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Quantifying the Impact of Supermarket Distance on Childhood Obesity in Greater London, UK: Exploring Different Access Measures and Modification Effects of Transportation

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Abstract

Background: Healthy food access may be relevant for predicting trends in childhood obesity. The goal was to determine associations between childhood overweight (including obesity) and distance to three nearest supermarkets stratified by transportation modes (walking, cycling, driving).

Methods: Bivariate and multivariate linear regressions examine the relationship with obesity, including interacting active and inactive modes.

Results: Proximity to at least three supermarkets shows small but significant positive association with obesity. Walking mode showed higher obesity rates than driving, and distance was not related to the mode of travel.

Conclusions: Disparities in healthy food access may not contribute meaningfully to childhood obesity, as other individual factors may be largely at play.

Keywords: childhood obesity; food access; supermarket; transportation

Introduction

Obesity continues to rise in the United Kingdom (UK), mirroring global trends[1] and threatening to become a grave public health threat because of its associated health and economics consequences.[2,3] The current obesity crisis may be driven by qualities of the environment that promote both excess energy consumption and inadequate energy expenditure.[4] Healthy food access may therefore be relevant for predicting trends in childhood obesity in restricted environments[5]; for example, this restriction in access and availability of low-cost healthful food may occur in areas limited by public transportation, higher cost of nutritious foods, or where fast-food restaurants or convenience stores dominate.[6] The presence of a supermarket is often viewed as the "gold standard" in food access research, as supermarkets typically offer lower prices, increased quantity, and improved quality of food items

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Correction added on November 15, 2022 after first online publication of November 2, 2022: The article reflects Open Access, with copyright transferring to the author(s), and a Creative Commons Attribution Noncommercial License (CC-BY-NC) added (http://creativecommons.org/licenses/by-nc/4.0/).

compared with smaller food venues, such as convenience stores,[7] therefore are thought to have a generally preventive effect on obesity, encouraging more healthful eating.[4]

Systematic reviews and meta-analyses confirm rather mixed relationship between weight-related behaviors/outcomes among children and adolescents and food environments,[8,9] which may be owing to various theoretical and methodological constructs being used in relation to the choice of dataset, definition of healthy vs. unhealthy food outlets, food neighborhood definition (*e.g.*, residential, school), or the choice of measure (*e.g.*, proximity, density) and buffer cutoffs.[10] In addition to impacting associations with obesity,[11,12] this ongoing heterogeneity in measuring food access has been found to increase likelihood of conclusions with either type 1 errors or type 2 errors,[13] contribute to a conflicting evidence base and confusing policy messages,[10] and impair evidence synthesis and translation when measurement differences are overlooked[10,12] Consequently, to better understand associations between food access and obesity, researchers have called for better designed studies[9] and following an intuitive approach based on convergence of results.[10] In this study, I further examine this sensitivity of the association to the metric used; Euclidean distance, which represents the shortest distance between two points, is also considered for comparison with literature, as it could be a reasonable surrogate for true distances,[14] including all real-life applications of the vehicle routing problem.[14]

Transportation systems are important in understanding links between food access and diet-related health outcomes because they can affect which food sources consumers can reach, thus moderating healthy eating.[15–17] Evidence shows that mode choice varies according to trip purpose and distance.[18] Moreover, those living below the poverty line rely on walking, bicycling, public transportation, or shuttle service for food provisioning.[19] The limited literature also suggests that motor vehicle ownership may buffer the effect of poor access to high-quality neighborhood food environments.[20–22] It is also possible that food environment may influence dietary intake by demanding an extra transportation burden for low-income populations.[23,24] Others found that greater dependence on passive forms of transportation could promote obesity,[25] which may be owing to ''increased inactivity by reducing the need for more active forms of transportation,''[26] as opposed to active travel (*i.e.*, walking and cycling) that could lower obesity rates by increasing levels of physical activity (PA).[27,28] For example, some argue that walking to public transit helps meeting PA recommendations,[29] with one systematic review concluding that increased level of access to public transport may prevent the development of childhood obesity.[30] Moreover, another systematic review and meta-analysis has demonstrated effects of air pollution, which is secondary to motorized transit, on obesity in children.[31]

Limited evidence also shows that reductions of distances between homes and grocery stores could lead to less driving for grocery shopping,[32] whereas larger distances were predictive of using car as the major transportation mode for grocery shopping.[33] Similarly, others found that commuting to a distant workplace increases the risk of obesity; however, the mediating effects of mode of transport may be subject to reverse causality.[34] What remains unclear, however, is how the growing distance to food stores may influence childhood obesity depending on travel modes (*e.g.*, cycling as opposed to driving), and whether encouraging continued dependence on active forms of transportation for daily grocery shopping may help reduce obesity. To the best of author's knowledge, this is the first study to look directly at the impact of motorized and non-motorized transportation on childhood obesity, while accounting for the effect of distance to healthy foods.

The main purpose was to determine associations between childhood overweight (including obesity) and healthy food access as approximated by distance to three nearest supermarkets in Greater London, United Kingdom. Both proximity and density-based measures are used to capture different aspects of food environments; for example, proximity measures food choice influence through food cost and availability, whereas density accounts for differences in price, quality, and selection. The latter can also be quantified by proximity to additional nearest outlets (*i.e.*, second and third) because the distance to additional nearest shops gives a sense of the amount of choice consumers have and the amount of competition the nearest store faces.

