

1 **Reconsidering the relationship between fast-food outlets, area-level**
2 **deprivation, diet quality and body mass index: an exploratory structural**
3 **equation modelling approach**

4
5 Hobbs, M^{1,2}., Green M. A³., Roberts, K⁴., Griffiths, C²., McKenna, J²

6
7 ¹ GeoHealth Laboratory, Geospatial Research Institute, University of Canterbury,
8 New Zealand.

9 ² Institute for Sport Physical Activity & Leisure, Leeds Beckett University, Leeds, LS6
10 3QT, United Kingdom.

11 ³ Department of Geography & Planning, University of Liverpool, Liverpool, United
12 Kingdom.

13 ⁴ School of Health and Related Research, University of Sheffield, Sheffield, United
14 Kingdom.

15
16 **Corresponding Author**

17 Matthew Hobbs, GeoHealth Laboratory, Geospatial Research Institute, University of
18 Canterbury, Christchurch, New Zealand
19 matt.hobbs@canterbury.ac.nz

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58 **Ethics statement**

59 The study was approved by the institutional review boards of Carnegie Faculty, Leeds
60 Beckett University.

61 **Abstract**

62

63 **Background:** Internationally, the prevalence of adults with obesity is a major public
64 health concern. Few studies investigate the explanatory pathways between fast-food
65 outlets and body mass index (BMI). We use structural equation modelling (SEM) to
66 explore an alternative hypothesis to existing research, using area-level deprivation as
67 the predictor of BMI and fast-food outlets and diet quality as mediators.

68 **Methods:** Adults (n=7,544) from wave two of the Yorkshire Health Study provided
69 self-reported diet, height and weight (used to calculate BMI). Diet quality was based
70 on sugary drinks, wholemeal (whole grain) bread, and portions of fruit and vegetables.
71 Fast-food outlets were mapped using the Ordnance Survey Points of Interest (PoI)
72 within 2km radial buffers around home postcode which were summed to indicate
73 availability. Age (years), gender (female/male) and longstanding health conditions
74 (yes/no) were included as covariates.

75 **Results:** There was little evidence linking fast-food outlets to diet or BMI. An
76 independent association between fast-food outlet availability and BMI operated
77 counterintuitively and was small in effect. There was also little evidence of mediation
78 between fast-food outlet availability and BMI. However, there was more evidence that
79 area-level deprivation was associated with increased BMI, both as an independent
80 effect and through poorer diet quality.

81 **Conclusion:** This exploratory study offers a first step for considering complexity and
82 pathways linking fast-food outlets, area-level deprivation, diet quality and BMI.
83 Research should respond to and build on the hypothesised pathways and our simple
84 framework presented within our study.

85 **1. Introduction**

86 Globally, existing approaches for reducing the prevalence of adults with obesity have
87 only resulted in modest improvements suggesting an incomplete understanding of the
88 mechanisms [1]. Internationally, fast-food outlets have received substantial attention
89 as they sell cheap, energy dense and nutritionally poor foods which contribute to
90 increases in BMI. Within England for instance, Public Health guidelines suggest that
91 Local Planning Authorities can use their responsibilities to address local health needs.
92 Restrictions have been applied to approving planning applications for new fast-food
93 outlets in areas with a high density of existing fast-food outlets [2]. The decision to
94 target fast-food outlets is supported by evidence showing associations between fast-
95 food outlets and BMI. However, the majority of evidence has demonstrated a lack of,
96 or even counterintuitive associations [1 3 4]. A plethora of issues may affect evidential
97 consistency [5] however, these inconsistencies may exist due to a lack of evidence
98 exploring potential pathways through which fast-food outlets and BMI may be
99 interlinked.

