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The association between fast-food outlet proximity and density and Body Mass Index: Findings from 147,027 Lifelines Cohort Study participants

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ABSTRACT

Unhealthy food environments may contribute to an elevated Body Mass Index (BMI), which is a chronic disease risk factor. We examined the association between residential fast-food outlet exposure, in terms of proximity and density, and BMI in the Dutch adult general population. Additionally, we investigated to what extent this association was modified by urbanisation level. In this cross-sectional study, we linked residential addresses of baseline adult Lifelines Cohort participants ($n = 147{,}027$) to fast-food outlet locations using geo-coding. We computed residential fast-food outlet proximity, and density within 500 m, 1, 3, and 5 km. We used stratified (urban versus rural areas) multilevel linear regression models, adjusting for age, sex, partner status, education, employment, neighbourhood deprivation, and address density. The mean BMI of participants was 26.1 (SD 4.3) kg/m^2. Participants had a mean (SD) age of 44.9 (13.0), 57.3% was female, and 67.0% lived in a rural area. Having two or more (urban areas) or five or more (rural areas) fast-food outlets within 1 km was associated with a higher BMI (B = 0.32, 95% confidence interval (CI): 0.03, 0.62; B = 0.23, 95% CI: 0.10, 0.36, respectively). Participants in urban and rural areas with a fast-food outlet within <250 m had a higher BMI (B = 0.30, 95% CI: 0.03, 0.57; B = 0.20, 95% CI: 0.09, 0.31, respectively). In rural areas, participants also had a higher BMI when having at least one fast-food outlet within 500 m (B = 0.10, 95% CI: 0.02, 0.18). In conclusion, fast-food outlet exposure within 1 km from the residential address was associated with BMI in urban and rural areas. Also, fast-food outlet exposure within 500 m was associated with BMI in rural areas, but not in urban areas. In the future, natural experiments should investigate changes in the fast-food environment over time.

1. Introduction

Overweight is an increasingly prevalent risk factor for various chronic diseases (Bhaskaran et al., 2018). Overweight, defined as having a Body Mass Index (BMI; weight in kilograms divided by square height in metre (kg/m^2)) of 25.0 or higher, is caused by an excess of energy intake relative to energy expenditure. Previously, energy intake and energy expenditure were considered as the result of individual determinants, yet individually-focused policies have been unsuccessful in reducing overweight (Papas et al., 2007). Nowadays, it has become widely acknowledged that environmental determinants also play an important role in the development of an elevated BMI (Papas et al., 2007).

Fast-food outlet exposure is among the most highlighted environmental determinants of overweight (Gamba et al., 2015). Over the past decades, the number of fast-food outlets, such as snack bars, has increased substantially. These outlets are typically easily accessible, and predominantly offer cheap and quickly served portions of energy-dense foods (McCrory et al., 2019). Still, evidence on the association between fast-food outlet exposure and BMI is inconsistent due to a lack of accurate and comprehensive exposure measurement (Ding and Gebel, 2012; Dixon et al., 2020; Jia et al., 2017).

An accurate measurement of fast-food outlet exposure is costly and requires computationally challenging linkages between individual participant health data, fast-food outlet locations, and privacy-sensitive participant addresses (Jia et al., 2017). Also, studies usually measure fast-food outlet exposure either in terms of proximity (i.e., the distance towards the nearest fast-food outlet from the residential address) or density (i.e., the amount of fast-food outlets within a certain range

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around the residential address) (Burgoine et al., 2013). Proximity and density are correlated but conceptually distinct (Burgoine et al., 2013). For example, a fast-food outlet may be nearby (high proximity), but the only one in the area (low density). Thus, using both proximity and density provides a more comprehensive and valid assessment of fast-food outlet exposure.

Besides the lack of accurate measurement of fast-food outlet exposure, most research is conducted without taking into account urbanisation level. The association between fast-food outlet exposure and BMI may differ between urban and rural areas for several reasons. First, overweight is typically more prevalent in rural areas than in urban areas (Bixby et al., 2019). Second, individuals from urban and rural areas differ in dietary patterns (Dekker et al., 2017). Third, the structure of the built environment differs substantially between urban and rural areas (Zijlema et al., 2015). Fourth, individuals from urban and rural areas contain different socio-demographic characteristics, as individuals from rural areas tend to be older and more often from low educational level (Zijlema et al., 2015). Still, studies investigating whether the association between fast-food outlet exposure and BMI differs across urban and rural areas are scarce, as most studies have a small sample and a narrow geographical spread (Mason et al., 2018). One of the few European-wide studies examining the association between fast-food outlet exposure and BMI did not observe effect modification by urbanisation level (Mackenbach et al., 2018). However, this study relied on self-reported BMI. Because individuals with overweight tend to underreport their BMI (Goris et al., 2000), associations may have been weakened, including effect modification by urbanisation level. Thus, more rigorous research is needed to investigate the association between fast-food outlet exposure and BMI separately for urban and rural areas.