Specifically, this study examines: (1) which access measure best defines access to healthy food for various transportation profiles; and (2) whether the relation between distance and overweight changes given the nonmotorized/active (walking, cycling) versus motorized/inactive (driving) transportation. Moreover, secondary aim includes (3) examining whether the relationship between active–inactive transportation and childhood overweight changes depending on distance that needs to be travelled. Greater London was chosen as a suitable case study because the city has the highest rates of childhood obesity of any global city,[35] as well as a good variation in the type of transportation used.[36] Results are relevant to the United Kingdom and other countries because the factors debarring access to a healthy diet operate in broadly similar ways in many developed nations besides the United Kingdom.[37]

Data and Methods

The analysis uses publicly available data by the National Child Measurement Programme (NCMP) and Open Route Service, the latter which provided database of road distances for various transport modes. A geospatial database that was created includes street network distances between 312,000 postcode centroids and three closest of total 1,600 supermarkets. The sample includes older children aged 10–11 years. The unit of analysis is the Middle Super Output Area (MSOA) level, which is a geographic hierarchy in England and Wales with the minimum population of 5000 (or 2000 households) and the mean of 7200 (or 4000 households). The final dataset includes 983

Table 1. Classification of Access Measures

Designed		Derived			Transformed	
			Averaged[d]		Second-order[e]	
Road[a]	Euclidean[b]	No of stores[c]	Road	Euclidean	Road	Euclidean
1st store	1st store	1500 m for walking (Inner: 0.5/1/1.5 km)			1st store	1st store
2nd store	2nd store	3000 m for cycling (″/″/″/2/2.5/3 km)	2nd store	2nd store	2nd store	2nd store
3rd store	3rd store	5000 m for driving (1/3/5 km)	3rd store	3rd store	3rd store	3rd store

[a]Road distance alongside street network from postcode centroid.

[b]Straight line distance from postcode centroid.

[c]Number of stores for walking, cycling, and driving within predefined thresholds, inner cut offs in parentheses.

[d]Averaged distances from postcode centroid to two and three nearest supermarkets.

[e]Distance raised to the second power for fitting polynomial models.

observations for each transport profile; nine observations were missing owing to data confidentiality. In the next sections, I describe the data in more detail.

Data

Dependent variable. Proportion of children that are overweight (including obese) by the NCMP constituted the dependent variable. The NCMP program measures the height and weight of children in Reception (aged 4–5) and year 6 (aged 10–11) to assess overweight and obesity levels in children within primary state schools. Heights and weights are used to calculate a BMI percentile by dividing weight (in kilograms) by the square of height (in meters); children are classified as overweight (including obese) if their BMI is on or above the 85th centile of the British 1990 growth reference (UK90) according to age and sex.[38] The measurement process is overseen by trained health care professionals. The data for all the geographic areas are based on the child's Lower Super Output Area (LSOA) of residence, which is the second smallest level of geography published in England and Wales and has an average population of ∼1500 residents or 650 households. LSOA data, using 2011 LSOA codes, were aggregated to 2011 MSOA geographies using an LSOA to MSOA lookup and data averaged across three consecutive years 2013/14, 2014/15, and 2015/16.*

Explanatory variables. Locations of supermarkets belonging to major UK supermarket chains (Tesco, Sainsbury's, ASDA, Morrisons, Waitrose, Aldi, and Co-operative)[39] were sourced from Ordnance Survey Points of Interest, which is the most comprehensive, location-based directory of all public and privately owned businesses, education, and leisure services across the United Kingdom.[40] In total, 16 different food access measures were estimated, including proximity (road network and Euclidean distances) and density of supermarkets (the number of outlets within various Euclidean thresholds for different travel modes); averaged and transformed distances (second order) were also calculated to account for variability around the data and explore polynomial models, respectively. Buffer cutoffs (upper and inner) have been informed by the policy and literature or based on data exploration (percentiles); for example, in the UK context, 500 m walking distance away from the closest supermarket defines threshold for limited accessibility to healthful food (Beverley Hughes, Minister for Local Government and Regions, July 12, 2000).[41] Table 1 provides the classification of measures as used in this study; for detailed description of measures and how the geospatial database was built (Supplementary File S1).

In addition, the following socioeconomic factors thought to be associated with the childhood obesity prevalence were collated from UK Census 2011 and Office for National Statistics: population density,[42] non-White ethnicity,[43] unemployment level,[44] household income level,[45,46] and educational level.[47,48] Finally, because certain demographic factors would further affect demand for mobility and access, for example, the availability of a car, being full-time employed, or having dependents would increase demand for driving as opposed to walking or cycling[48,49]; these additional covariates were also sourced from the UK Census and entered in the models.

Table 2 lists all the variables used in the study, including description and source, level of analysis and years covered, and descriptive statistics; statistical descriptions for all the distance measures, including transformations applied and distances to the nearest outlet, are given in Supplementary File S2. At the time of conducing the analysis, the most recent data were used. Temporal mismatch between the data could not be avoided because of data availability issues; however, as the purpose of this research is not to study causal links, this should not impact interpreting results and drawing conclusions.

