FF, CS	Density	NA	Government
Albalawi 2020	Postcode district (PD)	FF, restaurants, delivery, takeaways, pubs, and cafes	Density	Postcode district	Government and Commercial databases
Backes 2019	residential address	Supermarkets, GC, CS	Density	400m radius buffer around residential locations	Systematic survey
Block et al., 2011a	CTA	FF, restaurants, bakeries/coffee shops, supermarkets, GS, CS	Proximity (driving time)	NA	Government, Yellow pages, Commercial
Bodor et al., 2010	CTA	Supermarkets, medium food stores, small food stores, CS, general merchandise stores, FF	Density	2km	Government
Boone-Heinonen et al., 2013	Census block group	FF, supermarkets, CS	Proximity	1km Euclidean	Commercial
Burgoine 2017	Residential address	Supermarkets	Proximity	Street network proximity	Government
Burgoine 2018	Residential address	FF	%	1-mile straight-line radius (circular) residential address	Government
Burgoine et al., 2011	LSOA	FF, supermarkets, greengrocer, CS, pizza delivery, takeaway	Density	NA	Yellow pages
Burgoine et al., 2016	residential and work address	FF, supermarkets	Density	1-mile straight-line radius (circular) buffers, cantered on home and work addresses	Government
Carroll 2020	Census collection districts	FF; RFEI	Density, RFEI	1600m road-network proximity buffers from participants' residence	Government and commercial databases

Reference	Geographic unit of observation	Store type	Spatial food store measure	Buffer size	Food outlet source
Cerin et al., 2011	CTA	FF, CS, restaurants, gas/non gas food marts	Density, proximity, diversity	1km residential, 1km network	Government, Yellow Pages, online business, directories, and ground-truthing
Chaparro et al., 2017	CTA	FF, CS, LS	Density	NA	Government
Chen et al., 2010	County	Chain grocers	Density	1-mile	Government
Chen et al., 2013	CTA	Restaurants, FF	Density, proximity	0·5 mile	Government
Chen et al., 2016	County, food desert tract	Supermarkets, GS, clubs and supercentres, CS, specialty food stores, pharmacies, restaurants	Density	NA	Government
Chen 2019	CTA	mRFEI	mRFEI	None	Government
Chen 2020	CTA	mRFEI	mRFEI	None	Government
Christian, 2012	CTA	Supermarkets, CS, FV markets, limited-service restaurants	Density	0·50 miles Euclidian	Government
Conroy 2018	Census block group	REI, RFEI	REI, RFEI	1·6 km pedestrian network	Government and commercial databases
Crawford et al., 2008	State	FF chains	Proximity, density	2km	Yellow pages, commercial/online
Crawford et al., 2008	Residential address	FF	Density, proximity	2km	Government
Dake et al., 2016	Enumeration areas	Out-of-home cooked food, CS, FV	Density	NA	Ground truthing
Drewnowski et al., 2012	County and block group code	Supermarkets	Network proximity (3 types, driving)	NA	Field work
Drewnowski et al., 2014a	County	Supermarkets	Network proximity	Buffers cantered on each study participant's residence·	Government
Du et al., 2014	Neighbourhood	FF, indoor restaurants, and	Density	NA	Community questionnaire

Reference	Geographic unit of observation	Store type	Spatial food store measure	Buffer size	Food outlet source
		fixed outdoor food stalls			, community leader
Dubowitz et al., 2012	Tract and metropolitan statistical area	GS, supermarkets, FF	Density	0·75, 1·5, and 3·0 miles	Yellow pages, commercial
Dunn et al., 2012	CTA	FF	Density	1, 3 miles	Ground-truthing
Fan et al., 2014	Census block group, CTA, zip code, 1 km buffer around residential address.	GS, CS, restaurants	Density	1km	Commercial
Frankenfeld et al., 2015	Block group	FF, CS and pharmacies, GS, and specialty food stores	Ratio unhealthy: healthy food outlets, k-mean cluster	NA	Commercial
Fuller et al., 2013	CTA	Primary food stores	Road network proximity	NA	Commercial and participant survey
Gartin, 2012	Census block group	Open-air markets, CS, supermarkets	Proximity	0·5-1 miles	Ground-truthing
Ghosh-Dastidar et al., 2014	CTA	Supermarkets, specialty grocery stores, discount grocery stores, supercentres, meat/seafood markets, wholesale clubs	Network proximity	NA	Geocoded from participant's interview
Gibson, 2011	Zip code	GS, CS, restaurants	Density	NA	Government
Hanibuchi et al., 2011	Block	CS, FF, supermarkets	Radial proximity based on street network	500m	Yellow pages
Hattori et al., 2013	Residential address	FF, restaurants, CS, small food stores, GS, supermarkets	Density, Euclidian proximity within walking proximity	0·25, 0·5, 1-, 1·5-, and 3-miles circular buffers	Commercial
Hobbs 2017	Residential address	Supermarkets, takeaways, CS	Density	800m and 2000m) residential address; LSOA (km^2)	Government and commercial databases

