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The association between fast food outlets and overweight in adolescents is confounded by neighbourhood deprivation: a longitudinal analysis of the Millennium Cohort Study

Mark A Green[1]*, Matthew Hobbs[2,3], Ding Ding[4], Michael Widener[5], John Murray[1], Lindsay Reece[4], Alex Singleton[1].

[1] Geographic Data Science Lab, Department of Geography & Planning, University of Liverpool, Liverpool, L69 7ZT, United Kingdom. Email: mark.green@liverpool.ac.uk

[2] GeoHealth Laboratory, University of Canterbury–Te Whare Wānanga o Waitaha, Christchurch, New Zealand.

[3] School of Health Sciences, University of Canterbury–Te Whare Wānanga o Waitaha, Christchurch, New Zealand.

[4] School of Public Health, University of Sydney, Sydney, Australia.

[5] Department of Geography & Planning, University of Toronto, Toronto, Canada.

* Corresponding author

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ABSTRACT

The aim of our study is to utilise longitudinal and representative national data to explore the extent that the association between the fast food environment and overweight in adolescents is confounded by neighbourhood deprivation. Longitudinal data from the Millennium Cohort Study for England were obtained for waves 5 (ages 11/12; 2011/12; n=13,469) and 6 (ages 14/15; 2014/15; n=11,884). Our outcome variable was overweight/obesity defined using age and sex-specific International Obesity Task Force cut points. Individuals were linked, based on their residential location, to data on the density of fast food outlets and neighbourhood deprivation. Structural Equation Models were used to model associations at both ages and explicitly test for confounding. While we found some evidence for an association between the number of fast food outlets and overweight, any associations disappeared following accounting for the confounding nature of neighbourhood deprivation. Neighbourhood deprivation was consistently associated to overweight, with adolescents who resided in deprived areas more likely to be overweight. Results were largely consistent depending on different methodological decisions. Our findings suggest that policy efforts should prioritise focusing on tackling the social determinants of excess body mass which will be more effective than interventions aimed at the built environment.

Key words: fast food, neighbourhood, deprivation, overweight, obesity, adolescence, confounding.

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1. INTRODUCTION

Socio-ecological models have long emphasised the importance of environmental factors in understanding obesity [1]. One prominent area of investigation focuses on the fast food environment (FFE), defined here as the shops and restaurants in neighbourhoods with high speed of service that sell energy dense and nutritionally poor foods (commonly referred to as 'fast food'). Studies have found associations demonstrating that individuals who live in areas with a greater number (density) of fast food outlets had larger body weights [2–4]. Possible explanations for these associations include fast food being more readily available or easier to access out of the home (and conversely fewer outlets selling healthier foods), and outlets acting as visual advertisements that nudge people's dietary choices later at home. Such evidence has underpinned efforts, for instance in the UK [5], Canada [6], and Australia [7], by policymakers to tackle unhealthy food environments through utilising planning regulations to limit the locations of new fast food outlets (e.g., surrounding schools or in areas of high density of existing outlets). Adolescent health is often the focus of such interventions, partly due to adolescents high consumption of fast food and since dietary behaviours can become habitual into adulthood. While dietary choices are often determined by parents, secondary school children can often leave school premises during lunch or may access outlets walking home [5].

The translation of evidence into policy action may be misguided when viewed alongside the whole context of the evidence base. Systematic reviews have persistently demonstrated inconsistent associations between measures of the FFE (e.g., density of fast food outlets) and obesity-related outcomes [8–11]. One recent systematic review concluded that null associations dominated findings, comprising 76.0% of the 1,937 associations analysed [12]. There are several possible reasons for the inconsistency in associations across the literature. First, there may be no association and the smaller proportion of studies that do find a positive association are actually spurious associations. Second, inconsistent study design, methods, and lack of transparency in reporting of decisions, makes it difficult to compare findings [12–15]. It is plausible that those reporting positive associations may reflect either effective or poorly designed studies. Third, cross-sectional studies dominate the literature and are often less suitable for identifying relationships, especially as longitudinal studies tend to find null associations [16,17]. Fourth, a focus on local case studies in specific cities or regions may produce results that are less generalisable elsewhere or to national populations. Fifth, analyses are often purely associational rather than testing specific pathways or mechanisms for how and why the FFE matters [18–20].