*The data is freely available from NHS Digital NCMP: https://digital.nhs.uk/services/national-child-measurement-programme/

Table 2. Descriptive Statistics (Mean ± Standard Deviation) for the Variables in the Study Including Base for England

Variables	Level and year	London	England incl. London	England excl. London
Prevalence of obesity[a]	MSOA, 2013–2016	21.40 ± 4.89	22.19 ± 4.60	22.34 ± 4.51
Euclidean distance (third)[b]	Postcode, 2018	82 ± 0.37	—	—
Walking distance (third)[c]	Postcode, 2018	84 ± 0.28	—	—
Cycling distance (third)[d]	Postcode, 2018	1.55 ± 0.62	—	—
Driving distance (third)[e]	Postcode, 2018	1.4 ± 0.7	—	—
Income[f]	MSOA, 2018	52,889.73 ± 8910.52	43,857.36 ± 9720.05	42,128.2 ± 8897.22
Population density[g]	LSOA, 2018	94.01 ± 49.51	41.64 ± 36.30	33.05 ± 24.08
Non-White ethnicity[h]	LSOA, 2011	2.08 ± 2.39	0.26 ± 0.35	0.18 ± 0.27
Unemployment level[i]	LSOA, 2011	3.78 ± 0.92	0.33 ± 0.07	0.34 ± 0.07
Education level[j]	LSOA, 2011	7.09 ± 4.02	0.23 ± 0.08	0.24 ± 0.08
Car availability[k]	LSOA, 2011	402.07 ± 101.66	—	—
Having no children[l]	LSOA, 2011	0.14 ± 0.04	—	—
Part-time job[m]	LSOA, 2011	0.26 ± 0.06	—	—

[a]Proportion of overweight children (incl. obese) for MSOAs in England and Wales, NCMP 2013–2016 ORS 2018.
[b]Straight line distance between postcode centroid and third nearest supermarket, designed measure, ORS 2018.
[c]Walking distance between postcode centroid and third nearest supermarket, designed measure, ORS 2018.
[d]Cycling distance between postcode centroid and third nearest supermarket, designed measure, ORS 2018.
[e]Driving distance between postcode centroid and third nearest supermarket, designed measure, ORS 2018.
[f]Estimates of total annual household income for MSOAs in England and Wales, ONS 2018.
[g]Number of persons per hectare as a measure of density, ONS 2018.
[h]Proportion of households from the non-White group, ethic group classification, UK Census 2011.
[i]Proportion of households with adults not in employment, UK Census 2011.
[j]Proportion of households with the highest level of qualification, UK Census 2011.
[k]Proportion of households with one or more cars, UK Census 2011.
[l]Proportion of households with no dependent children, UK Census 2011.
[m]Proportion of households in part-time employment, UK Census 2011.
LSOA, Lower Super Output Area; MSOA, Middle Super Output Area; NCMP, National Child Measurement Programme; ONS, Office for National Statistics 2018; ORS, Open Route Service.

Statistical Analysis

Controls for levels of unemployment and education were initially removed owing to multicollinearity with income; other highly correlated (>0.7) variables were not removed as this could cause omitted-variable-bias (*e.g.*, car availability is highly correlated with density, but the former is associated with the probability to walk or cycle while the latter is a strong predictor of childhood obesity). Variables for ethnicity, cycling, and driving were positively skewed thus transformed to normality, which is recommended for parametric statistics, using the *gladder* function in Stata showing the quantiles of transforms according to the ladder of powers against the quantiles of a normal distribution.

Stepwise semi-automatic approach was used to guide the choice of explanatory variables, and bivariate and multivariate linear regressions examined their relationship with childhood obesity, including effect modification with distance stratified by transportation mode. In addition, the effect modification was examined by interacting nonmotorized (combined walking and cycling profiles) and motorized (driving) travel modes. Initially the results were obtained for nontransformed distance to the third nearest supermarket, followed by sensitivity analyses using transformed distance and distances to the nearest store (Supplementary File S3). The research was conducted with ArcGIS for building the service area, R for building the origin–destination cost matrix solver, and Stata 16 for performing statistical analyses.

Results

The unadjusted and adjusted regression models with road network distance to the third nearest supermarket as the primary exposure variable are given in Table 3;

Table 3. Bivariate and Multivariate Associations between Childhood Overweight, Road vs. Euclidean Distance to the Third Nearest Supermarket and Other Explanatory Variables in a Sample of 974 Middle Super Output Areas, Greater London

	Bivariate association, β (SE)	Multivariate association, β (SE)	
Dependent variable: BMI Road distance in km	0.61** (0.22)	0.88*** (0.19)	—
Euclidean in km	0.49 (0.43)	–	1.64*** (0.42)
Income[a]	–0.00*** (0.00)	–0.00*** (0.00)	–0.00*** (0.00)
Density[b]	0.02*** (0.00)	0.01 (0.00)	0.01 (0.00)
Ethnicity (log-10)[c]	6.51*** (0.62)	−1.6 (0.9)	−1.25 (0.9)
Car availability[d]	–0.02*** (0.00)	–0.01 (0.00)**	–0.01** (0.00)
Having no children[e]	–57.78*** (3.3)	–28.11 (7.12)***	–26.77*** (7.19)
Part-time job[f]	27.9*** (2.67)	−16.81 (3.61)***	−17.95*** (3.63)

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

[a]Total annual household income.

[b]Number of persons per hectare.

[c]Proportion of households from the non-White group, the base 10-logarithm transformation.

[d]Proportion of households with one or more cars.

[e]Proportion of households with no dependent children.

[f]Proportion of households in part-time employment.

BMI, body mass index; SE, standard error.