Reference	Geographic unit of observation	Store type	Spatial food store measure	Buffer size	Food outlet source
Hobbs 2019	Residential postcode	FF, LS, CS, and restaurants	Density	2km	Commercial database
Hobbs 2019	Residential postcode	FF	Density	2km radial buffers around home postcode	Commercial database
Hobbs 2019	Cluster of food outlets	FF, LS, restaurants, CS, independent supermarkets, specialty, café	Density	1600m Euclidean radial buffer	National database
Hollands et al., 2013	Forward sortation area	FF, coffee outlets, restaurants	Density	NA	Commercial
Hollands et al., 2014	Forward sortation area	FF, restaurants	Density	NA	Commercial
Hosler, 2009	Census block group	Food stores, farmer's markets	Density, Euclidian proximity	NA	Research centre
Inagami et al., 2009	CTA	FF	Density	NA	Government
Jaime et al., 2011	Sub-municipality	Supermarket, GS, FV, FF chains	Density	NA	Government and commercial
Jeffery et al., 2006	Not defined	FF, restaurants	Proximity, density, frequency	Radio of 0·5 miles, 1 mile and 2 miles (home and work addresses)	Government and commercial
Jilcott et al., 2011	County	Farmers' markets, GS, supermarkets, supercentres	Density	NA	Government
Jilcott Pitts et al., 2015	County	Farmers' market	Network proximity	NA	Ground truthing
Kruger et al., 2014	County	FF	Proximity	NA	Yellow pages and internet
Laxy et al., 2015	Neighbourhood	FF, CS, supermarkets	Network proximity	NA	Commercial
Li et al., 2008	Census block group	FF	Density	NA	Commercial
Li et al., 2009b	Census block group	FF	Density	NA	Government and commercial
Li et al., 2009c	Census block group	FF	Density	NA	Government and commercial
Liese 2017	Residential address	Supermarkets, supercentre, or warehouse club	Proximity	None	Ground-truthing survey and government

Reference	Geographic unit of observation	Store type	Spatial food store measure	Buffer size	Food outlet source
Lopez, 2007	Zip code	Supermarkets, FF, general retail	Density	NA	Government and commercial
Macdonald et al., 2011	Postal code	Supermarkets, independent food stores and chain outlets, FV	Network Proximity	500m and 1000m	Government
Mackenbach 2019	Neighbourhood	FF	Spatial access	300m Euclidean buffer around selected residential neighbourhoods	Commercial database
Mackenbach 2019	Residential address	FF	Spatial access	300m Euclidean buffers around participants' home addresses	Commercial database
Maddock, 2004	State	FF	Square miles per food outlet	NA	Yellow pages and online verification
Mason 2018	Residential address	FF	Street-network Proximity	500m, 500–999m, 1000–1999m, 2000m from residential address	National database
Mazidi and Speakman, 2017	County	FF and restaurants	Density	NA	Government
Mehta and Chang, 2008	County	FF	Density	NA	Government
Mejia et al., 2015	Neighbourhood	FF, CS, small food stores, GS, supermarkets.	Density, Euclidian proximity	0·25, 0·5, 1, 1·5, and 3 miles	Commercial
Mendes et al., 2013	Postal code	Supermarkets, hypermarkets	Presence, health vulnerability index	NA	Commercial
Meyer et al., 2015	Neighbourhood	CS, coops/natural food stores, specialty markets, supermarkets, GS, FF, food stances/cafeterias, restaurants	Density	3km	Commercial
Michimi and Wimberly, 2010	County	Supermarkets and supercentres other grocery stores (except convenience stores), and warehouse clubs	Euclidian proximity	NA	Government

Reference	Geographic unit of observation	Store type	Spatial food store measure	Buffer size	Food outlet source
Michimi and Wimberly, 2015	County	Supermarkets, snack/coffee shops, restaurants, FF, CS	Factor analysis	NA	Government
Morland et al., 2006	CTA	Supermarkets, grocery stores, or smaller non–corporate-owned food stores, CS, restaurants, FF, and limited-service restaurant	Density	NA	Government
Murphy 2017	Residential address	Supermarkets	Density, proximity	800, 1000, 1600, 2000 and 3000m network	Government, commercial, and ground truthing
Murphy 2018	Residential address	FF, supermarkets	Density, proximity	800m, 1000m, 1600m, 2000m, and 3000m network	Government and commercial
Mylona 2020	Residential address	FF	kernel Density	3·1 km	Commercial database
Oexle et al., 2015	County	FF	Count, proximity	1 mile	Ground truthing
Oka et al., 2013	CTA	Food markets, CS, grocers, restaurants, pizza stores, gyms	Principal component analysis	NA	Government
Patel et al., 2017	census enumeration blocks	FF, restaurants	Density	1-km	Ground truthing
Pearce et al., 2009	Census mesh block	Multinational/local FF	Travel proximity	NA	Yellow pages
Pineda et al.., 2021	CTA	FF, restaurant, CS, supermarkets	Density	NA	Government and ground truthing
Polsky et al., 2016	Census block group	FF, restaurants	Absolute density, relative density	720m along the street network	Commercial
Polsky et al., 2016	Dissemination blocks	Restaurants	Absolute and relative Density	720m	Commercial
Pouliou and Elliott, 2010	Postal code	FF, CS, GS, supermarkets	Density	1km	Government
Prince et al., 2012	Neighbourhood	GS, CS, specialty food stores, FF, restaurants	Density	NA	Another study