100

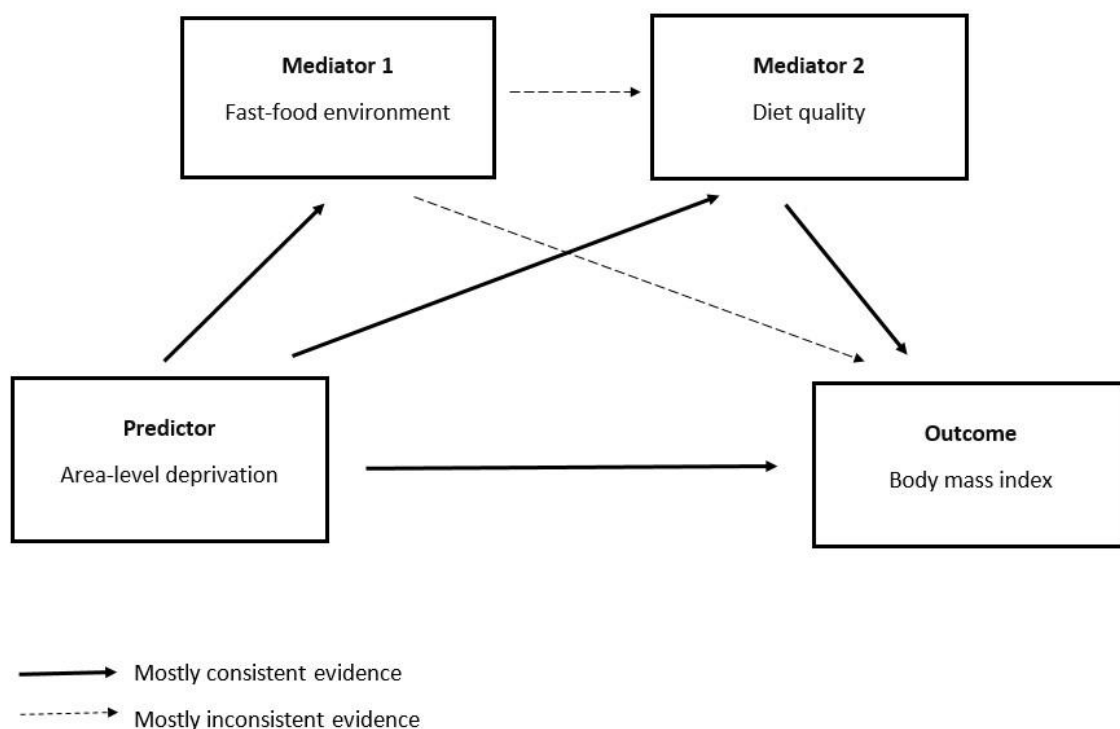
101 A focus on only fast-food outlets ignores the broader social context in which they
102 operate. For instance, fast-food outlets are more commonly located in deprived areas
103 [6 7]. While literature from other developed nations outside the US is much less
104 consistent with respect to other food retail outlets [8], the impact of fast-food outlets
105 may be more strongly felt in deprived areas. Obesity and diet quality are independently
106 associated with social disadvantage [9 10]. Separating out the independent effects of
107 social disadvantage from fast-food outlets is therefore difficult. However, most, if not
108 all, of the current evidence exploring these issues are based on methods like linear
109 regression. While acceptable, they do not specify how different variables may operate
110 [11]. Using techniques such as structural equation modelling (SEM) may therefore
111 help outline how fast-food outlets, area-level deprivation, diet quality and BMI are
112 interlinked [12 13].

113

114 Following a scoping review of the literature, most research in this area conceptualised
115 fast-food outlets as an exposure or predictor, BMI as the outcome and controlled for
116 area-level deprivation. Despite this, evidence was largely inconsistent [1]. Area-level
117 deprivation was more consistently linked to fast-food outlets, diet and BMI [1 7 14].
118 We therefore provide an alternative hypothesis to much existing research that area-

119 level deprivation (predictor) is associated with BMI (outcome) through fast-food outlets
 120 (mediator 1) and diet quality (mediator 2). We test two simple frameworks to delineate
 121 these associations. First, we investigate associations based on all pathways within
 122 Figure 1 based on both consistent and inconsistent evidence [1]. Second, we include
 123 only those pathways with more consistent evidence identified in prior literature.
 124 Importantly, this study is exploratory in nature, however it serves as a starting point to
 125 explore complexity from which other research can build on and refine the simple
 126 framework presented here.