Euclidean distance is also given for comparison. In both the bivariate and multivariate analyses, slight differences in childhood overweight were found between road and Euclidean measures, both showing proportion of overweight children and supermarket distance tend to increase in the same direction. When considering distance in multivariate association, both measures become strongly significant.

The adjusted results from the linear and interaction regressions with overweight stratified by transportation mode (including active vs. inactive transportation) to the third nearest supermarket are given in Table 4. All profiles showed that childhood overweight increases with growing distance and association were significant; however, the interaction term was not significant.

Regressions with best candidate measures per transport mode are given in Table 5. Overall, distance to the third nearest store was best approximation for all the profiles. Results of the sensitivity analyses did not change the interpretation of the results (except results for cycling to the nearest store were sensitive to the transformation applied but these were not statistically significant) but further highlighted that distance to the third nearest supermarket is stronger predictor of childhood overweight than distance to the nearest supermarket.

Discussion

The objective of this study was to examine different measures of healthy food access stratified by nonmotorized vs. motorized transportation mode in relation to childhood overweight outcome. Results show that distance to at least three closest supermarkets is important for explaining obesity rates. This could be explained by the context of a densely populated metropolis where high-volume transportation networks enable faster commute between food outlets located in relatively near proximity to each other. It is also possible that people do not shop for their groceries at the closest store[50] because other factors may influence their shopping preference, such as cost and perceived value for money,[51,52] brand loyalty,[53] the store layout or atmosphere,[54] or whether a store offers certain facilities or not.[55]

Walking profile shows higher obesity rates than driving, which contradicts simulation evidence that ''local walkability interventions can achieve measurable declines in childhood obesity rates.''[56] Walking and cycling are beneficial not only in terms of PA, health outcomes (including childhood obesity[57]), and all-cause mortality,[58,59] but also sustainable mobility[60]; on the contrary, active modes are also associated with health *risks* related to pollution exposure and injury,[61] which may outweigh the benefits of PA.[62,63] One systematic review and meta-analysis also argues that bike lane access is associated with children and adolescents' PA[64]; still, others contest these results[65]; and the relationship with obesity is unclear.[64] The mix of neighborhood-level barriers and facilitators of weight-related health behaviors is likely leading to additional difficulties in disentangling their associations with adolescent obesity.[66]

Table 4. Associations between Childhood Overweight, Distance to the Third Nearest Supermarket Stratified by Travel Modes, Including Interaction between Active and Passive Modes, and Other Covariates in a Sample of 974 Middle Super Output Areas, Greater London

	i, Walking, β (SE)	ii, Cycling, β (SE)	iii, Active, β (SE)	iv, Driving, β (SE)	v, Active#, driving
Dependent variable: BMI					
Walking distance	2.33*** (0.49)	—	—	—	—
Cycling distance	—	0.75*** (0.21)	—	—	—
Active distance[a]	—	—	1.55*** (0.34)	—	0.82 (0.61)
Driving distance	—	—	—	0.88*** (0.19)	0.41 (0.56)
Interaction[b]	—	—	—	—	0.04 (0.2)
Income[c]	–0.00*** (0.00)	–0.00*** (0.00)	–0.00*** (0.00)	–0.00*** (0.00)	–0.00*** (0.00)
Density[d]	0.01 (0.00)	0.00 (0.00)	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
Ethnicity (log-10)[e]	−1.58 (0.9)	−1.34 (0.91)	−1.36 (0.9)	−1.62 (0.9)	−1.48 (0.9)
Car availability[f]	–0.01** (0.00)	–0.01** (0.00)	–0.01** (0.00)	–0.01** (0.00)	–0.01** (0.00)
Having no children[g]	–28.65*** (7.15)	–27.23*** (7.2)	–26.32*** (7.17)	–28.11*** (7.12)	–26.86*** (7.19)
Part-time job[h]	−18.04*** (3.67)	−15.29*** (3.65)	−15.66*** (3.62)	−16.82*** (3.61)	−16.14*** (3.64)

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

[a]Walking and cycling distances combined and averaged.

[b]Interaction between active and inactive (driving) mode of travel.

[c]Total annual household income.

[d]Number of persons per hectare.

[e]Proportion of households from the non-White group, the base 10-logarithm transformation.

[f]Proportion of households with one or more cars.

[g]Proportion of households with no dependent children.

[h]Proportion of households in part-time employment.

BMI, body mass index; SE, standard error.

When interacting active–inactive transportation distance, results show that people may not substitute one for the other when distance changes. This contrasts with the evidence suggesting distance would be related to the mode of travel,[18,32,67,68] and as such requires further examination. For example, it was found that reductions of distances between homes and grocery stores could lead to less driving for grocery shopping.[32] In another study, children who lived farther from school were less likely to walk, which was partly attributed to certain features within neighborhoods.[67]

Similarly, Nelson et al[68] argue that inactive commuting to schools for children is mainly owing to distance and time constrains, not the bike lane access,[68] and that the relationship depends on the intensity of PA.[69] It is also possible that more advanced models could identify patterns in the data that measures used in this study have missed. For example, a model using the floating catchment area approach and integrating residential transportation mode choices probabilities and the travel friction coefficient has been shown to get closer to the reality of transportation, including multiple mode representation, than traditional estimations of accessibility.[70]