Reference	Geographic unit of observation	Store type	Spatial food store measure	Buffer size	Food outlet source
Pruchno et al., 2014	CTA	FF, store fronts, supermarkets, GS, CS	Density	NA	Government
Richardson et al., 2015	Residential address	FF, restaurants, supermarkets, CS	Density	3 and 8km Euclidean	Commercial
Rummo 2017	Residential address	FF, restaurants, CS, GS, supermarkets	percentage of CS, GS, and S out of sum of them, percentage of FF and FSR out of the sum of them	1-km street network proximity from respondents' residences	Commercial database
Rundle et al., 2009	Network buffer around residential address	Supermarkets, FV markets, FF, pizzerias, bakeries, and candy and nut stores	Density	805m network	Commercial
Salois, 2012	County	Restaurants, FF, supermarkets, GS, gas-based CS, no-gas CS, super centre/warehouse club stores, farmers' markets	Density	NA	Government
Singleton et al., 2016	County	GS, CS, farmer's markets, supercentres, supermarkets, FF, restaurants	Density	NA	Government
Slack et al., 2014	County/food desert tract	FF	Density	NA	Government
Spence et al., 2009	Postal code	Supermarkets, FF, specialty food stores, CS	Count, ratio, Retail Food Environment Index (RFEI)	800m and 1600m	Government and commercial
Stark et al., 2013	Zip code	GS, supermarkets, national/local FF, pizza restaurants, CS, Food outlets were categorized, bodegas, bakeries, candy and nut stores, meat markets, restaurants, GS, fish markets and specialty food stores	Density, relative concentration (proportion), diversity	NA	Commercial
Tung et al., 2016	Neighbourhood	GS	Euclidian Proximity	NA	Self-reported

Reference	Geographic unit of observation	Store type	Spatial food store measure	Buffer size	Food outlet source
Viola et al., 2013	Postal code	FF, pizzerias, supermarkets	Density, Network Proximity	¼ miles	Commercial
Walker 2020	Residential postcode	FF, restaurants, pubs to liquor stores, markets	ratio (FF/FSR, pubs/liquor stores); Count (markets)	500m	Ground-truthing survey
Wang et al., 2007	Census tracts and/or block groups	FF, food retail stores	Density, Euclidian Proximity	0·5 miles	Government and commercial
Xu and Wang, 2015	County	FF and restaurants	Ratio FF:Restaurants	NA	Government
Xu et al., 2013	Street committee	FF, restaurants	Density	720m street network	Government
Yan et al., 2015	County	Supercentres, GS, CS, specialized food stores	Density	NA	Government
Yenerall 2017	Residential address	GS	accessibility (network Proximity)	None	National database
Zenk 2017	Census block group	CS, small GS, large GS, liquor stores	availability (Count)	0·5-mile radial buffer around participants' census block centroid	Ground-truthing survey
Zhang 2019	CTA	mRFEI	mRFEI	0·5 miles	Commercial database
Zhang 2020	Subdistrict/town	FF, restaurants, small GS, LS	Density	NA	National database
Zick et al., 2009	Census block group	Healthy grocery stores, CS, restaurants, FF, multiple retail food options	Density, diversity, and design	NA	Government and commercial

CS: convenience store, FF: fast-food outlet, FV: fruit and vegetable store, GS: grocery store, LS: liquor store, RFEI: retail food environment index, mRFEI: modified retail food environment index. NA: not available/not applicable