One additional explanation for the existence of positive associations among a larger number of null findings may relate to the mechanistic role of neighbourhood deprivation. Neighbourhood deprivation is strongly associated with both obesity-related outcomes and the locations of fast food outlets. Individuals who reside in poorer areas are more likely to be obese, due to the complex interplay between materialistic (e.g., fewer resources to afford a healthy diet), psychosocial (e.g., lower sense of control) and geographical (e.g., poor access to healthy food outlets) disadvantage they often face [21–23]. Fast food outlets tend to cluster in deprived areas due to cheaper rents and greater social desirability [24,25]. As such, this dual relationship suggests that neighbourhood deprivation may confound the association between the FFE and obesity-related outcomes. Separating out the independent effects of neighbourhood deprivation from fast-food outlets is therefore difficult [19]. Most studies simply adjust for neighbourhood deprivation using a single variable within a regression model. However, this is not always appropriate, as it does not specify how different variables operate, and a residual effect may be left through strongly correlated variables [26]. Accounting for the correct pathway and nature of the role of neighbourhood deprivation plays is key to robustly assess if the FFE matters for obesity-related outcomes. We are not aware of any previous research that has rigorously evaluated the confounding nature of neighbourhood deprivation on obesity-related outcomes in adolescents.

The aim of our study is to utilise longitudinal and representative national data to explore the extent that the association between the fast food environment and overweight in adolescents is confounded by neighbourhood deprivation. We do this through focusing on the most commonly used measure of the FFE – density of fast food outlets [8–12]. To help guide our investigation, we specify the following hypotheses:

1. Individuals who live in areas with more fast food outlets have a higher likelihood of being overweight – Here we hypothesise there is an association between FFE and body weight when just considering these two variables alone. Our hypothesis follows evidence in the literature of a positive association between density of fast food outlets and measures of body weight [2–4].
2. Individuals who live in deprived neighbourhoods have a higher likelihood of being overweight – We hypothesise that neighbourhood deprivation is related to body weight when no other variables are considered. This follows evidence in the literature demonstrating that poor social disadvantage is associated with obesity-related outcomes [21–23].
3. Neighbourhood deprivation confounds the association between fast food outlets and likelihood of being overweight – When we explicitly account for the proposed confounding nature of neighbourhood deprivation on the FFE, we find that the association between the FFE and overweight disappears. Similarly, we expect to find a positive relationship between deprivation and the FFE, and deprivation and overweight. We expect this due to the dual relationship neighbourhood deprivation has with both obesity-related outcomes [21–23] and the locations of fast food outlets [24,25].
4. In areas where the number of fast food outlets increased, individuals were not more likely to be overweight – Using a quasi-experimental longitudinal design to our study [27], we examine if changes in our exposures (i.e., increasing or decreasing numbers of fast food outlets over time) were associated with changes in our outcome (i.e., risk of overweight). We hypothesise that because there is no real association between FFE and overweight, individuals who moved to areas with more fast food outlets were no more or less different to have been overweight. We also subsequently hypothesise that individuals who moved to more deprived areas were more likely to be overweight due to importance of neighbourhood deprivation. There are relatively few studies that have explored the temporal element of these associations, partly due to the dominance of cross-sectional studies [10,17].
5. The confounding role of neighbourhood deprivation persists even after controlling for diet and physical activity – We next adjust our model to incorporate two key determinants of body weight that may sit on the pathways (e.g., as mediators) between associations for density of fast food outlets and neighbourhood deprivation to risk of overweight; consumption of fast food and physical activity. Specifically, we hypothesise that (i) individuals who consume fast food or are physically inactive are more likely to be overweight, (ii) individuals who are exposed to more fast food outlets are more likely to consume fast food, and (iii) individuals from deprived neighbourhoods are more likely to consume fast food and be physically inactive. These hypotheses are grounded in existing research, especially for understanding social inequalities in health [23].

2. MATERIALS AND METHODS

2.1 Participants and setting

The Millennium Cohort Study (MCS) is a UK representative longitudinal cohort survey following the lives of 18,827 children born in 2000 (Connelly and Platt, 2014). Waves 5 (ages 11/12; 2011/12; n=13,469) and 6 (ages 14/15; 2014/15; n=11,884) were used to match the same period of food outlet data. These were the only waves that we had fast food location data for at the time of analysis. Participants who resided in England in both waves (n=9,736) were selected for our analytical sample to match our FFE measures. Special access to the LSOA codes of participants in MCS were granted by the data controllers. Full residential address or postcode were not available, meaning we could generate accessibility metrics.