127



128

129 **Figure 1** – The simple framework outlining potential associations between area-level
 130 deprivation, fast-food outlets, diet quality and BMI and consistency of evidence.

131

132 **2. Methods**

133

134 *2.1 Participants and settings*

135 Cross-sectional survey data collected by questionnaire from wave II (2013-15) of the
 136 Yorkshire Health Study (YHS) were used. The Yorkshire Health Study is a longitudinal
 137 observational regional health study collecting health information on the residents from
 138 the Yorkshire and Humberside region in England [15]. Data were collected on current

139 and long-standing health, health care usage and health-related behaviours, with a
140 focus on weight and weight management. While the data are self-reported, we
141 selected the YHS since very few alternative data sources included measures for both
142 diet behaviours and BMI that were spatially referenced by postcode (in the UK,
143 postcodes contain around 15 addresses). A two-stage approach was used for the
144 initial data collection. Firstly, general practitioner (GP) surgeries were invited to
145 participate in the study (43 agreed: 50% acceptance). Compared to the 2011 census
146 for the total South Yorkshire population, participants over-represented people who
147 were older, of white ethnicity, and female [15]. Total sample size was 11,164 adults
148 (aged 18-86 at baseline) living within the study area. We included all individuals with
149 a valid height, weight, postcode, ethnicity, gender, long-standing health conditions and
150 diet quality measures. This resulted in an analytical sample of 7,554 participants (see
151 supplementary material 2 for flow of participants). Ethical clearance for secondary data
152 analysis was granted by the ethics committee of the Carnegie Faculty, Leeds Beckett
153 University.

154

155 *2.2 Outcome variable: Body mass index*

156 Self-reported body mass index (BMI) was calculated as weight (kg) divided by height-
157 squared (m^2). While it is an imperfect measure of excess body weight and obesity, the
158 measure does hold some validity and is also important for policy decisions [16].

159

160 *2.3 Measure of Fast-food Environment*

161 Environmental data were provided by Ordnance Survey (OS), a national mapping
162 agency for the UK. The dataset (Points of Interest (PoI), 2013) included information
163 on the locations of all commercial facilities in the UK. It provided food outlet locations
164 (easting and northings). Food outlets were categorised into fast-food outlets ($n=6,259$)
165 containing the PoI categories of “fast-food and takeaway outlets”, “fast-food delivery
166 services” and “fish and chip shops”.

167

168 We created a radial buffer of 2km centred on an individual’s home postcode to
169 represent their exposure to features of the food environment. Although we
170 acknowledge that individuals are known to operate outside a radial buffer, previous
171 research shows little variation in outcomes by different neighbourhood definitions [17].
172 Furthermore, when previously using 1600m radial buffers which are hypothesised to

173 better reflect walking behaviours [18] few differences in associations were seen [17].
174 Food outlets within each 2km buffer were counted using a point in polygon analysis
175 using ArcGIS V10.2.2 (ESRI Inc., Redlands, CA) and summed using a spatial join
176 between food outlet layers and each individual's 2000m radial buffer. Sensitivity
177 analyses were undertaken for 1600m radial buffers in this study.

178

179 *2.4 Diet*

180 Four diet variables on the consumption of sugary drinks, wholemeal (whole grain)
181 bread, portions of fruit and portions of vegetables were used to provide a proxy
182 measure of diet quality. These indicators have been shown to be moderately predictive
183 of a Nutrient-based Diet Quality Score (NDQS) based on adherence to UK Diet
184 Reference Values and government recommendations for consumption of 12 key
185 nutrients and alcohol [19 20]. Consumption of sugary drinks and wholemeal (whole
186 grain) bread were collected as five ordinal categories; (i) never/occasionally, (ii) 1-3
187 times a week, (iii) 4-6 times a week, (iv) daily and (v) more than once a day.
188 Consumption of portions of fruit and vegetables were collected as servings per 'typical'
189 day, however these were also split into ordinal outcomes in order to allow for a
190 comparison with the former to categories. These four variables were then added
191 together to provide a score out of 20. Sugary drinks were reverse coded as they were
192 associated negatively with diet quality.