Therefore, we aimed to examine the association between fast-food outlet exposure (in terms of proximity and density) and BMI in the Dutch adult general population, separately for urban and rural areas.

2. Methods

2.1. Study population

In this cross-sectional study, we used baseline adult (age range 18–91 years) data from the Lifelines Cohort Study. Lifelines is a multi-disciplinary prospective population-based cohort study examining in a unique three-generation design the health and health-related behaviours of 167,729 persons living in the North of the Netherlands. It employs a broad range of investigative procedures in assessing the biomedical, socio-demographic, behavioural, physical and psychological factors which contribute to the health and disease of the general population, with a special focus on multi-morbidity and complex genetics. Participants were recruited between December 2006 and December 2013 through general practitioners, family members of participants, and online registrations. Participants with a severe psychiatric or physical illness, a limited life expectancy (<5 years), or insufficient knowledge of the Dutch language to complete a Dutch questionnaire were excluded (Scholtens et al., 2015). Lifelines participants are broadly representative of the Northern Netherlands adult general population with respect to socioeconomic characteristics, lifestyle factors, the prevalence of chronic diseases, and general health (Klijs et al., 2015). Participant residential addresses were obtained from a nationwide address registry and geo-coded (Zijlema et al., 2016).

Specifically for this study, we excluded (1) nursing home residents ($n = 994$), because they may not be able to interact with their fast-food environment; and (2) pregnant women (currently or in the past year; $n = 4,159$), since their BMI may not represent their actual weight status.

2.2. Data linkage

We linked participant residential addresses to LISA ('Landelijk Informatiesysteem van Arbeidsplaatsen'; www.lisa.nl), a Dutch database containing geo-coded retail outlet locations where paid work is performed for at least one hour per month. LISA data are collected and updated annually. We used LISA data from April 1st, 2012 (updated in 2017), as close as possible to the median recruitment date of Lifelines' baseline participants (March 2012). LISA data have been validated against a comparable register from Statistics Netherlands (regiobase); 82% of the retail outlets in LISA were present in this database from Statistics Netherlands, and 75% of the retail outlets from the database from Statistics Netherlands were present in LISA (Scholtens and van Gessel-Dabekaussen, 2018).

We identified fast-food outlets within LISA through Standardised Business Information codes that indicated the specific type of retail outlet (e.g., lunchrooms, snack bars, ice cream parlours, and food stalls; Supplementary Table S1). We defined fast-food outlets as outlets offering food that was (1) paid for at the counter, (2) predominantly highly caloric, unhealthy, and prepared in bulk, and (3) meant to be eaten directly with minimal table service (Mackenbach et al., 2019). Standardised Business Information codes to identify fast-food outlets were based on a previous study on this topic (Stark et al., 2013).

Additionally, we linked our data to Statistics Netherlands neighbourhood data from 2012 (Scholtens, 2016).

2.3. Exposure

Linking Lifelines to LISA data enabled computation of fast-food outlet proximity by calculating the straight-line distance to the nearest fast-food outlet from each participant's residential address. We computed fast-food outlet density within straight-line distances of 500 m, 1 kilometre (km), 3 km, and 5 km around participants' residential address. Fast-food outlet proximity and fast-food outlet density were treated categorically due to their non-linear relationship with BMI. Fast-food outlet proximity was categorized into living within <250 m, 250–499 m, 500–999 m, or at least 1,000 m from the nearest fast-food outlet. We categorized 500 m density into 0, 1, 2, and at least 3 fast-food outlets and 1 km density into 0, 1, 2–4 and at least 5 fast-food outlets, based on a Dutch study that used fast-food outlet density as an independent variable in relation to cardiovascular disease occurrence (Poelman et al., 2018). 3-km density and 5-km density were categorized in such a way that each category contained a sufficient number of participants to ensure sufficient power in the statistical analysis, and in such a way that the least exposed group still was as unexposed as possible. To ensure quality reporting in food environment research, we followed the Geographic Information System Food Environment Reporting checklist (Supplementary Table S2) (Wilkins et al., 2017). Proximity and density were computed using address points in QGIS version 3.4.2 (match rate 99.6%).

2.4. Outcome

Body Mass Index (in kg/m^2) was the outcome, based on objectively measured weight (without shoes and heavy clothing) and height.

2.5. Effect modifier

Based on the linkage with Statistics Netherlands, we defined urbanisation level as living in an urban (neighbourhood containing ≥ 1,000 addresses/km^2) or rural area (neighbourhood containing < 1,000 addresses/km^2). The cut-off of 1,000 addresses/km^2 to define urban and rural areas was based on a study that investigated the role of fast-food outlet exposure in relation to cardiovascular disease occurrence in the Dutch setting (Poelman et al., 2018). Neighbourhoods were defined by official administrative boundaries from Statistics Netherlands (Statistics Netherlands, 2015).