2.2 Outcome: overweight

Interviewers objectively measured anthropometrics including height and weight of participants. Overweight (including obesity) was defined using age and sex-specific International Obesity Task Force (IOTF) cut points (Cole *et al.*, 2000). As our outcome was adjusted for age and sex, they were not accounted for as covariates in the analysis. Overweight and obesity were considered together since (i) this is a common outcome variable when studying adolescents, and (ii) excess body weight in adolescents is associated with obesity in later life [28], as well as current and future health [29]. Z-score values were not available for analysis.

2.3 Exposure: fast food environment

The FFE was measured using data collected from the Food Standards Agency (FSA) website. FSA are a governmental department in England that coordinate Local Government inspections of hygiene in shops and services selling fresh food. They publish an open database based on both their internal records, as well as information supplied by Local Governments. Data from the FSA has been collected by the authors from their website since December 2012. Information includes name of organisation, address, coordinates, food hygiene rating and a classification of outlet type. We selected two time periods of data closest to the mid-point of survey data collection periods (December 2012 and August 2015).

Counts of each outlet type per year were aggregated to Lower Super Output Areas (LSOAs; small neighbourhood zones containing ~1500 people) and Local Authority Districts (LADs; town/city-region with mean population size ~180k). We selected two geographical scales to account for the immediate local context surrounding where individuals reside (LSOAs), as well as the broader context they may live their lives in (LADs). The category ‘takeaway shop’ was used to measure unhealthy outlets within the FFE since these outlets contain fast food outlets and outlets selling nutritionally poor foods for takeaway. We recoded chain fast food outlets (e.g. MacDonald’s, KFC, Burger King) into this category since they were often recorded as restaurants. We were unable to determine if other outlet types were primarily selling fast food from the data.

We modelled the count of fast food outlets in our analysis to preserve information, rather than identify arbitrary cut points that may produce misleading results [30,31]. We included a sensitivity analysis testing different types of measures to aid comparisons of our analyses to other studies (see supplementary appendix).

2.4 Confounder: neighbourhood deprivation

Neighbourhood deprivation was measured using quintiles of the ranks for the Index of Multiple Deprivation (IMD) [32]. IMD is a multidimensional measure of neighbourhood (LSOA) deprivation that is commonly used by national and local governments, as well as by many studies of food environments in the UK. As each constituent country of the UK has their own version of the IMD that are not comparable, we restricted our analyses to England.

2.5 Additional measures

We included measures of physical activity and fast food consumption that were only available for wave 6. Physical activity was measured as the number of days per week participants undertook moderate to vigorous physical activity ('every day', '5-6 days', '3-4 days', '2 or fewer days'). Fast food consumption was measured as how often a participant consumed fast food ('weekly', 'monthly' and 'less/never'). Finally, urban areas were also identified using the ONS Urban Rural Classification (2011), which classifies output areas as urban or rural based on population density.

2.6 Statistical analysis

Structural Equation Models (SEMs) were used in the analysis. SEMs are a family of multivariate methods which allow the modelling of structural pathways between observed and unobserved variables. The need to make explicit pathways of hypothesised relationships is important. Calls for better conceptual models to identify the pathways through which food environments may influence obesity are not new (Cummins, 2007), however they need incorporating within analytical frameworks that allow for their empirical testing (Hobbs *et al.*, 2019).

A variety of generalised model specifications and regression analyses were used depending on the outcome variable for a specific pathway. Overweight was modelled using a binomial logit. IMD quintile was analysed using an ordinal regression model. Count of fast food outlets was analysed using a Poisson regression model because (a) the distribution of data for both LSOAs and LADs were right skewed, and (b) negative values of counts were impossible. Alternative model specifications for fast food outlets (e.g. logged outcome and linear model) produced similar findings. Physical activity and fast food consumption were both analysed using an ordinal regression model (binary models did not substantially change the findings). In the sensitivity analyses, change over time measures were modelled as linear OLS due to their normal distributions.

3. RESULTS

As shown in Table 1 (n=9736), the prevalence of overweight declined slightly (1%) between waves. Individuals had greater exposure to fast food outlets over time. The largest increase was at the LAD level (34.9 additional outlets) compared to LSOA level (0.13). The distribution for deprivation remains similar across waves with more participants from the most deprived areas.

Table 1: Analytical sample characteristics by wave.