Limitations and Directions for Further Research

This research accounts for measures of healthy food access to supermarkets only; future research could consider adding other food retailers in addition to supermarkets, including unhealthy food outlets. Public transportation should also be considered in the future as those living below the poverty line and without ready access to a vehicle rely on it for accessing healthy food. Obesity is measured using high-quality, aggregated indicators, which may be useful for policy that is already based on the same level data; however, individual data may better capture people's actual behaviors, feelings, and thoughts (*e.g.*, about food and diet or travelling). Future research could also look at different thresholds of tolerance for nonmotorized travel to stores and investigate disparities in food access between inner and outer London boroughs to account for differences in urban arrangement (*e.g.*, public

Table 5. Associations between Childhood Overweight and Best Candidate Measures Per Transport Mode in a Sample of 974 Middle Super Output Areas, Greater London

	i, Walking, β (SE)	ii, Cycling, β (SE)	iii, Driving, β (SE)
Dependent variable: BMI			
Road distance to the third store	1.84*** (0.54)	—	—
Euclidean distance to the third store	0.94* (0.47)	1.64*** (0.42)	—
Average distance to the three closest stores	—	—	0.99*** (0.23)
Income[a]	−0.00*** (0.00)	−0.00*** (0.00)	−0.00*** (0.00)
Density[b]	0.01 (0.00)	0.01 (0.00)	0.01 (0.00)
Ethnicity (log-10)[c]	−1.42 (0.9)	−1.25 (0.9)	−1.64 (0.9)
Car availability[d]	−0.01** (0.00)	−0.01** (0.00)	−0.01** (0.00)
Having no children[e]	−26.74*** (7.15)	−26.77*** (7.19)	−28.74*** (7.12)
Part-time job[f]	−18.46*** (3.61)	−17.95*** (3.63)	−16.68*** (3.61)
N	974	974	974
Adj R^2	0.413	0.407	0.408

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

[a]Total annual household income.

[b]Number of persons per hectare.

[c]Proportion of households from the non-White group, the base 10-logarithm transformation.

[d]Proportion of households with one or more cars.

[e]Proportion of households with no dependent children.

[f]Proportion of households in part-time employment.

BMI, body mass index; SE, standard error.

transport provision, areas' resilience to retail environmental changes), including sociodemographic inequities in accessing active transportation.

A further limitation to this study's overall approach exists with regard to its sample, including children aged 10–11 years. Children rely on their caregivers to provide them with nutritious food; however, older children may be more independent in their food decisions than their younger counterparts,[71] as well as more mobile in terms of travelling around their own neighborhood or city without adult supervision.[72] For example, recent evidence shows that during the COVID pandemic parents were more likely to eat with their younger children, providing more structure around meals and restricting snacks, whereas older children tended to have unrestricted access to unhealthy snacking.[73] Therefore, in addition to the distance and food access, future studies could look at how independently older children are allowed to make their own food choices and how much may this affect their weight status, while accounting for personal, environmental, and macrosystem factors.[74] In addition, as obesity and travel behavior are related to gender,[75,76] gender differences should be considered, especially when inconsistent results have been reported between men and women.[77]

Conclusions

This research tested a real-world network analysis approach to approximate walkability to three nearest supermarkets, in addition to operationalizing cycling and driving distances to realistically consider population level exposures to healthy foods and their associations with childhood obesity. Walking mode showed higher obesity rates than driving, and distance was not related to the mode of travel. The results can be extrapolated to other densely populated cities and metropolitan areas. Tackling nutritional inequality and encouraging continued dependence on active forms of transportation to reduce obesity rates may require individual approaches, in addition to relocating road space and creating new routes for safer walking and cycling.

Impact Statement

The results provide a better understanding of supermarket access and transportation disparities in childhood overweight prevalence in the context of large metropolis, including effects of active versus inactive modes and consideration for whether distance moderates their relationship with childhood overweight.

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Authors' Contributions

Conception and design of the work; acquisition, analysis, and interpretation of data. Author gave her final approval for the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Author Disclosure Statement

The author declares no conflict of interest.