5. Risk of bias assessment

Table S5. Risk of bias and quality assessment of reviewed studies

Reference	Population sampling	Outcome	Exposure (food environment)	Food outlet data source	Spatial analysis method	PA	Study design	Statistical Method	Data temporality/ time match	Score
Abbott et al., 2014	Low	High	Low	High	High	High	High	High	High	2
Adachi-Mejia et al., 2017	High	High	Low	Low	Low	Low	High	High	High	4
Ahern et al., 2011	Low	High	Low	High	High	Low	High	High	High	3
Albalawi 2020	High	Low	Low	Low	High	High	High	High	High	3
Backes 2019	Low	High	Low	Low	High	High	High	High	Low	4
Block et al., 2011a	Low	Low	Low	High	High	High	Low	Low	Low	6
Bodor et al., 2010	High	High	Low	Low	High	High	High	High	Low	3
Boone-Heinonen et al., 2013	Low	Low	Low	High	High	Low	Low	High	Low	6
Burgoine 2017	Low	Low	High	Low	High	Low	High	High	High	3
Burgoine 2018	Low	Low	Low	Low	High	Low	High	High	High	4
Burgoine et al., 2011	Low	High	Low	High	High	Low	Low	High	Low	5
Burgoine et al., 2016	Low	Low	High	Low	Low	High	High	High	Low	5
Carroll 2020	Low	Low	Low	Low	Low	Low	Low	High	Low	7
Cerin et al., 2011	Low	High	Low	Low	Low	Low	High	Low	High	6
Chaparro et al., 2017	Low	High	High	High	Low	High	High	Low	Low	4
Chen et al., 2010	Low	High	High	Low	High	High	High	Low	High	3
Chen et al., 2013	High	High	High	Low	Low	Low	High	Low	Low	5
Chen et al., 2016	Low	High	High	High	High	High	High	Low	High	2
Chen et al., 2019	High	Low	Low	Low	High	High	High	Low	High	4
Chen et al., 2020	High	Low	High	Low	High	High	High	High	High	2

Reference	Population sampling	Outcome	Exposure (food environment)	Food outlet data source	Spatial analysis method	PA	Study design	Statistical Method	Data temporality/ time match	Score
Christian, 2012	High	High	Low	Low	High	High	High	High	Low	3
Conroy 2018	High	High	Low	Low	High	High	High	High	High	2
Cooksey-Stowers et al., 2017	Low	High	Low	High	Low	Low	High	High	Low	5
Crawford et al., 2008	High	High	High	High	High	Low	High	High	High	1
Dake et al., 2016	High	Low	Low	High	Low	Low	High	Low	Low	6
Drewnowski et al., 2014b	High	High	High	Low	High	High	High	Low	Low	3
Drewnowski, 2012	High	High	High	Low	High	High	High	High	Low	2
Du et al., 2014	Low	Low	Low	High	Low	Low	Low	High	High	6
Dubowitz et al., 2012	Low	Low	Low	Low	High	Low	Low	High	High	6
Dunn et al., 2012	Low	High	High	Low	High	High	High	Low	Low	4
Fan et al., 2014	Low	High	Low	High	High	High	High	High	High	2
Frankenfeld et al., 2015	Low	High	Low	High	High	High	High	High	High	2
Fuller et al., 2013	High	High	High	Low	High	Low	High	Low	Low	4
Gartin, 2012	High	Low	Low	Low	High	High	High	High	Low	4
Ghosh-Dastidar et al., 2014	Low	Low	Low	Low	Low	High	High	High	Low	6
Gibson, 2011	Low	Low	Low	Low	High	High	High	High	Low	5
Hanibuchi et al., 2011	Low	High	Low	High	High	High	High	High	High	2
Hattori et al., 2013	Low	High	Low	High	Low	Low	High	Low	High	5
Hobbs 2017	High	High	Low	Low	Low	High	High	High	Unclear	3
Hobbs 2019	High	High	Low	Low	High	High	Low	Low	High	4
Hobbs 2019	High	High	High	Low	High	High	High	High	High	1
Hobbs 2019	High	High	High	Low	High	High	High	High	Unclear	1

Reference	Population sampling	Outcome	Exposure (food environment)	Food outlet data source	Spatial analysis method	PA	Study design	Statistical Method	Data temporality/ time match	Score
Hollands et al., 2013	High	High	Low	Low	High	Low	High	Low	Low	5
Hollands et al., 2014	Low	High	High	Low	High	Low	High	Low	Low	5
Hosler, 2009	Low	High	High	Low	High	High	High	High	High	2
Inagami et al., 2009	Low	High	High	Low	High	High	High	Low	High	3
Jaime et al., 2011	Low	High	Low	Low	High	Low	High	High	Low	5
Jeffery et al., 2006	Low	High	High	High	Low	Low	High	High	High	3
Jilcott et al., 2011	Low	High	Low	Low	High	Low	High	Low	High	5
Jilcott Pitts et al., 2015	High	High	High	Low	Low	High	High	High	Low	3
Kruger et al., 2014	High	High	High	High	High	High	High	High	High	0
Laxy et al., 2015	Low	Low	Low	High	Low	Low	High	High	Low	6
Li et al., 2008	Low	High	High	High	High	Low	High	Low	Low	4
Li et al., 2009c	Low	High	High	High	High	Low	High	Low	Low	4
Li et al., 2009c	Low	High	High	High	High	Low	High	Low	Low	4
Liese 2017	High	Low	Low	Low	High	Low	High	High	Low	4
Lopez, 2007	Low	High	Low	High	High	High	High	Low	High	3
Macdonald et al., 2011	Low	High	Low	Low	High	High	High	High	High	3
Mackenbach 2019	High	High	High	Low	Low	High	High	Low	High	3
Mackenbach 2019	High	High	High	Low	High	High	High	High	Low	2
Maddock, 2004	Low	High	High	High	High	Low	High	Low	High	3
Mason 2018	High	Low	High	Low	High	Low	High	High	Unclear	2
Mazidi and Speakman, 2017	Low	High	High	Low	Low	Low	High	High	Low	5
Mehta and Chang, 2008	Low	High	High	High	High	High	High	High	Low	2