Measure	Ages 11/12 - Wave 5	Ages 14/15 - Waves 6
Mean Age	10.6	13.8
Males	49.4%	49.4%
Females	50.7%	50.6%
Overweight	26.4%	25.4%

Mean Fast food outlets LSOAs	1.1	1.2
Mean Fast food outlets LADs	179.2	214.1
IMD Q1 (Most Deprived)	23.9%	23.7%
IMD Q2	19.3%	19.2%
IMD Q3	18.8%	18.7%
IMD Q4	18.4%	18.6%
IMD Q5 (Least Deprived)	19.7%	19.9%

3.1 Hypothesis 1: Individuals who live in areas with more fast food outlets have a higher likelihood of being overweight.

Figure 1 (insert A and B) presents results from two separate SEMs for the count of fast food outlets at LSOA (neighbourhood) level and LAD level respectively. Full statistical output is provided in the Supplementary Appendix (see Table A1). For LSOA count of fast food outlets, there was no association to whether an individual was overweight at both ages. This contrasts to findings when using the count of fast food outlets at the LAD level. There were positive associations to overweight at both age 11/12 (Odds Ratio (OR) = 1.0006, 95% Confidence Intervals (CIs) = 1.0002,1.0009) and 14/15 (OR = 1.0005, CIs = 1.0002,1.0008). While effect sizes were small, these represent a one-unit increase in the count of fast food outlets. Since the mean number of fast food outlets at this scale was large (see Table 1), the translation of the actual effect size is reasonable. For example, at age 11/12 a 100-unit difference in exposure would equate to 5.9% increase in the probability of being overweight. We accept hypothesis one at the LAD level and reject it at the LSOA level.

3.2 Hypothesis 2: Individuals who live in deprived neighbourhoods have a higher likelihood of being overweight.

At both ages, we find evidence of social gradients in the risk of overweight among adolescents (see Figure 1C and Table A2). At age 11/12, there is a dose-response relationship whereby we detect greater risk of overweight as quintile of deprivation becomes more deprived. Participants who resided in the most deprived quintile were 89% (OR = 1.89, CIs = 1.64,2.18) more likely to be overweight compared to those in the least deprived quintile. At age 14/15, we find similar associations albeit not all quintiles were statistically significant. We find a smaller effect size for deprivation with individuals in the most deprived quintile being 41% (OR = 1.41, CIs = 1.16,1.71) more likely to be overweight than those in the least deprived quintile. This confirms hypothesis two.

3.3 Hypothesis 3: Neighbourhood deprivation confounds the association between fast food outlets and likelihood of being overweight.

Having identified associations between fast food outlets and neighbourhood deprivation to overweight independently, we next investigated whether the association between fast food outlets and overweight is confounded by deprivation (Figure 1D-E and Tables A3-4). Findings display associations between neighbourhood deprivation and both count of fast food outlets and overweight. No associations were detected between fast food outlets and overweight. For deprivation, the associations with overweight remain like those described in Section 3.2, suggesting the consistency in evidence for social inequalities in overweight risk. We also detect strong positive associations between deprivation and count of fast food outlets, suggesting greater exposure of adolescents in deprived areas to fast food outlets compared to those in the least deprived quintiles. The associations between LAD density of fast food outlets and overweight for both ages have now disappeared once we account for the confounding effect of deprivation (with no association at the LSOA level). Sensitivity analyses testing alternative specifications of the FFE exposure found that

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associations were consistently non-significant or confounded by deprivation. Hypothesis three is confirmed.

[Figure 1 here]

Figure 1: Five Structural Equation Models exploring the extent that the association between density of fast food outlets and overweight in children is confounded by deprivation. (Note: Odds Ratios are presented. Dotted lines represent insignificant associations, solid lines represent significant associations)

3.4 Hypothesis 4: In areas where the number of fast food outlets increased, individuals were not more likely to be overweight.

1351 (14.8%) individuals moved LSOA between ages 11/12 and 14/15. We considered for those who moved whether there was an association between the change in the FFE exposure (count of fast food outlets) between waves and overweight at ages 14/15, adjusting for the confounding effect of deprivation at wave 6 (Table 2). We find no associations at either geographical scales (models A and B). Repeating the analyses with the alternative measures of FFE did not alter these findings (results not shown).

Table 2: Results from logistic regression of association between changing geographical context and wave 6 overweight in participants who migrated (n=1351).