Supplementary Material

Supplementary File S1
Supplementary File S2
Supplementary File S3

References

1. World Health Organisation. Obesity and Overweight. 2020. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight [Last accessed: August 15, 2022].
2. Cecchini M, Vuik S. The heavy burden of obesity in The Heavy Burden of Obesity: The Economics of Prevention, OECD Publishing, Paris, 2019; doi; 10.1787/3c6ec454-en
3. Sahoo K, Sahoo B, Choudhury A, et al. Childhood obesity: Causes and consequences. J Family Med Prim Care 2015;4(2):187–192; doi: 10.4103/2249-4863.154628
4. Mitchell NS, Catenacci VA, Wyatt HR, et al. Obesity: Overview of an epidemic. Psychiatr Clin N Am 2011;34(4):717–732; doi: 10.1016/j.psc.2011.08.005
5. Lytle LA. Measuring the food environment. State of the science. Am J Prev Med 2009;36(4S):S134–S144; doi: 10.1016/j.amepre.2009.01.018
6. Gittelsohn J, Sharma S. Physical, consumer, and social aspects of measuring the food environment among diverse low-income populations. Am J Prev Med 2009;36(4 Suppl.):S161–S165; doi: 10.1016/j.amepre.2009.01.007
7. Caspi CE, Pelletier JE, Harnack LJ, et al. Pricing of staple foods at supermarkets versus small food stores. Int J Environ Res Public Health 2017;14(8):915; doi: 10.3390/ijerph14080915
8. Jia P, Luo M, Li Y, et al. Fast-food restaurant, unhealthy eating, and childhood obesity: A systematic review and meta-analysis. Obes Rev 2021;22(Suppl. 1):e12944; doi: 10.1111/obr.12944
9. Zhou Q, Zhao L, Zhang L, et al. Neighborhood supermarket access and childhood obesity: A systematic review. Obes Rev 2021; 22(S1):e12937; doi: 10.1111/obr.12937
10. Titis E, Procter R, Walasek L. Assessing physical access to healthy food across United Kingdom: A systematic review of measures and findings. Obes Sci Pract 2022;8(2):233–246; doi: 10.1002/osp4.563
11. Maguire ER, Burgoine T, Penney TL, et al. Does exposure to the food environment differ by socioeconomic position? Comparing area-based and person-centred metrics in the Fenland Study, UK. Int J Health Geogr 2017;16(1):1–4; doi: 10.1186/s12942-017-0106-8
12. Wilkins E, Morris M, Radley D, et al. Methods of measuring associations between the retail food environment and weight status: Importance of classifications and metrics. SSM Popul Health 2019;8:100404; doi: 10.1016/j.ssmph.2019.100404
13. Thornton LE, Pearce JR, Macdonald L, et al. Does the choice of neighbourhood supermarket access measure influence associations with individual-level fruit and vegetable consumption? A case study from glasgow. Int J Health Geogr 2012;11(1):29–41; doi: 10.1186/1476-072X-11-29
14. Boyacı B, Dang TH, Letchford AN. Vehicle routing on road networks: How good is euclidean approximation? Comput Oper Res 2021;129:105197; doi: 10.1016/j.cor.2020.105197
15. Horner MW, Wood BS. Capturing individuals' food environments using flexible space-time accessibility measures. Appl Geogr 2014; 51:99–107; doi: 10.1016/j.apgeog.2014.03.007
16. Burgoine T, Forouhi NG, Griffin SJ, et al. Associations between exposure to takeaway food outlets, takeaway food consumption, and body weight in Cambridgeshire, UK: Population based, cross sectional study. BMJ 2014;348:g1464; doi: 10.1136/bmj.g1464
17. Burgoine T, Monsivais P. Characterising Food Environment Exposure at Home, at Work, and along Commuting Journeys Using Data on Adults in the UK. Int J Behav Nutr Phys Act 2013;10:85; doi: 10.1186/1479-5868-10-85
18. Bureau of Transportation Statistics. U.S. DEPARTMENT OF TRANSPORTATION. Long Distance Transportation Patterns: Mode Choice. 2011. Available from: https://www.bts.gov/archive/publications/america_on_the_go/long_distance_transportation_patterns/entire [Last accessed: September 14, 2022].
19. ver Ploeg M, Mancino L, Todd JF, et al. Where do Americans usually shop for food and how do they travel to get there? Initial findings from the national household food acquisition and purchase survey. In: Food Shopping Patterns and Geographic Access to Food: Comparisons and Data. 2015. A report summary from the Economic Research Service (No. 1476-2017-3882), United States Department of Agriculture, March 2018.
20. Fuller D, Cummins S, Matthews SA. Does transportation mode modify associations between distance to food store, fruit and vegetable consumption, and BMI in low-income neighborhoods? Am J Clin Nutr 2013;97(1):167–172; doi: 10.3945/ajcn.112.036392