Reference	Population sampling	Outcome	Exposure (food environment)	Food outlet data source	Spatial analysis method	PA	Study design	Statistical Method	Data temporality/ time match	Score
Mejia et al., 2015	High	High	Low	Low	Low	Low	High	High	High	4
Mendes et al., 2013	High	High	High	High	High	High	High	High	High	0
Meyer et al., 2015	High	Low	Low	High	High	Low	Low	High	High	4
Michimi and Wimberly, 2010	High	High	Low	High	High	High	High	High	Low	2
Michimi and Wimberly, 2015	High	High	Low	Low	High	High	High	Low	Low	4
Morland et al., 2006	Low	Low	Low	High	High	Low	High	Low	High	5
Murphy 2017	High	High	High	Low	High	High	High	Low	Low	3
Murphy 2018	High	High	High	Low	High	Low	High	Low	Unclear	2
Mylona 2020	High	Low	High	Low	High	Low	High	Low	Unclear	3
Oexle et al., 2015	High	High	High	Low	Low	High	High	High	High	2
Oka et al., 2013	Low	Low	Low	High	High	Low	High	Low	High	5
Patel et al., 2017	Low	Low	High	Low	Low	Low	High	High	High	5
Pearce et al., 2009	Low	Low	High	High	High	High	High	Low	High	3
Pineda et al., 2021	Low	Low	Low	Low	Low	Low	High	Low	High	7
Polsky 2016	High	High	Low	Low	Low	Low	High	High	High	3
Polsky et al., 2016	Low	Low	High	High	High	Low	High	High	High	3
Pouliou and Elliott, 2010	Low	High	Low	High	High	Low	High	High	High	3
Prince et al., 2012	Low	High	Low	High	High	Low	High	Low	High	4
Pruchno et al., 2014	High	High	Low	High	High	High	High	Low	Low	3
Richardson et al., 2015	High	Low	High	High	High	Low	Low	Low	Low	5
Rummo 2017	High	Low	Low	Low	High	Low	Low	High	Low	5
Rundle et al., 2009	Low	Low	Low	High	High	Low	High	Low	High	5

Reference	Population sampling	Outcome	Exposure (food environment)	Food outlet data source	Spatial analysis method	PA	Study design	Statistical Method	Data temporality/ time match	Score
Salois, 2012	Low	High	Low	High	High	Low	High	High	Low	4
Singleton et al., 2016	High	High	Low	Low	Low	High	High	High	High	
Slack et al., 2014	Low	High	High	High	High	Low	High	Low	High	3
Spence et al., 2009	High	High	Low	High	Low	High	High	High	High	2
Stark et al., 2013	High	High	Low	High	Low	Low	High	Low	Low	5
Tung et al., 2016	High	Low	High	High	High	Low	High	High	Low	3
Viola et al., 2013	High	High	Low	High	Low	Low	High	Low	Low	5
Walker 2020	High	Low	Low	Low	Low	Low	High	Low	Unclear	5
Wang et al., 2007	Low	High	Low	High	Low	Low	High	Low	High	5
Xu and Wang, 2015	Low	High	High	High	High	Low	High	Low	Low	4
Xu et al., 2013	High	High	High	Low	Low	Low	Low	Low	Low	6
Yan et al., 2015	High	High	Low	High	High	High	High	High	High	1
Yenerall 2017	Low	High	High	Low	High	High	High	High	Unclear	2
Zenk 2017	High	Low	Low	Low	High	High	Low	High	Low	5
Zhang 2019	High	Low	Low	Low	High	High	High	High	High	3
Zhang 2020	High	Low	Low	Low	High	Low	High	High	Low	4
Zick et al., 2009	High	High	Low	High	Low	Low	High	Low	High	4

A high score represents a lower risk of bias while a low score indicates a higher risk of bias. The maximum possible score was 9.