Table 1
Characteristics for the total study sample, and stratified for rural areas and urban areas.

Variable	Total *n* = *147,027*	Urban areas[†] *n* = *48,292* (33.0%)	Rural areas[‡] *n* = *98,198* (67.0%)
Socio-demographic characteristics			
Age (in years), mean ± SD	44.9 ± 13.0	43.5 ± 14.1	45.6 ± 12.3
Sex			
Female, *n* (%)	*84,231* (57.3)	*28,275* (58.6)	*55,641* (56.7)
Male, *n* (%)	*62,796* (42.7)	*20,017* (41.4)	*42,557* (43.3)
Education			
Low, *n* (%)	*44,431* (30.9)	*13,083* (27.8)	*31,170* (32.5)
Middle, *n* (%)	*56,795* (39.5)	*17,331* (36.8)	*39,250* (40.9)
High, *n* (%)	*42,399* (29.5)	*16,730* (35.5)	*25,542* (26.6)
Partner status			
Having a partner, *n* (%)	*124,002* (84.5)	*37,321* (77.4)	*86,281* (88.0)
Weekly working hours			
0 (not working), *n* (%)	*36,926* (25.1)	*13,076* (27.1)	*23,677* (24.1)
1–11 hours, *n* (%)	*8,365* (5.7)	*2,921* (6.0)	*5,403* (5.5)
12–19 hours, *n* (%)	*11,530* (7.8)	*3,181* (6.6)	*8,298* (8.5)
20–31 hours, *n* (%)	*26,423* (18.0)	*8,036* (16.6)	*18,311* (18.6)
≥32 hours, *n* (%)	*63,783* (43.4)	*21,078* (43.6)	*42,509* (43.3)
Neighbourhood characteristics			
Neighbourhood deprivation, mean ± SD	0.00 ± 1.00	0.64 ± 1.01	−0.35 ± 0.80
Neighbourhood address density (addresses/km^2), median (IQR)	616 (209–1157)	1,482 (1,168–2,282)	350 (127–620)
Fast-food outlet exposure			
Proximity, distance to nearest fast-food outlet, median (IQR)	441 (231–891)	282 (155–452)	589 (303–1259)
500-m density, median (IQR)	1 (0–3)	2 (1–6)	0 (0–1)
1-km density, median (IQR)	3 (1–8)	10 (5–26)	1.5 (0–4)
3-km density, median (IQR)	11 (4–37)	42 (33–110)	6 (3–12)
5-km density, median (IQR)	30 (11–51)	69 (43–126)	15 (8–34)
Overweight measures			
Body Mass Index (in kg/m^2), mean ± SD	26.1 ± 4.3	25.7 ± 4.4	26.2 ± 4.3
Overweight (BMI ≥ 25.0), *n* (%)	*80,443* (54.7)	*24,483* (50.7)	*55,686* (56.7)
Obesity (BMI ≥ 30.0), *n* (%)	*22,884* (15.6)	*6,917* (14.3)	*15,877* (16.2)
Waist-to-height ratio, mean ± SD	0.52 ± 0.07	0.51 ± 0.07	0.52 ± 0.07

Note: Characteristics are based on non-imputed data. Presented percentages concern valid percentages.
[†] : Urban areas contain ≥1,000 addresses per km^2.
[‡] : Rural areas contain <1,000 addresses per km^2.

2.6. Covariates

Individual-level covariates included sex, age (in years), partner status (having a partner or no partner, irrespective of cohabiting), highest level of completed education (categorised into low (less than primary, primary, and lower secondary education), middle (upper secondary and post-secondary non-tertiary education) or high (short-cycle tertiary, bachelor or equivalent, master or equivalent, doctoral or equivalent) based on the International Standard Classification of Education (Statistics Netherlands, 2020)), and weekly working hours (0, 1–11, 12–19, 20–31, or ≥ 32 hours).

Neighbourhood-level covariates included neighbourhood address density (i.e., number of addresses per km^2) and neighbourhood deprivation. Neighbourhoods were defined by administrative boundaries. Neighbourhood deprivation was a composite measure based on the (1) average value of a house, (2) percentage of houses being owner-occupied, and (3) percentage of low-income households (< 25,100 euros, net yearly). After reversing the first two indicators, we aggregated all three indicators into one z-standardised index through principal component analysis.

2.7. Statistical analyses

Non-imputed data were used to describe the characteristics of the study population. Subsequently, missing data were imputed by Multiple Imputation by Chained Equations on Multilevel Data. Based on statistical recommendations (Bodner, 2008), we created 13 imputed datasets, and presented pooled estimates.