21. Burns CM, Inglis AD. Measuring food access in Melbourne: Access to healthy and fast foods by car, bus and food in an urban municipality in Melbourne. Health Place 2007;13(4):877–885; doi: 10.1016/j.healthplace.2007.02.005
22. Inagami S, Cohen DA, Brown AF, et al. Body mass index, neighborhood fast food and restaurant concentration, and car ownership. J Urban Health 2009;86(5):683–695; doi: 10.1007/s11524-009-9379-y
23. Hill BG, Moloney AG, Mize T, et al. Prevalence and predictors of food insecurity in migrant farmworkers in Georgia. Am J Public Health 2011;101(5):831–833; doi: 10.2105/AJPH.2010.199703
24. Ver Ploeg M. Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences Report to Congress. Diane Publishing, 2009.
25. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. Am J Prev Med 2004;27(2):87–96; doi: 10.1016/j.amepre.2004.04.011
26. Lear SA, Teo K, Gasevic D, et al. The association between ownership of common household devices and obesity and diabetes in high, middle and low income countries. CMAJ 2014;186(4):258–266; doi: 10.1503/cmaj.131090
27. Gordon-Larsen P, Boone-Heinonen J, Sidney S, et al. Active commuting and cardiovascular disease risk: The CARDIA study. Arch Intern Med 2009;169(13):1216–1223; doi: 10.1001/archinternmed.2009.163
28. Bassett DR, Pucher J, Buehler R, et al. Walking, cycling, and obesity rates in Europe, North America and Australia. J Phys Act Health 2008;5(6):795–814; doi: 10.1123/jpah.5.6.795
29. Besser LM, Dannenberg AL. Walking to public transit: Steps to help meet physical activity recommendations. Am J Prev Med 2005;29(4):273–280; doi: 10.1016/j.amepre.2005.06.010
30. Xu F, Jin L, Qin Z, et al. Access to public transport and childhood obesity: A systematic review. Obes Rev 2021;22(Suppl. 1):e12987; doi: 10.1111/obr.12987
31. Parasin N, Amnuaylojaroen T, Saokaew S. Effect of air pollution on obesity in children: A systematic review and meta-analysis. Children 2021;8(5):327; doi: 10.3390/children8050327
32. Jiao J, Moudon AV, Drewnowski A. Grocery shopping: How individuals and built environments influence choice of travel mode. Transp Res Rec 2011;2230:85–95; doi: 10.3141/2230-10
33. Scheiner J. Far, far away—Micro-spatial analyses of trip distances and mode choice. Proceedings of the European Transport Conference (ETC) 2007 Held October 17–19, 2007, Leiden, The Netherlands; 2007.
34. Parise I, Abbott P, Trankle S. Drivers to obesity—A study of the association between time spent commuting daily and obesity in the Nepean Blue Mountains Area. Int J Environ Res Public Health 2022;19(1):410; doi: 10.3390/ijerph19010410
35. Impact on Urban Health. Childhood Obesity. 2022. Available from: https://urbanhealth.org.uk/our-work/childhood-obesity?gclid=Cj0KCQjw3eeXBhD7ARIsAHjssr9eLxNGjC2fTs2tQEvzUlnvO9ce4piIl3czKrRvXaoPw1Jg8xMMhNMaAm-tEALw_wcB [Last accessed: September 14, 2022].
36. CDP. Transport Data Explorer. 2019. Available from: https://www.c40knowledgehub.org/s/article/Transport-Data-Explorer?language=en_US [Last accessed: August 15, 2022].
37. Shaw HJ. Food deserts: Towards the development of a classification. Geogr Ann Ser B 2006;88(2):231–247; doi: 10.1111/j.0435-3684.2006.00217.x
38. NHS Digital. National Child Measurement Programme. 2021. Available from: https://digital.nhs.uk/services/national-child-measurement-programme/#further-information [Last accessed: September 16, 2022].
39. Kantar Worldpanel. Great Britain Grocery Market Share (12 Weeks Ending 03.01.16). 2016. Available from: https://www.kantarworldpanel.com/en/grocery-market-share/great-britain [Last accessed: September 16, 2022].
40. Ordnance Survey. Points of Interest. 2022. Available from: https://www.ordnancesurvey.co.uk/business-government/products/points-of-interest [Last accessed: September 16, 2022].
41. Wrigley N. "Food Deserts" in British Cities: Policy context and research priorities. Urban Stud 2002;39(11):2029–2040; doi: 10.1080/0042098022000011344
42. Chalkias C, Papadopoulos AG, Kalogeropoulos K, et al. Geographical heterogeneity of the relationship between childhood obesity and socio-environmental status: Empirical evidence from Athens, Greece. Appl Geogr 2013;37:34–43; doi: 10.1016/j.apgeog.2012.10.007
43. Williams AS, Ge B, Petroski G, et al. Socioeconomic status and other factors associated with childhood obesity. J Am Board Fam Med 2018;31:514–521; doi: 10.3122/jabfm.2018.04.170261
44. Oddo VM, Nicholas LH, Bleich SN, et al. The impact of changing economic conditions on overweight risk among children in California from 2008 to 2012. J Epidemiol Community Health 2016;70:874–880; doi: 10.1136/jech-2015-207117
45. Evans GW, Jones-Rounds ML, Belojevic G, et al. Family income and childhood obesity in Eight European Cities: The mediating roles of neighborhood characteristics and physical activity. Soc Sci Med 2012;75:477–481; doi: 10.1016/j.socscimed.2012.03.037
46. Rogers R, Eagle TF, Sheetz A, et al. The relationship between childhood obesity, low socioeconomic status, and race/ethnicity: Lessons from Massachusetts. Child Obes 2015;11(6):691–695; doi: 10.1089/chi.2015.0029
47. Padez C, Mourao I, Moreira P, et al. Long sleep duration and childhood overweight/obesity and body fat. Am J Hum Biol 2009;21:371–376; doi: 10.1002/ajhb.20884
48. Mitra R. Independent mobility and mode choice for school transportation: A review and framework for future research. Transp Rev 2013;33(1):21–43; doi: 10.1080/01441647.2012.743490
49. Heinen E, van Wee B, Maat K. Commuting by bicycle: An overview of the literature. Transp Rev 2010;30(1):59–96; doi: 10.1080/01441640903187001
50. Drewnowski A, Aggarwal A, Hurvitz PM, et al. Obesity and supermarket access: Proximity or price? Am J Public Health 2012;102(8):e74–e80; doi: 10.2105/AJPH.2012.300660
51. Chahal M. Can Loyalty Exist in the Grocery Sector? 2017. Available from: https://www.marketingweek.com/grocery-loyalty/ [Last accessed: August 22, 2022].
52. d'Angelo C, Gloinson E, Draper A, et al. Food Consumption in the UK: Trends, Attitudes and Drivers. RAND Corporation: Santa Monica, CA; 2020.
53. Murray J, Elms J, Teller C. Examining the role of store design on consumers' cross-sectional perceptions of retail brand loyalty. J Retail Consumer Serv 2017;38:147–156; doi: 10.1016/j.jretconser.2017.06.001
54. Carroll M. How Retailers Can Replicate the "Magic" of the Apple Store… Online—Forbes. Forbes; 2012. Available from: https://www.forbes.com/sites/matthewcarroll/2012/06/26/how-retailers-can-replicate-the-magic-of-the-apple-store-online/ [Last accessed: August 25, 2022].
55. Moore L. Why Should Anyone Drive 20 Miles To Do A Food Shop When There Is A Supermarket Five Minutes Away? 2017. Available from: https://www.huffingtonpost.co.uk/entry/why-should-anyone-drive-20-miles-to-do-a-food-shop-when-there-is-a-supermarket-five-minutes-away_uk_5a1d7c8ce4b09413e786af2c [Last accessed: August 22, 2022].