193

194 *2.5 Area-level deprivation*

195 We used the Index of Multiple Deprivation (IMD) 2010 as a measure of area-level
196 deprivation as it provides a multidimensional measure of deprivation and is commonly
197 used by Local Governments. Neighbourhood deprivation has been shown to be
198 associated both to BMI and the food environment; particularly fast-food outlets [1 7].
199 IMD is measured at the Lower Super Output Area (LSOA) level. A LSOA is a
200 geographical area that typically contains a minimum population of 1000 and a mean
201 of 1500.

202

203 *2.6 Covariates*

204 We controlled for individual-level factors that may explain an individual's BMI. Non-
205 modifiable personal characteristics of age, gender (male or female) were each
206 included since they each display associations to BMI. Whether an individual had a

207 long-standing health condition or not was also included since health status is
208 associated with BMI [21]. As described previously in detail [15] long-standing health
209 conditions included but was not limited to, cancer, heart disease, stroke, high blood
210 pressure, depression and diabetes. Ethnicity was not included as a covariate due to
211 the low number of individuals classified as non-white.

212

213 *2.7 Statistical Analysis*

214 SEM was used to test our proposed conceptual frameworks. SEM includes a series of
215 multivariate approaches including factor analysis, regression, and path models. An
216 exploratory approach is conducted to analyse their structural associations based on
217 two frameworks. The first framework using pathways with both consistent and
218 inconsistent evidence and the second using pathways based on only consistent
219 evidence. Within the SEM covariates were included to adjust for their effects directly
220 impacting upon BMI and are reported in full in the supplementary material. We report
221 several measures estimating the goodness of fit of the model including the
222 comparative fit index (CFI), root mean square error of approximation (RMSEA) and a
223 chi-squared test. An RMSEA value of <0.05 indicates good fit, <0.08 indicates
224 acceptable fit, while 0.08-0.10 is stated as neither good or bad [22]. A good fit for CFI
225 relates to a value greater than 0.95 while >0.90 indicates a satisfactory fit [22]. Due to
226 the high statistical power in the dataset and assumption that data were missing at
227 random (Supplementary Table S3) missing data were dealt with by listwise deletion.
228 All analyses were undertaken using STATA MP 14.2.

229

230 **3 Results**

231

232 *3.1 Sample characteristics*

233 Descriptive statistics (n=7,544) are shown in Table 1. Mean BMI was 26.33 (sd= 4.73)
234 and 17.9% of individuals were obese (BMI≥30). Individuals were exposed to a
235 median of 5 fast-food outlets.

236

237 **Table 1** - Overall sample and environmental (% (n)) characteristics (n=7,544; n=3,136 male)

Variable	Male	Female	Overall
+Age	61.86 (13.10)	58.07 (14.73)	59.65 (14.20)