To examine the association between fast-food outlet exposure and BMI, multivariable multilevel linear regression analysis was performed addressing clustered data within neighbourhoods. For each of the exposure variables, we first used an unadjusted model (model 0), subsequently adjusting for individual covariates (model 1) and neighbourhood covariates (model 2). To assess effect modification by urbanisation level, we stratified the analyses *a priori* between urban (≥ 1,000 addresses/km^2) and rural areas (< 1,000 addresses/km^2).

Our study population of 147,027 participants within 3,306 neighbourhoods meets general rules of thumb on the number of level-1 and level-2 units to ensure sufficient statistical power in multilevel analyses (e.g. having at least 30 level-1 units and 10 level-2 units (Maas and Hox, 2005)). All statistical analyses were performed in Rstudio (version 3.5.2).

2.8. Sensitivity analyses

To evaluate the robustness of the results, we first used the waist-to-height ratio instead of BMI as an outcome. Although BMI is the most commonly used overweight measure in the literature due to its straightforward and inexpensive assessment, the waist-to-height ratio more precisely measures central adiposity (Sehested et al., 2010). Second, we repeated the analyses with the most exposed instead of the least exposed group as the reference. Investigating whether the choice of reference group affects the findings may be important as certain least exposed reference groups were relatively small (e.g., participants in urban areas with 0 fast-food outlets within 1 km).

2.9. Ethics approval

The Lifelines Cohort Study complies with the Declaration of Helsinki. The ethics committee of the University Medical Center Groningen approved the protocol (number 2007/152). All Lifelines participants provided their informed consent.

3. Results

3.1. Study population

The final study population consisted of 147,027 participants from 3,306 neighbourhoods. Participants had a mean BMI of 26.1 (SD 4.3) kg/m^2. Out of all participants, 54.7% was overweight (BMI $\geq$ 25.0) and 15.6% was obese (BMI $\geq$ 30.0) (Table 1). The median (IQR) distance to the nearest fast-food outlet was 441 (231–891) m. The mean (SD) age was 44.9 (13.0) years and 57.3% of the participants was female. Overall, 33.0% of the participants lived in an urban area and 67.0% lived in a rural area. Compared to participants in urban areas, participants in rural areas were less exposed to fast-food outlets, had a higher BMI (Fig. 1), were older, and more often had a low educational level.

3.2. Association between fast-food outlet proximity and BMI

In urban areas, people living within 250 m to the nearest fast-food outlet had a higher BMI than people living further away than 1,000 m to the nearest fast-food outlet (B = 0.30, 95% CI: 0.03, 0.57; Fig. 2 and Table 2). In rural areas, people living within 250 m and 250-499 m to the nearest fast-food outlet had a higher BMI than people living further away than 1,000 m to the nearest fast-food outlet (B = 0.20, 95% CI: 0.09, 0.31 and B = 0.14, 95% CI: 0.03, 0.24, respectively; Fig. 2 and Table 2).

3.3. Association between residential fast-food outlet density and BMI

In urban areas, people living with two or more fast-food outlets within 1 km had a higher BMI than people with no fast-food outlet within 1 km around their residential address (B = 0.32, 95% CI 0.03, 0.62; Table 3). Fast-food outlet densities within 500 m, 3 km, and 5 km were not associated with BMI. In rural areas, people living with at least one fast-food outlet within 500 m had a higher BMI than people living with no fast-food outlet within 500 m around their residential address (B = 0.10, 95% CI: 0.02, 0.18; Table 4). Also, people in rural areas with five or more fast-food outlets within 1 km around the residential address had higher BMI than people in rural areas with no fast-food outlet within 1 km around the residential address (B = 0.23, 95% CI: 0.10, 0.36). Fast-food outlet 3-km and 5-km density were not associated with BMI.

3.4. Sensitivity analyses

Observed associations did not change with waist-to-height ratio instead of BMI as outcome (Supplementary Tables S6–S9). Furthermore, fast-food outlet proximity within 250-499 m and 500-999 m (urban areas) and having $\geq$40 and $\geq$ 28 fast-food outlets within 3 and 5 km (rural areas) were associated with waist-to-height ratio but not with BMI. When repeating the analyses with the most exposed instead of the least exposed group as the reference, results did not change meaningfully (Supplementary Tables S10–S13).

4. Discussion

This study shows that people with at least two (urban areas) or at least five (rural areas) fast-food outlets within 1 km around the residential address had a higher BMI than people with no fast-food outlet within 1 km around the residential address. Also, individuals living with at least one fast-food outlet within 500 m in rural areas had a higher BMI than those without any fast-food outlet within 500 m in rural areas. Furthermore, people in urban and rural areas living within less than 250 m to the nearest fast-food outlet had a higher BMI compared to those living further away than 1 km to the nearest fast-food outlet. We found regression coefficients up to 0.41 on BMI for fast-food outlet density, equalling a 1.26 kg heavier weight for Dutch average-height (i.e., 1.75 m (Statistics Netherlands, 2012)) adults. As this may represent the average effect of fast-food environments on entire living areas, the influence of fast-food outlet exposure may be substantial on a population level.