56. Shahid R, Bertazzon S. Local spatial analysis and dynamic simulation of childhood obesity and neighbourhood walkability in a Major Canadian City. AIMS Public Health 2015;2(4):616–637.

57. Laverty AA, Hone T, Goodman A, et al. Associations of active travel with adiposity among children and socioeconomic differentials: A longitudinal study. BMJ Open 2021;11(1):e036041; doi: 10.1136/bmjopen-2019-036041

58. Wanner M, Götschi T, Martin-Diener E, et al. Active transport, physical activity, and body weight in adults a systematic review. Am J Prev Med 2012;42(5):493–502; doi: 10.1016/j.amepre.2012.01.030

59. Patterson R, Panter J, Vamos EP, et al. Associations between commute mode and cardiovascular disease, cancer, and all-cause mortality, and cancer incidence, using linked census data over 25 years in England and Wales: A cohort study. Lancet Planet Health 2020;4(5):186–194; doi: 10.1016/S2542-5196(20)30079-6

60. Komanoff C, Roelofs C, Orcutt J, et al. Environmental Benefits of Bicycling and Walking in the United States. Transp Res Rec 1993; 1405:7–12.

61. Mueller N, Rojas-Rueda D, Cole-Hunter T, et al. Health impact assessment of active transportation: A systematic review. Prev Med (Baltim) 2015;76:103–114; doi: 10.1016/j.ypmed.2015.04.010

62. Rojas-Rueda D, de Nazelle A, Andersen ZJ, et al. Health impacts of active transportation in Europe. PLoS One 2016;11(3): e0149990; doi: 10.1371/journal.pone.0149990

63. Tainio M, de Nazelle AJ, Götschi T, et al. Can air pollution negate the health benefits of cycling and walking? Prev Med (Baltim) 2016;87:233–236; doi: 10.1016/j.ypmed.2016.02.002

64. Pan X, Zhao L, Luo J, et al. Access to bike lanes and childhood obesity: A systematic review and meta-analysis. Obes Rev 2021; 22(Suppl. 1):e13042; doi: 10.1111/obr.13042

65. Li L, Zhao X, Tang X. Comment on ''access to bike lanes and childhood obesity: A systematic review and meta-analysis.'' Obes Rev 2022;23(4):e13434; doi: 10.1111/obr.13434

66. Wall MM, Larson NI, Forsyth A, et al. Patterns of obesogenic neighborhood features and adolescent weight: A comparison of statistical approaches. Am J Prev Med 2012;42(5):e65–e75; doi: 10.1016/j.amepre.2012.02.009

67. Larsen K, Buliung RN, Faulkner GEJ. School travel how the built and social environment relate to children's walking and independent mobility in the Greater Toronto and Hamilton Area, Ontario, Canada. Transp Res Rec 2015;2513:80–89; doi: 10.3141/2513-10

68. Nelson NM, Foley E, O'Gorman DJ, et al. Active commuting to school: how far is too far? Int J Behav Nutr Phys Act 2008;5:1; doi: 10.1186/1479-5868-5-1

69. Chomitz VR, Aske DB, McDonald J, et al. The role of recreational spaces in meeting physical activity recommendations among middle school students. J Phys Act Health 2011;8(Suppl. 1):S8–S16; doi: 10.1123/jpah.8.s1.s8

70. Zhou X, Yu Z, Yuan L, et al. Measuring accessibility of healthcare facilities for populations with multiple transportation modes considering residential transportation mode choice. ISPRS Int J Geoinf 2020;9(6):394; doi: 10.3390/ijgi9060394

71. Buijzen M, van Reijmersdal EA, Owen LH. Introducing the PCMC model: An investigative framework for young people's processing of commercialized media content. Commun Theory 2010;20(4): 427–450; doi: 10.1111/j.1468-2885.2010.01370.x

72. Riazi NA, Wunderlich K, Yun L, et al. Social-ecological correlates of children's independent mobility: A systematic review. Int J Environ Res Public Health 2022;19(3):1604; doi: 10.3390/ijerph19031604

73. Titis E. Parental perspectives of the impact of COVID-19 lockdown on food-related behaviors: Systematic review. Foods 2022; 11(18):2851.

74. Das JK, Salam RA, Thornburg KL, et al. Nutrition in adolescents: Physiology, metabolism, and nutritional needs. Ann N Y Acad Sci 2017;1393(1):21–33; doi: 10.1111/nyas.13330

75. Sallis JF, Cervero RB, Ascher W, et al. An ecological approach to creating active living communities. Annu Rev Public Health 2006;27:297–322; doi: 10.1146/annurev.publhealth.27.021405 .102100.

76. Chynoweth J, Hosking J, Jeffery A, et al. Contrasting impact of androgens on male and female adiposity, fat distribution and insulin resistance in childhood and adolescence (EarlyBird 75). Pediatr Obes 2020;15(12):e12685; doi: 10.1111/ijpo.12685

77. Oliveira A, Lopes L, Abreu S, et al. Environmental perceptions and its associations with physical fitness and body composition in adolescents: Longitudinal results from the LabMed physical activity study. Int J Adolesc Med Health 2020;32(5):20170205; doi: 10.1515/ijamh-2017-0205

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