		Odds Ratio	Lower CI	Upper CI	p value
Model A: Lower Super Output Areas					
	Change in fast food outlets	0.967	0.929	1.007	0.105
Model B: Local Authority District					
	Change in fast food outlets	1.0001	0.999	1.002	0.903
Model C: Deprivation					
	Stayed same	Reference			
	Less deprived	1.049	0.755	1.460	0.774
	More deprived	1.520	1.096	2.109	0.012

We considered change by neighbourhood deprivation (model C) between ages 11/12 and 14/15 as a predictor overweight at ages 14/15. Change in decile (not used previously due to low number issues), as opposed to quintile, was used to capture a greater sensitivity of individuals changing socioeconomic context (changes in quintiles resulted in too few cases). Individuals who moved to a more deprived area by age 14/15 were 52% more likely (OR = 1.52, CIs = 1.10,2.11) to report that they were overweight at age 14/15 compared to those who moved to an area of equal level of deprivation at age 14/15.

Overall change in takeaway count between ages 11/12 and 14/15 for all participants irrespective of whether they moved or not was examined in their association to overweight in wave 6 (Table A6). We found no association between the change in count and risk of overweight at either geographical scale, as well as evidence that the association is confounded by deprivation (e.g. individuals who resided in deprived areas saw larger increases in the number of fast food outlets between waves). Stratifying the analysis by whether a participant had migrated or not did not alter the findings, nor did changing the measure for takeaway exposure.

Hypothesis four is therefore accepted.

3.5 Hypothesis 5: The confounding role of neighbourhood deprivation persists even after controlling for diet and physical activity.

Diet and physical activity were next introduced into our SEM models (see Figure 2 and Tables A7-A8). At the LSOA level, the associations for fast food outlets to overweight at both ages remain null and there was no association to consumption of fast food either. At the LAD level, there was no association between density of fast food outlets and overweight at either age. There is a positive association where a greater density of fast food outlets is associated to greater consumption of fast food (OR = 1.0008, CIs = 1.0005,1.001).

[Figure 2 here]

Figure 2: Two Structural Equation Models exploring whether the association between density of fast food outlets and overweight in children persists after account for fast food consumption and physical activity. (Note: Odds Ratios are presented. Dotted lines represent insignificant associations, solid lines represent significant associations)

There were social inequalities evident in both fast food consumption and physical activity. Deprivation level at age 14/15 was associated to physical activity, with individuals in the most deprived quintiles more likely to engage in fewer days of exercise in a week. Deprivation level at age 14/15 was also positively associated to fast food consumption, with individuals in the most deprived quintile being more likely to consume fast food at higher frequencies.

We find mixed associations for how fast food consumption and physical activity are associated to overweight. Individuals who engaged in physical activity less frequently were more likely to be overweight; participants who undertook two or fewer days of physical activity a week were two times more likely (OR = 2.04, CIs = 1.65,2.51 in both models) to be overweight than those who were physically active every day. For fast food consumption, a weak association was detected. Participants who consumed fast food weekly were ~20% less likely (OR = 0.81, CIs = 0.67-0.97)to be overweight than compared to those who consumed fast food rarely or never. This has implications for the interpretation of the association between density of fast food outlets and fast food consumption, as there is no clear pathway to overweight.

The inconsistency of associations between fast food outlets and our outcomes, as well as the lack of a clear pathway between fast food consumption to overweight, leads us to cautiously accept hypothesis five.

4. DISCUSSION

Our study utilises a longitudinal design to demonstrate that neighbourhood deprivation confounds the association between the FFE and overweight in adolescents. Associations between the density of fast food outlets surrounding participants and overweight were largely inconsistent across analyses. Detected associations disappeared following accounting for the confounding effect of deprivation, with deprivation strongly associated to both density of fast food outlets and likelihood of being overweight. We provide a rigorous evaluation of our model and series of sensitivity analyses that demonstrate that our findings are relevant and consistent. This is particularly important given the methodological considerations which are said to contribute to evidential inconsistency [10,12].

Our findings contribute important longitudinal evidence to a largely cross-sectional body of literature [9]. In particular, previous studies employing cross-sectional data are more likely to report that an association exists between FFE and body weight [10], which contrasts to evidence utilising longitudinal data including our study and others [16,17]. Our study suggests that neighbourhood deprivation confounds the association between FFE and overweight, and it is plausible that cross-sectional designs may be more susceptible to these biases than longitudinal study designs. However, such an explanation is more nuanced than this since longitudinal study designs are still subject to bias and do not ultimately identify causal effects alone. Rather, our study demonstrates the need for better quality of evidence that extends longitudinal study designs to truly understand the role of FFEs and places a critical eye over confounding processes.