+Body mass index (BMI)	26.65 (4.06)	26.11 (5.11)	26.33 (4.71)
Ethnicity			
White	98.1 (3,077)	98.6 (4,347)	98.4 (7,424)
Non-white	1.9 (59)	1.4 (61)	1.6 (120)
Weight status			
Underweight	0.4 (13)	1.4 (62)	1.0 (75)
Healthy weight	37.4 (1,173)	47.1 (2,075)	43.1 (3,248)
Overweight	45.0 (1,411)	33.1 (1,460)	38.1 (2,871)
Obese	17.2 (539)	18.4 (811)	17.9 (1,350)
Long standing health condition			
Yes	66.4 (2,082)	63.3 (2,790)	64.6 (4,872)
No	33.6 (1,054)	36.7 (1,618)	35.4 (2,672)
Area-level deprivation (IMD score)			
Quartile 1 (<= 9.38)	26.9 (843)	27.4 (1,207)	27.2 (2,050)
Quartile 2 (9.39 - 15.79)	25.1 (788)	24.9 (1,097)	25.0 (1,885)
Quartile 3 (15.80 - 29.05)	24.8 (778)	25.4 (1,118)	25.1 (1,896)
Quartile 4 (>=29.06)	23.2 (727)	22.4 (986)	22.7 (1,713)
Fast-food outlets			
Median (Q1 - Q3)	5.00 (2.00 – 9.00)	5.00 (2.00 – 9.00)	5.00 (2.00 – 9.00)
Minimum - Maximum	0.00 – 68.00	0.00 – 72.00	0.00 – 72.00

IMD score = Index of Multiple Deprivation. +BMI and +age are presented as mean (standard deviation)

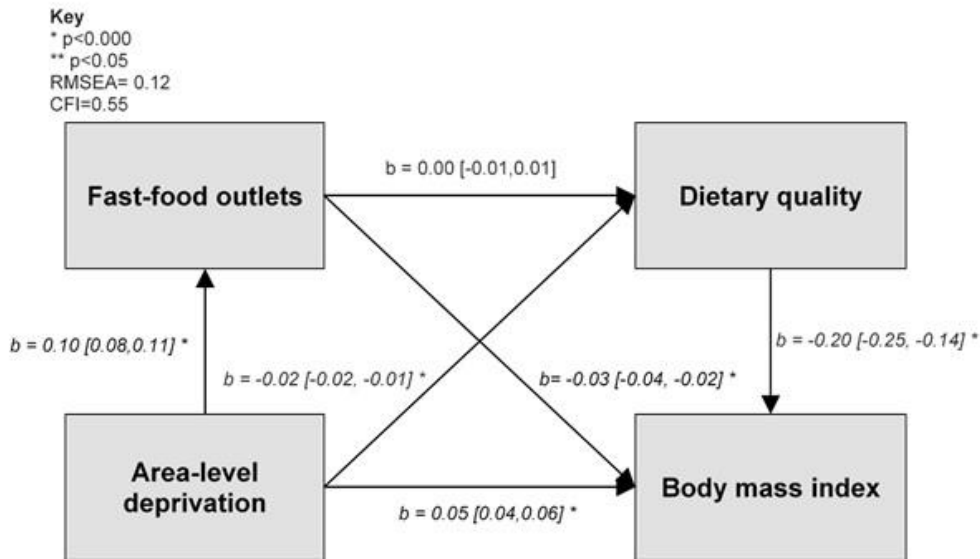
238

239

240 *3.2 Associations between area-level deprivation, fast-food outlets, diet quality and* 241 *body mass index*

242 The first SEM includes pathways with both consistent and inconsistent evidence
243 (Figure 2). Goodness of fit statistics indicate that the framework has a relatively poor
244 model fit (RMSEA=0.12; CFI=0.55). Count of fast-food outlets was independently but
245 counterintuitively associated with BMI and was small in effect (b= -0.03, [-0.04, -0.02]).
246 Fast-food outlets were not associated with diet quality (b=0.00, [-0.01, 0.01]).
247 However, area-level deprivation was associated with fast-food outlet count (b= 0.10,
248 [0.08, 0.11]), diet quality (b = -0.02, [-0.02, -0.01]) and BMI (b= 0.05, [0.04, 0.05]) in
249 the expected direction. Diet quality was associated with BMI (b= -0.20, [-0.25, -0.14]).
250 Full indirect and direct effects are included within supplementary material (Table S4.7,
251 S4.8 and S4.9). The results from Figure 2 should be interpreted with caution however,
252 effects were similar to those within Figure 3 which exhibited a better model fit.