The main added value of this study lies in the assessment of urban-rural differences in the association between fast-food outlet exposure and BMI, since previous studies could not demonstrate such urban-rural differences (Cunningham-Myrie et al., 2020; Mackenbach et al., 2018). In our study, associations with BMI were stronger in rural than urban areas for 500 m density but not 1 km density. This may be explained by the notion that there are relatively few other healthy food outlets such as supermarkets within short distance in rural areas (Whelan et al., 2018), and that these healthy food outlets in rural areas may have relatively limited opening hours. This could make the most nearby fast-food outlets (i.e., within <500 m) more important. Yet, we used LISA data from 2012, and healthy food access may have changed since then (e.g., because of changes in opening hours of healthy food outlets and quicker grocery delivery services). Furthermore, fast-food outlet proximity within <250 m and 250-499 m was not more strongly associated with

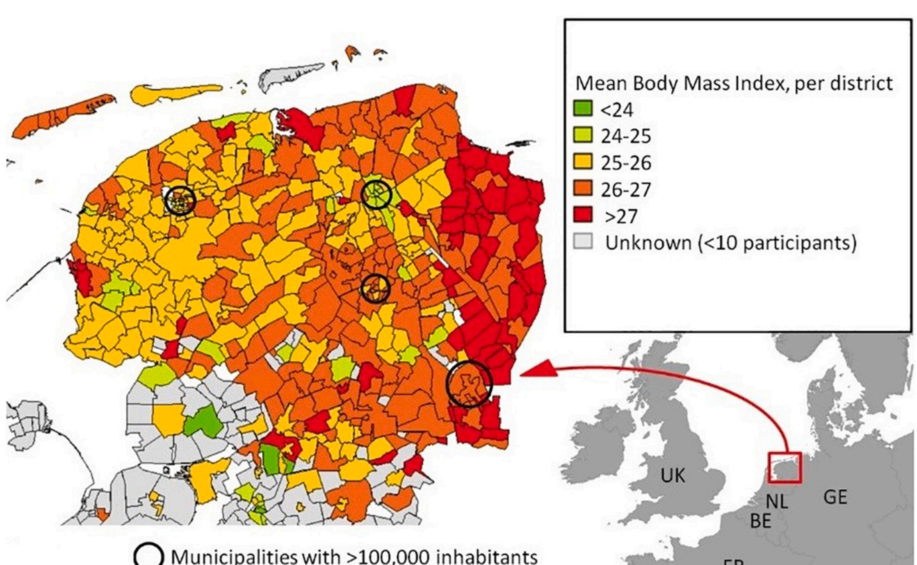

Fig. 1. Mean Body Mass Index of Lifelines adult participants, per district. Data are not shown for districts with fewer than 10 participants because of privacy reasons.

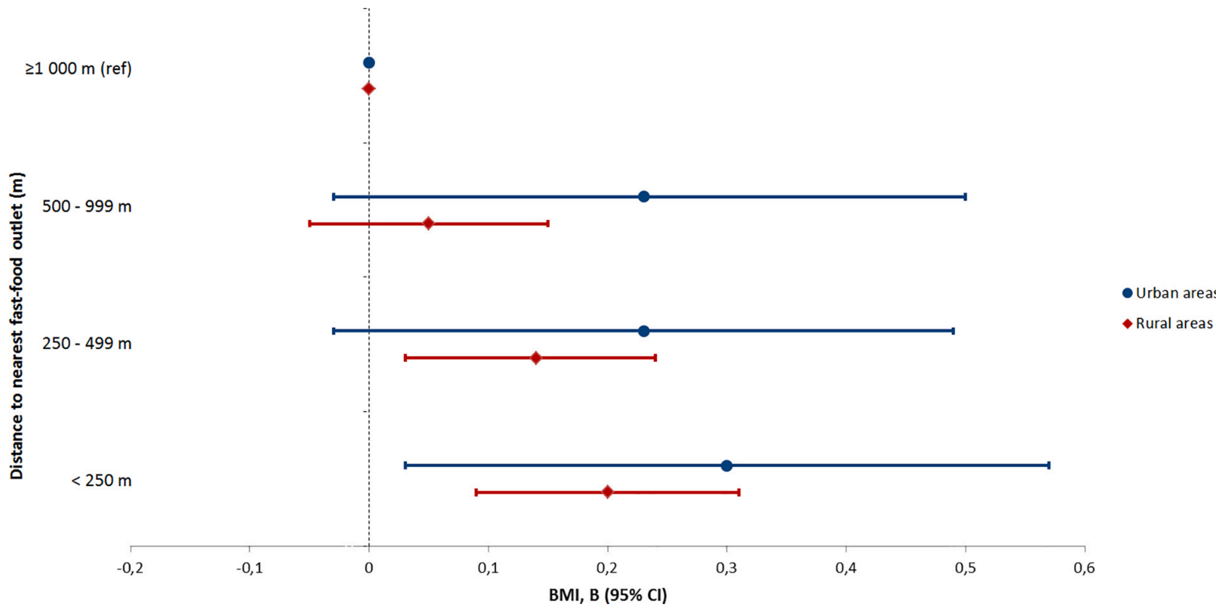

Fig. 2. Association between fast-food outlet proximity and BMI, stratified for urban and rural areas.