This study offers tentative evidence that density of fast food outlets at the city/town scale is associated to fast food consumption. However, the lack of a clear pathway to overweight via fast food consumption suggests this finding should be interpreted carefully. More frequent fast food consumption was associated in this study with lower likelihood of overweight which does not make intuitive sense. It may be that the distinct social inequalities evident in associations between deprivation in fast food consumption and overweight (both in expected directions) have produced a spurious result, especially given the wide confidence intervals. The self-reported nature of the fast food consumption measure in MCS may also partly explain the inverse association to overweight.

Our findings suggest that strategies aimed at reducing overweight or obesity prevalence in adolescents should focus on tackling the drivers of social inequalities. Socioeconomic context is often described as a fundamental cause of health inequalities [33], due to the powerful role it plays across multiple health behaviours and outcomes. This is especially so for adolescents who are often unable to modify their contexts. Explanations include a lack of material resources for family's to afford healthy diets, issues of control and power in decision making, stressful lives and the concentration of related harms via syndemics [23]. However, our study only considers one part of socioeconomic context in neighbourhood deprivation, and extending our approach to incorporate greater depth here is key (e.g., utilising latent variables to account for multiple factors simultaneously).

Social and spatial inequalities in overweight, obesity and related health outcomes are prevalent in the UK and have gained considerable policy attention [5]. Our results would suggest that Local Government strategies aimed solely at restricting the location of fast food outlets (both overall or clustered around schools) may be ineffective, especially if they are not tackling the underlying social inequalities and household dynamics which are often the driving reasons behind patterns in excess body weight, unhealthy diets or unhealthy environments among adolescents. Policy efforts should therefore focus on tackling levels of deprivation (e.g. poverty alleviation efforts) or mediating their influences (e.g. subsidizing healthy foods in schools or shops) which have been demonstrated to be effective elsewhere [34,35].

Our study has numerous strengths and weaknesses. We utilize novel longitudinal data to contribute to a field dominated by cross-sectional research [10,12]. Extending our approach to incorporate a life course perspective including a greater range of ages beyond our specific cohort will be important to improve the generalizability of findings. We utilize a novel methodological to test specific pathways rather than relying on associational based analyses. This is an important step for future research, both in setting out clearly assumptions about how phenomena operate, as well as being able to test specific mechanisms rather than treating geographical context as a 'black box'. The range of pathways and determinants we included is narrow and future research should seek to build more detailed models to assess the role of geographical context. Multi-level SEM models might offer some use here too, as they can explicitly account for spatial factors unlike in individual-level only analysis. While we link two longitudinal individual- and geographical-level datasets, our measure of geographical exposure is limited. Future research should look to link data that moves beyond residential location to assess daily movement patterns (e.g. GPS records) that can provide more precise measures of exposure, account for utilisation (rather than just geographical access) or allow the assessment of time sensitive periods in exposure [13]. Identifying the correct context for assessing geographical factors remains an outstanding challenge in health geography [36], in particular for aiding the design of relevant place-based interventions. Finally, there are numerous other confounding factors identified in the literatures for both the food environment and determinants of overweight that we have not consider. Future research should examine their integrating into our modelling framework to identify if they change our observations.

5. CONCLUSIONS

We find evidence that the association between the food environment and overweight in adolescents is confounded by neighbourhood deprivation. Our findings have a wide range of applications to researchers. Accounting for the confounding role of deprivation when assessing the nature of geographical contexts on health is key for future research studying social and spatial inequalities. Understanding the underlying systematic pathways which produce such disadvantage is necessary to design effective interventions.