253



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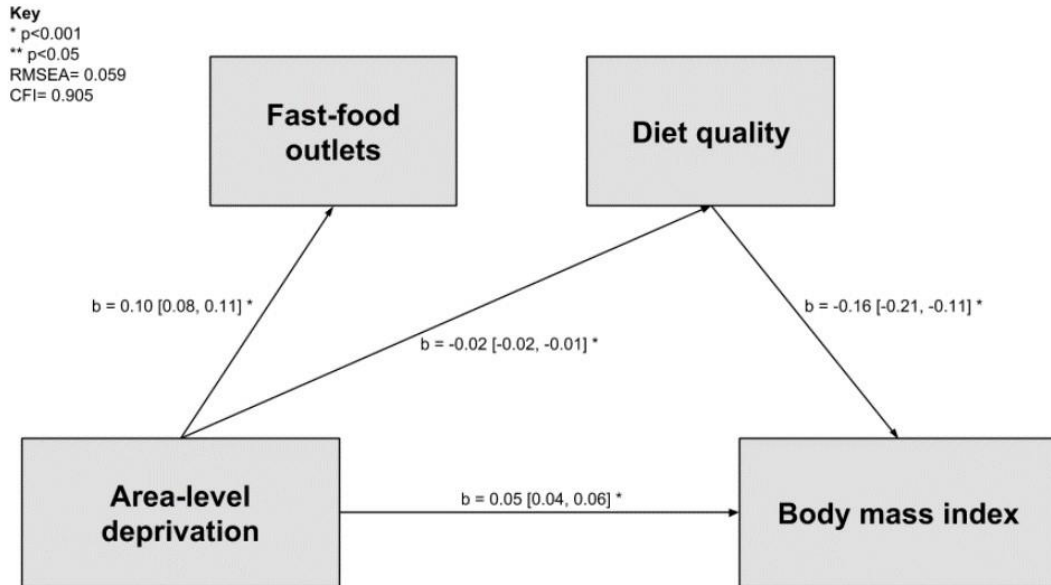
255 **Figure 2:** Results from a Structural Equation Model based on both inconsistent and
 256 consistent evidence, assessing the association between fast-food outlets, diet
 257 quality, area-level deprivation, and body mass index

258

259

260 Our second framework (Figure 3) only those pathways with more consistent evidence.
 261 Goodness of fit statistics indicated CFI fit was satisfactory (CFI=0.905) and RMSEA
 262 was acceptable (RMSEA=0.059). Increased area-level deprivation was associated
 263 with increased BMI (b=0.05 [0.04, 0.06]), lower diet quality (b= -0.02 [-0.02, -0.01]),
 264 and increased fast-food outlets (b= 0.10 [0.08, 0.11]) and diet quality was associated
 265 with BMI (b= -0.16 [-0.21, -0.11]). Models adjusted for age, gender, and longstanding
 266 health conditions and are shown in full in supplementary materials (Table S4.10, S4.11
 267 and S4.12).

268



269

270 **Figure 3:** Results from a Structural Equation Model based on only consistent
 271 evidence, assessing the association between fast-food outlets, diet quality, area-
 272 level deprivation, and body mass index

273

274 Two sensitivity analyses are shown within Supplement 4 (Table S4.1 to Table S4.6).
 275 The first with fast-food outlets as the predictor, BMI as the outcome and diet as the
 276 mediator; few associations were present. The second sensitivity analyses showed
 277 area-level deprivation as the predictor, BMI as the outcome and fast-food outlets as
 278 the mediator. Models adjusted for age, gender, and longstanding health conditions. A
 279 further sensitivity analysis on the effect of different buffer sizes for measuring fast food
 280 outlets also revealed consistent findings (Supplement 5).