Table 2
Associations between of fast-food outlet proximity and Body Mass Index in urban areas[†] (*n* = *48,292*) and rural areas[‡] (*n* = *98,198*).

Fast-food proximity (distance to nearest outlet, in m)	*n* (%)[§]	Model 0[‖] B (95% CI)	Model 1[**] B (95% CI)	Model 2[††] B (95% CI)
Urban areas				
<250 m	*21,198* (44.0)	0.09 (−0.30, 0.47)	0.33 (−0.02, 0.68)	**0.30 (0.03, 0.57)**
250-499 m	*17,064* (35.5)	**0.47 (0.10, 0.82)**	**0.48 (0.13, 0.83)**	0.23 (−0.03, 0.49)
500-999 m	*8,234* (17.1)	**0.56 (0.19, 0.92)**	**0.48 (0.14, 0.82)**	0.23 (−0.03, 0.50)
≥1,000 m	*1,635* (3.4)	Ref	Ref	Ref
Rural areas				
<250 m	*18,974* (19.3)	**0.46 (0.32, 0.59)**	**0.37 (0.25, 0.50)**	**0.20 (0.09, 0.31)**
250–499 m	*23,583* (24.0)	**0.32 (0.19, 0.45)**	**0.29 (0.16, 0.41)**	**0.14 (0.03, 0.24)**
500–999 m	*24,837* (25.3)	**0.13 (0.00, 0.25)**	**0.11 (0.00, 0.23)**	0.05 (−0.05, 0.15)
≥1,000 m	*30,625* (31.2)	Ref	Ref	Ref

Note: Bold values represent significant associations based on α = 0.05.
[†] : Urban areas contain ≥1,000 addresses per km^2.
[‡] : Rural areas contain <1,000 addresses per km^2.
[§] : The sample size and percentage per exposure group is based on non-imputed data.
[‖] : Model 0: Unadjusted for any covariates.
[**] : Model 1: Adjusted for age, sex, weekly working hours, partner status, and education.
[††] : Model 2: Model 1 plus additional adjustment for neighbourhood deprivation and neighbourhood address density.

BMI in rural than urban areas. Thus, more research is needed to confirm this notion. Besides urban-rural differences, another addition to previous literature lies in the comprehensive assessment of fast-food outlet exposure due to incorporating proximity and various density measures (Reitzel et al., 2014). Results suggest that fast-food outlet exposure within 1 km is associated with BMI, and that fast-food outlet exposure further away than 1 km is of lesser importance. Also, associations with BMI were relatively similar between fast-food outlet proximity and density, which is a pattern that has not been consistently found in previous studies (Mackenbach et al., 2018; Reitzel et al., 2014). This further underlines the importance of using large-sized and geographically dispersed study samples and objective exposure and outcome measurements.

We observed substantial differences in estimates between the models without covariates (model 0), the models with adjustment for individual-level covariates (model 1), and the models with additional adjustment for the neighbourhood-level covariates address density and neighbourhood deprivation (model 2). Differences were strongest between model 1 and model 2. This highlights the importance of adjusting for neighbourhood-level covariates in the association between fast-food outlet exposure and BMI, a notion that has been reported earlier (Mason et al., 2018).

Observed associations between fast-food outlet density and BMI contrast with another Dutch study (Mackenbach et al., 2019) which showed that higher fast-food density was associated with lower BMI. This discrepancy may be explained by differences in outcome measurement (self-reported compared to objectively measured BMI) and adjustment for specific neighbourhood-level variables (e.g., we adjusted for address density, which was strongly associated with fast-food density measures (Pearson's *r* up to 0.90) and negatively associated with BMI (Supplementary Table S14)). Besides, another recently published study on the Dutch setting found no association between fast-food outlet street-network densities within 400 m, 1 km and 1.5 km and BMI-based overweight and obesity in adults (Harbers et al., 2021). Discrepancies with our findings may be explained by the use of different study populations. For instance, the mean age in their study was ± 70 years and ± 45 years in Lifelines. Also, they relied on different exposure measurements (street-network distances vs. straight-line distances) and different model adjustments. Regarding fast-food proximity, we found larger estimates than a study on mostly urban UK Biobank participants (Mason

Table 3
Associations between fast-food outlet density and Body Mass Index of individuals living in urban areas[†] (*n* = *48,292*).