6. Figures

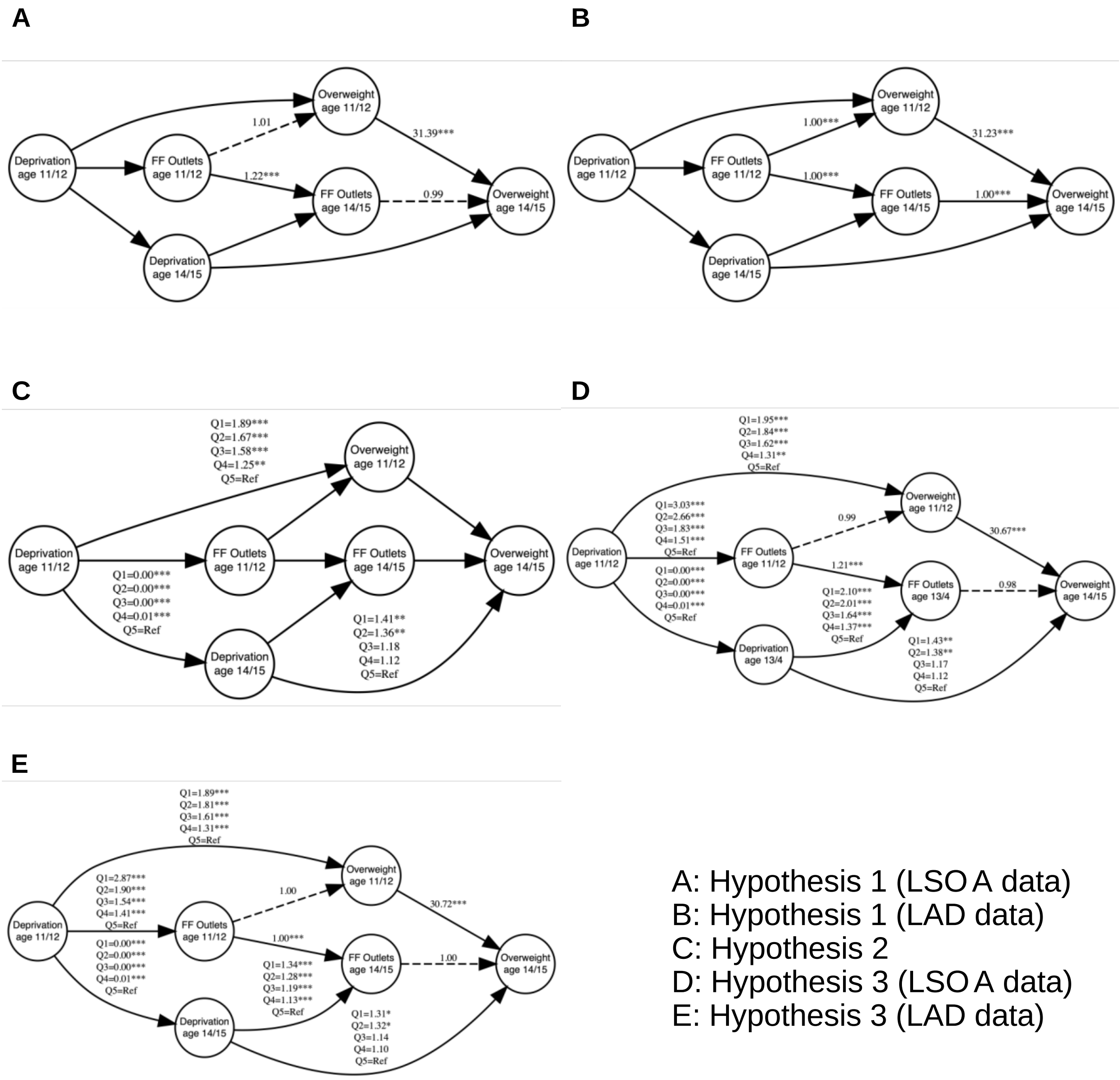

Figure 1: Five Structural Equation Models exploring the extent that the association between density of takeaways and overweight in children is confounded by deprivation. (Note: Odds Ratios are

presented. Error terms are not presented to aid visual interpretation. Dotted lines represent insignificant associations, hard lines represent significant associations. * = p < 0.5, ** = p < 0.01, *** p < 0.001.)