281

282 **4. Discussion**

283

284 Our study uses a large cohort of UK adults to explore two simple frameworks, based
 285 on previous evidence [1 7 10] that relate area-level deprivation, fast-food outlets, diet
 286 quality, and BMI. Our exploratory analysis revealed that the association between fast-
 287 food outlets and BMI was small and counterintuitive, and there was no mediation effect
 288 by diet quality. Our alternative explanation was thus confirmed as we found the
 289 strongest evidence for an association between area-level deprivation and increased
 290 BMI, both as an independent effect and through diet quality. While exploratory and
 291 cross-sectional in design, our simple model offers an opportunity to reconsider or

292 critically examine the pathways linking area-level deprivation, fast-food outlets, diet
293 quality, and BMI.

294

295 Our findings confirm existing inconsistencies linking geographical availability of fast-
296 food outlets and BMI [1]. Given that diet quality is the main hypothesised mediation
297 mechanism, the lack of evidence for any association or mediation suggests that this
298 pathway is perhaps misguided. Our study, may lack power to detect such distal effects
299 or unobserved effects or a suppressor variable could be operating [23]. However,
300 previous studies detecting associations may result from residual confounding through
301 social disadvantage; these associations are consistent throughout the literature
302 between location of fast-food outlets and deprivation [6] and deprivation and BMI [24
303 25]. This suggests that focusing on the role of social disadvantage rather than the fast-
304 food outlets may yield more effective policy gains. This has been reported previously
305 in the USA [12 26], but requires further research to confirm such effects.

306

307 A notable difference in our study was examining pathways with area-level deprivation
308 as a predictor not the food environment. Consistent with previous evidence [1 7 14],
309 increased area-level deprivation was associated with higher fast-food outlet
310 availability, lower diet quality and higher BMI. This provides insights into what the
311 explanatory variables may be that link these often-intertwined measures and
312 outcomes. While further research is needed to build on the hypothesised pathways
313 presented within this study, we suggest that research may benefit by including area-
314 level deprivation as the predictor of adults with obesity with fast-food outlets and
315 dietary quality as a potential mediator – a mechanism by which area-level deprivation
316 may operate [1]. We do not intend these models to be *the model*, instead we hope that
317 they are considered as a first step to building complexity in this area and at the very
318 least, provoke increased criticality around how we define the pathways which linking
319 food environments, diet quality, social disadvantage and health.

320

321 **Implications for policy and research**

322 Our key result suggests that area-level deprivation is more strongly associated with
323 BMI than fast-food outlets. This is particularly important given that socio-economic
324 inequalities in health continue to persist across generations despite policies being
325 designed to reduce them [24 27 28]. This may suggest that new policies such as those

326 that focus on the most deprived in tandem with an environmental approach may be
327 required [24]. If policymakers are to continue to focus on the environment as a
328 contributor to BMI, it may be important to consider the broader system within which
329 these environments operate. BMI and diet behaviours are influenced by a complex set
330 of interrelated psychological, social, economic, cultural, and environmental factors [29
331 30], therefore future research will benefit by building on our findings to test more
332 complex pathways that link food environments to BMI. Our study points to the potential
333 of SEM as an analytical approach to be considered in future research.

334

335 **Methodological considerations**

336 Our study raises several methodological considerations. First, we acknowledge that
337 our SEM is simplistic. This paper adds to the literature by examining specific pathways
338 by which fast-food outlets are associated with BMI. We conducted this study as a
339 useful first step for incorporating these approaches and building on current practice.
340 However, our models may still be insufficient to explain the complexities of obesity.
341 For example, our models only test one single pathway and measure of the food
342 environment and does not include other factors such as perceptions of the
343 environment. Furthermore, considering the broader food retail environment will be
344 important. For instance, a recent review [1] highlighted that relative measures were
345 more likely to be associated with obesity in adults in the expected direction than with
346 individual food outlet types. Furthermore, a recent multinational study from 60
347 neighbourhoods in urban regions of five different countries across Europe [31] showed
348 no association between objective measures of geographic availability of fast-food
349 outlets and obesity, but did show associations with individual perceptions of the fast-
350 food environment. To understand the association between the food environment and
351 BMI or diet, both geographic (i.e. physical availability) and economic availability (i.e.
352 price) measures of the food environment were required [32 33]. Our study did not
353 control for other covariates such as car ownership. We therefore aimed to keep the
354 focus purely on associations between area-level deprivation, fast-food outlets, diet
355 quality and BMI as a first step. We acknowledge that further study should now try to
356 tease out the complexities which shape and modify these associations [30].