Fast-food density (number of outlets)	*n* (%)[§]	Model 0[‖] B (95% CI)	Model 1[**] B (95% CI)	Model 2[††] B (95% CI)
500-m density				
0 fast-food outlets	*10,030* (20.8)	Ref	Ref	Ref
1 fast-food outlet	*9,353* (19.4)	0.09 (−0.14, 0.32)	0.12 (−0.11, 0.35)	0.05 (−0.08, 0.19)
2 fast-food outlets	*5,219* (10.8)	0.18 (−0.08, 0.44)	0.22 (−0.02, 0.46)	0.07 (−0.09, 0.22)
≥3 fast-food outlets	*23,690* (49.1)	**−0.41 (−0.66, −0.15)**	−0.10 (−0.31, 0.10)	0.04 (−0.09, 0.17)
1-km density				
0 fast-food outlets	*1,678* (3.5)	Ref	Ref	Ref
1 fast-food outlet	*1,701* (3.5)	0.29 (−0.09, 0.68)	**0.32 (0.00, 0.64)**	0.27 (−0.07, 0.60)
2–4 fast-food outlets	*6,614* (13.7)	**0.65 (0.24, 1.05)**	**0.58 (0.20, 0.96)**	**0.32 (0.03, 0.62)**
≥5 fast-food outlets	*38,299* (79.3)	0.33 (−0.05, 0.71)	**0.49 (0.14, 0.84)**	**0.41 (0.12, 0.69)**
3-km density				
0–15 fast-food outlets	*3,208* (6.6)	Ref	Ref	Ref
16–39 fast-food outlets	*16,919* (35.0)	−0.11 (−0.48, 0.27)	−0.05 (−0.40, 0.30)	0.09 (−0.20, 0.38)
40–99 fast-food outlets	*14,528* (30.1)	−0.13 (−0.49, 0.22)	−0.08 (−0.43, 0.26)	−0.04 (−0.33, 0.26)
≥100 fast-food outlets	*13,637* (28.2)	**−1.37 (−1.76, −0.98)**	**−0.72 (−1.07, −0.37)**	−0.07 (−0.40, 0.27)
5-km density				
0–15 fast-food outlets	*2,016* (4.2)	Ref	Ref	Ref
16–99 fast-food outlets	*28,104* (58.2)	0.04 (−0.17, 0.25)	0.14 (−0.13, 0.42)	0.32 (−0.06, 0.71)
100–249 fast-food outlets	*8,721* (18.1)	**−0.62 (−0.84, −0.40)**	−0.26 (−0.54, 0.02)	0.04 (−0.36, 0.45)
≥250 fast-food outlets	*9,451* (19.6)	**−1.56 (−1.86, −1.27)**	**−0.79 (−1.08, −0.50)**	−0.13 (−0.57, 0.31)

Note: Bold values represent significant associations based on α = 0.05.
[†] : Urban areas contain ≥1,000 addresses per km^2.
[§] : The sample size and percentage per exposure group is based on non-imputed data.
[‖] : Model 0: Unadjusted for any covariates.
[**] : Model 1: Adjusted for age, sex, weekly working hours, partner status, and education.
[††] : Model 2: Model 1 plus additional adjustment for neighbourhood deprivation and neighbourhood address density.

et al., 2018), possibly because Dutch adults live in closer distance to the nearest fast-food outlet (median 411 m in Lifelines and 1,136 m in UK Biobank). Yet, this discrepancy in results may also be due to exposure measurement issues in the UK Biobank study (Mason et al., 2018).

Strengths of this study are its focus on urbanisation differences in the association between fast-food outlet exposure and BMI, the objective exposure and outcome measurement, and the large and representative sample. However, this study also has some limitations. Because this study is cross-sectional, we cannot exclude the possibility of reverse causation. For example, fast-food outlets may have selectively opened or remained open in areas where BMI was higher as they were more likely to sell fast-food in these areas. Furthermore, participants with overweight could have selectively moved to neighbourhoods with many fast-food outlets. Yet, adults in the Northern Netherlands move relatively infrequently, possibly reducing the influence of selective mobility. Moreover, we could only rely on straight-line distances and not on

Table 4
Associations between fast-food outlet density and Body Mass Index in rural areas[‡] (*n* = *98,198*).