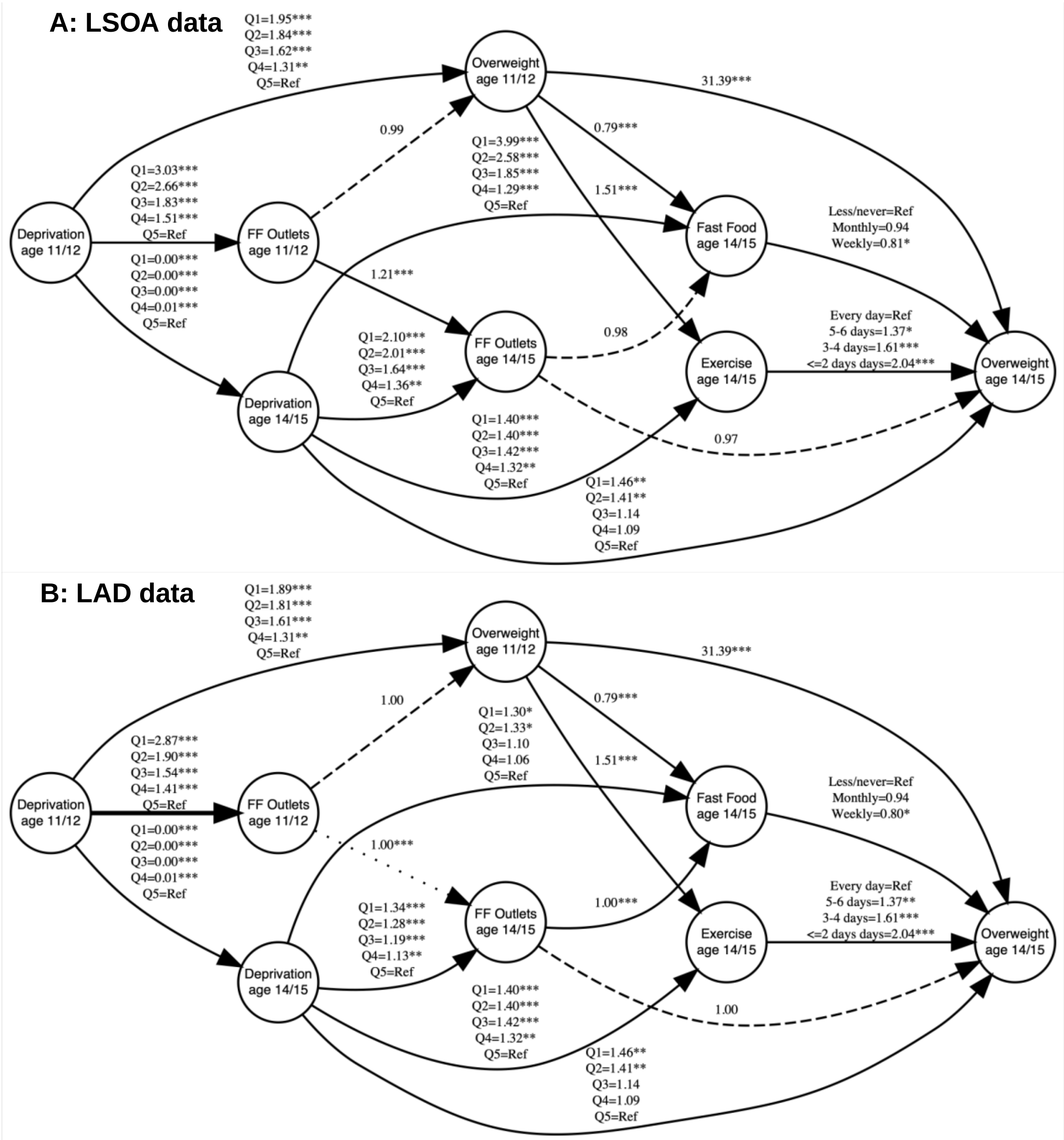

Figure 2: Two Structural Equation Models exploring whether the association between density of takeaways and overweight in children persists after account for fast food consumption and physical activity. Error terms are not presented to aid visual interpretation. Dotted lines represent insignificant associations, hard lines represent significant associations. * = p < 0.5, ** = p < 0.01, *** p < 0.001.)

7. Funding information

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8. Conflict of interest statement

None declared.

9. Author contributions

DD, MG, MH, and MW co-designed the study. MG, AS and JM were involved in collection of geospatial measures. MG cleaned the MCS data, linked observations and performed analyses, with input from MH reviewing results and refining analyses. All authors (MG, MH, DD, MW, LR, JM and AS) helped draft and revise the paper.

10. Ethical approval statement

University of Liverpool Research Ethics Committee do not require ethical review for the secondary analysis of data which have been anonymised by an external party and will be provided to the research team in a fully anonymised format.

11. Data sharing statement

Food Standards Agency data are openly available from https://www.food.gov.uk/our-data, with historical data sets freely available via the CDRC (see http://data.cdrc.ac.uk). Millennium Cohort Study data are freely available via the UK Data Archive:

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