357

358 It was plausible that results in this study were sensitive to the choice of buffer distance
359 and/or the measure of diet quality. However, previous research using the study sample

360 has shown few differences when using different buffer types and distances [17].
361 Moreover, our sensitivity analyses (Supplement 5) showed similar associations when
362 using different buffer sizes which are suggested to reflect walking behaviours in the
363 UK. Although buffers were based on the best available evidence, how to define a
364 neighbourhood remains a limitation across the evidence base as it is known individuals
365 may operate beyond a radial buffer, a concept known as the uncertain geographical
366 problem which has been discussed by Kwan extensively [34]. Future research may
367 consider employing measures of daily mobility, such as individual activity spaces [1
368 35]. While such approaches may result in notably different results, the practicality of
369 collecting such data in large cohort samples is still difficult and we use a method that
370 is comparable with existing literature [1]. The self-selection of individuals into
371 neighbourhoods remains a potential confounder and may have been driven by the
372 availability and type of food environment in the neighbourhood.

373

374 We only include a measure of diet quality, as opposed to information on the
375 consumption of fast-food. The four-item diet quality tool utilised was developed
376 through secondary analyses of the UK National Diet and Nutrition Survey. The tool
377 was moderately associated with a Nutrient-based Diet Quality Score (NDQS) that was
378 based on UK Dietary Reference Values and validated against biomarkers of nutrient
379 intake and nutritional status [19 20]. Brief dietary assessment tools such as this can
380 be error-prone and, in studies where cost, time and participant burden considerations
381 allow it, more detailed dietary assessment methods such as a 24 hour recall may be
382 preferable [36].

383

384 As geographical areas differ, the results presented here may not be generalisable to
385 settings outside of the Yorkshire Health Study. In addition, our measure of area-level
386 deprivation is measured at the lower-super output area (LSOA) which does not align
387 with an individual's radial buffer. This study also does not control for spatial
388 autocorrelation. Future research may benefit by using more novel approaches such
389 as multilevel SEM that deal with spatial confounding once further methodological
390 development has taken place to establish best practice approaches to integrate such
391 approaches in these methods. Finally, BMI was defined by self-reported height and
392 weight which can produce biased estimates of BMI.

393

394 **Conclusion**

395 This study empirically tested two simple frameworks that investigated associations
396 between area-level deprivation, fast-food outlets, diet quality and BMI. In our
397 exploratory analysis, there was little evidence to suggest fast-food outlet availability
398 was associated with diet or BMI. We found stronger evidence for the contribution of
399 area-level deprivation both as an independent effect and through diet quality for
400 increased BMI. It is worth emphasising that the models are exploratory however, they
401 may provoke increased criticality for both research and policy around how we define
402 the pathways linking food environments to BMI. Future research could build on the
403 pathways in this study to include additional complexity.

404 **What is already known on this subject?**

- 405 • Evidence linking geographical exposure to fast-food outlets and obesity is
406 equivocal.
- 407 • There is a dearth of evidence investigating the pathways by which area-level
408 deprivation, fast-food outlets, diet quality and BMI are linked.

409

410 **What this study adds?**

- 411 • The association between fast-food outlets and BMI was small and
412 counterintuitive, and there was no mediation effect by diet quality.
- 413 • We found stronger evidence for the contribution of area-level deprivation both
414 as an independent effect and through diet quality for increased BMI.
- 415 • This is an exploratory paper which aims to provoke discussion and criticality
416 around how we link social disadvantage, environments and health outcomes.

417

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