6. Food outlet density and proximity and its association with BMI

Figure S2. Fast-food outlet density and proximity and its association with BMI

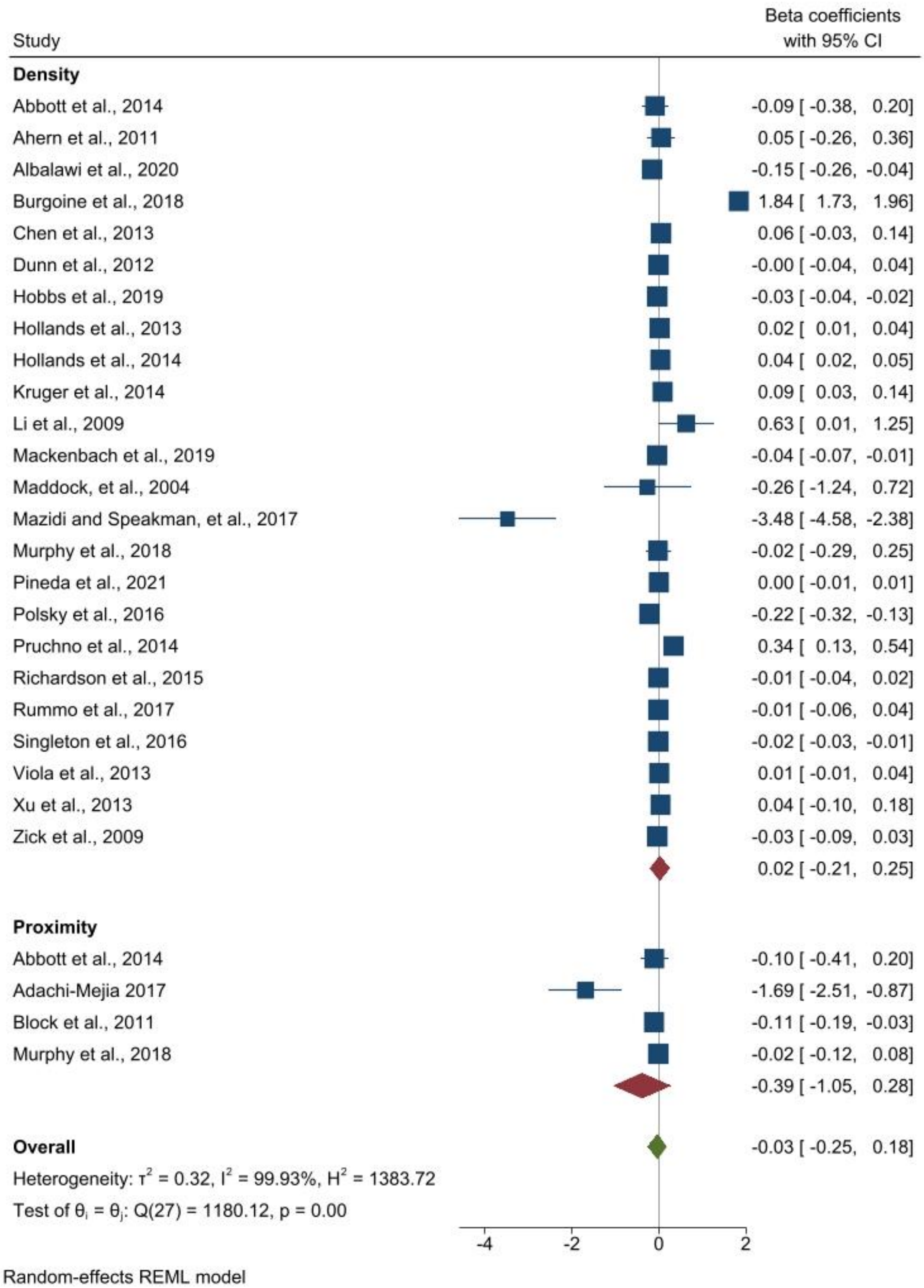


Figure S3. Restaurant density and its association with BMI.