Fast-food density (number of outlets)	*n* (%)[§]	Model 0[‖] B (95% CI)	Model 1[**] B (95% CI)	Model 2[††] B (95% CI)
500-m density				
0 fast-food outlets	*55,809* (56.8)	Ref	Ref	Ref
1 fast-food outlet	*19,245* (19.6)	**0.30 (0.19, 0.42)**	**0.26 (0.16, 0.37)**	**0.10 (0.02, 0.18)**
2 fast-food outlets	*8,649* (8.8)	**0.30 (0.11, 0.48)**	**0.27 (0.09, 0.44)**	**0.14 (0.02, 0.25)**
≥3 fast-food outlets	*14,495* (14.8)	**0.38 (0.23, 0.52)**	**0.30 (0.17, 0.43)**	**0.19 (0.09, 0.29)**
1-km density				
0 fast-food outlets	*30,934* (31.5)	Ref	Ref	Ref
1 fast-food outlet	*18,165* (18.5)	**0.23 (0.09, 0.37)**	**0.21 (0.09, 0.33)**	0.09 (−0.02, 0.19)
2–4 fast-food outlets	*29,148* (29.7)	**0.26 (0.12, 0.40)**	**0.23 (0.10, 0.36)**	0.09 (−0.02, 0.20)
≥5 fast-food outlets	*19,951* (20.3)	**0.38 (0.19, 0.57)**	**0.31 (0.13, 0.48)**	**0.23 (0.10, 0.36)**
3-km density				
0 fast-food outlets	*6,510* (6.6)	Ref	Ref	Ref
1–5 fast-food outlets	*39,843* (40.6)	0.17 (−0.02, 0.37)	0.13 (−0.05, 0.32)	0.01 (−0.16, 0.17)
6–27 fast-food outlets	*41,307* (42.1)	**0.23 (0.02, 0.45)**	0.19 (−0.01, 0.39)	0.08 (−0.11, 0.27)
≥28 fast-food outlets	*10,538* (10.7)	−0.05 (−0.31, 0.21)	0.01 (−0.22, 0.25)	0.18 (−0.06, 0.42)
5-km density				
0–9 fast-food outlets	*31,083* (31.7)	Ref	Ref	Ref
10–15 fast-food outlets	*19,572* (19.9)	0.04 (−0.12, 0.20)	0.03 (−0.12, 0.18)	0.03 (−0.09, 0.15)
16–39 fast-food outlets	*29,275* (29.8)	0.03 (−0.13, 0.19)	0.05 (−0.10, 0.20)	0.07 (−0.06, 0.19)
≥40 fast-food outlets	*18,268* (18.6)	−0.20 (−0.42, 0.02)	−0.08 (−0.27, 0.11)	0.11 (−0.05, 0.26)

Note: Bold values represent significant associations based on α = 0.05.
[‡] : Rural areas contain <1,000 addresses per km^2.
[§] : The sample size and percentage per exposure group is based on non-imputed data.
[‖] : Model 0: Unadjusted for any covariates.
[**] : Model 1: Adjusted for age, sex, weekly working hours, partner status, and education.
[††] : Model 2: Model 1 plus additional adjustment for neighbourhood deprivation and neighbourhood address density.

street-network distances to compute fast-food outlet proximity and density. Although there is evidence that the correlation between straight-line distances and street-network distances is high (Burgoine et al., 2013), the correlation may be weaker in rural areas which generally have a lower street connectivity. Besides, we cannot exclude the possibility of residual confounding since we did not control for income, ethnicity, disease status, physical activity, and disability. However, the impact of not controlling for ethnicity may be small as 98.0% of the Lifelines adult participants is of White/Western and Eastern European ethnicity (van der Ende et al., 2017). Also, we did not take into account potential data clustering within families and households.

Furthermore, we could not account for delivery services of fast-food outlets. Delivery services enable easier access to fast-food outlets further away, possibly strengthening associations within longer distances. This could explain why we found an association between fast-food 3-km and 5-km density and waist-to-height ratio in rural areas. Still, we should be cautious when interpreting this finding, since these densities were not associated with BMI.

5. Conclusion

This study shows that people who have at least two (urban areas) or at least five (rural areas) fast-food outlets within 1 km around their residential address have on average a higher BMI than people who did not have any fast-food outlets around their residential address. Also, fast-food outlets within 500 m were associated with BMI in rural areas, but not in urban areas. Results of this study may help policy-makers to create healthier food environments that may contribute to a healthier lifestyle. For this purpose, regulations such as calorie labelling and sugar taxation have been highlighted. A more aggressive approach would be to restrict the number of fast-food outlets itself. Our results may then be used for tailored advice for urban and rural areas on the maximum number of fast-food outlets or the minimum distance to the nearest fast-food outlet. However, more research is needed to strengthen causal inference in the association between fast-food outlet exposure and BMI, and to assess the effectiveness of aforementioned interventions. In the future, natural experiments should be conducted to assess whether changes in fast-food environment (e.g., by openings or closings of fast-food outlets) affect BMI over time. Moreover, potential mediating factors should be examined to get a deeper understanding of how the fast-food environment might influence BMI. Also, future studies should investigate the role of the *online* fast-food environments (i.e., online food delivery service websites) and online fast-food purchases in BMI. Furthermore, other moderators than urbanisation level such as age deserve more attention in future research. In addition, future studies could examine the fast-food outlet exposure-BMI association across an urban-rural gradient, rather than in binary categories. Ultimately, this study may provide a stepping stone in further unravelling associations between fast-food environments and BMI, which may be an important piece within the complex aetiological puzzle of overweight.

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Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

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