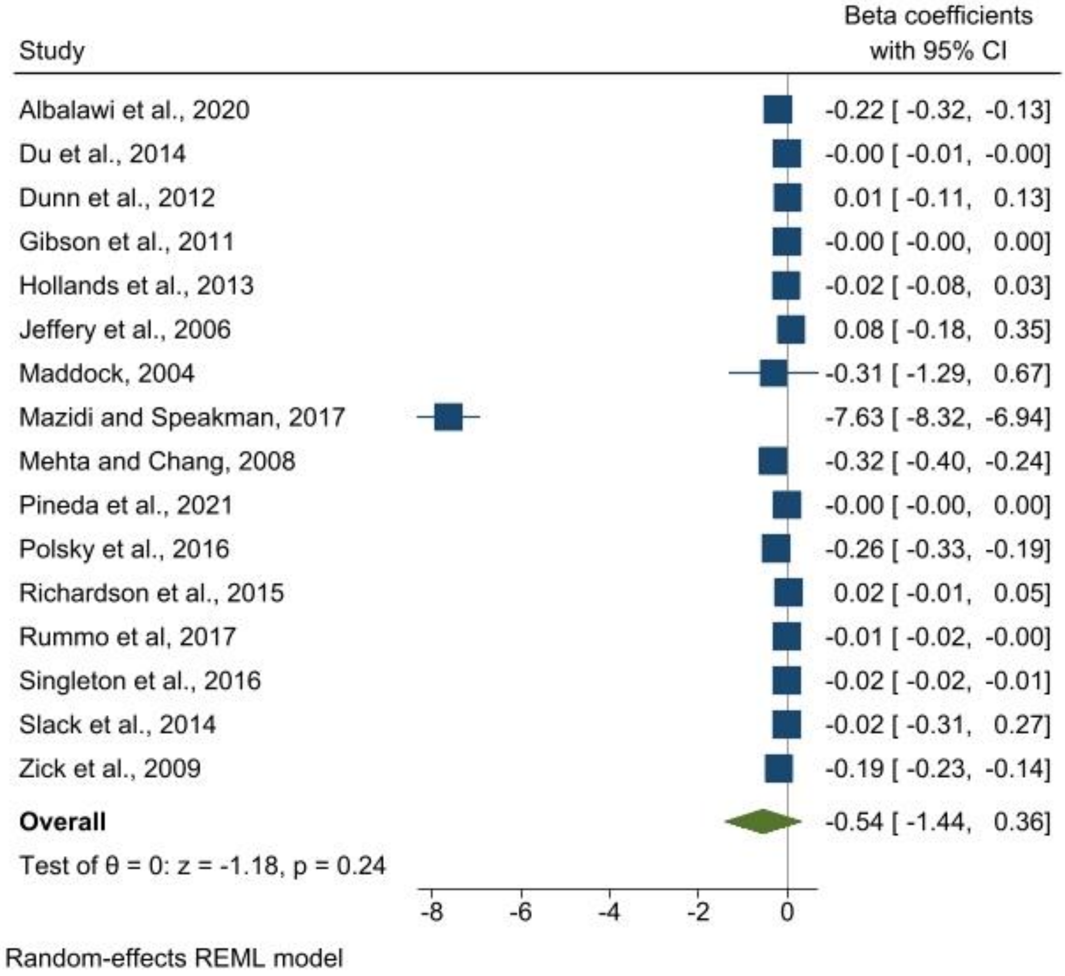


Figure S4. Convenience store density and proximity and its association with BMI.

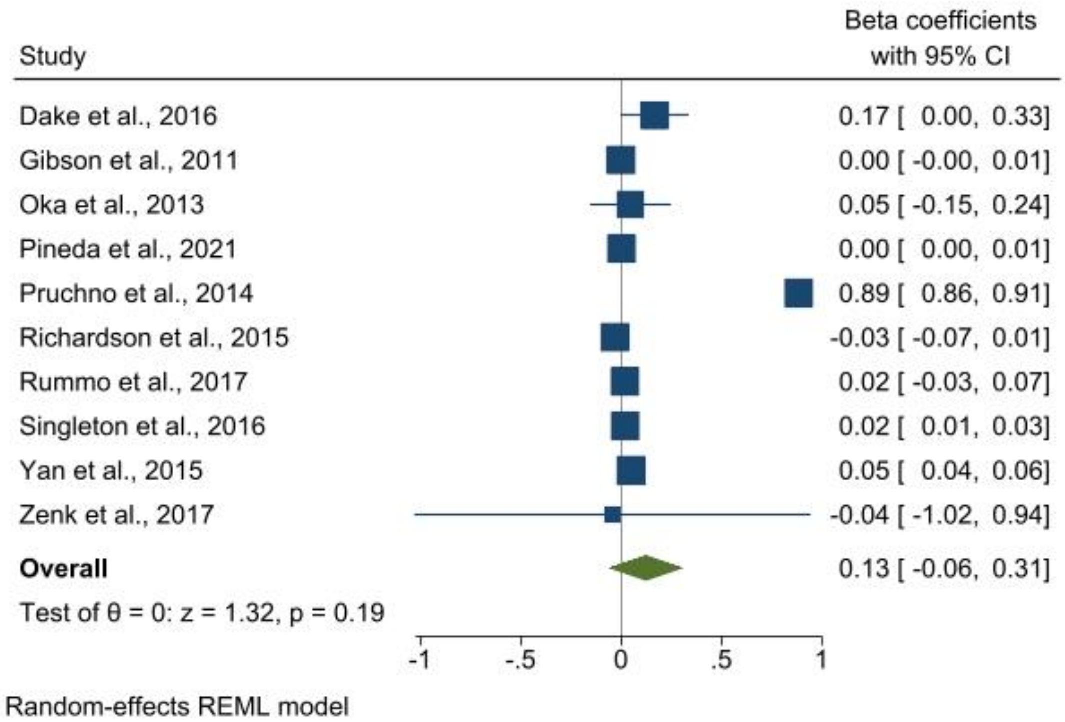


Figure S5. Supermarket density and proximity and its association with BMI.

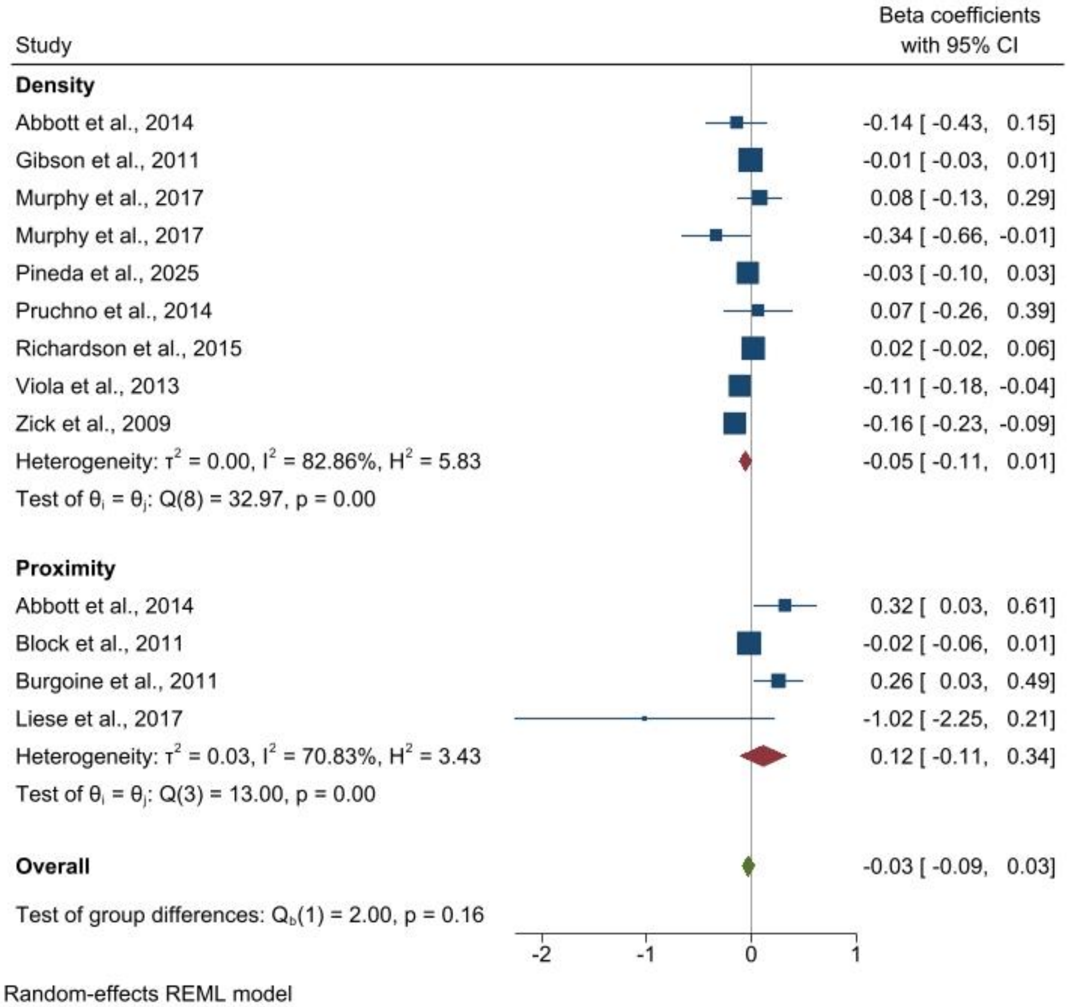


Figure S6. Fruit and vegetable store density and its association with BMI.

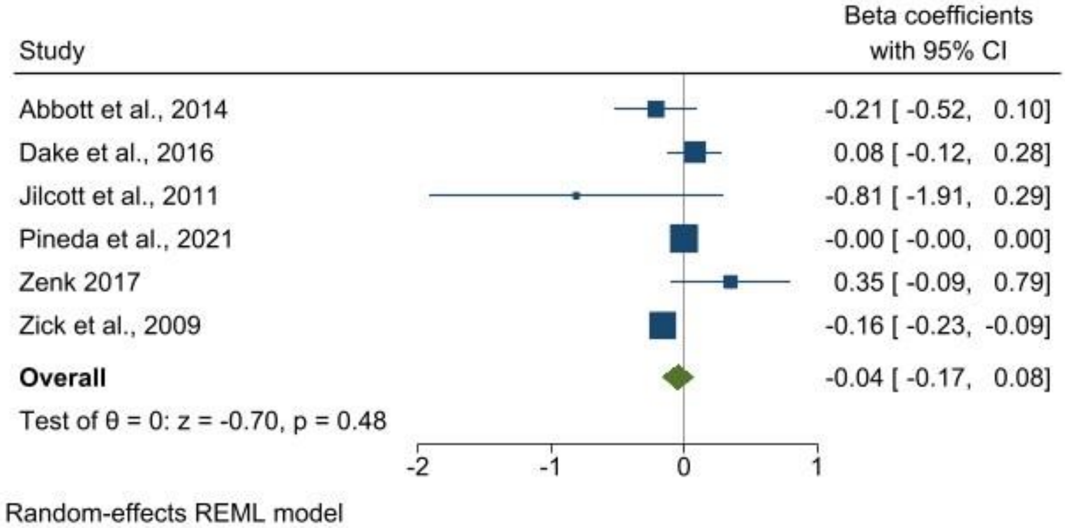


Figure S7. Retail food environment index (RFEI) and its association with BMI.