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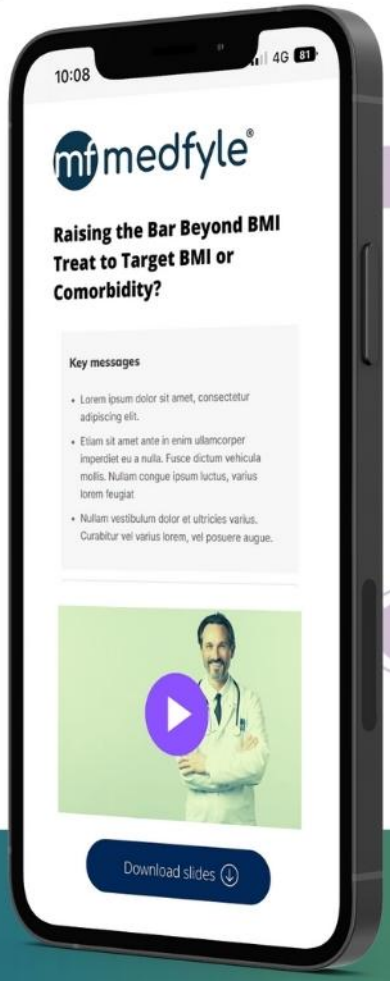

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Neighborhood socioeconomic differences in BMI: The role of fast-food outlets and physical activity facilities

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Abstract

Objective: The goal of this study was to investigate the association between neighborhood socioeconomic status (NSES) and BMI and to what extent this association is moderated by availability of fast-food (FF) outlets and pay-for-use physical activity (PA) facilities.

Methods: Baseline data of adults in Lifelines ($N = 146{,}629$) were linked to Statistics Netherlands and a register using geocoding to compute, respectively, NSES (i.e., low, middle, high) and the number of FF outlets and PA facilities within 1 km of the residential address. Multivariable multilevel linear regression analyses were performed to examine the association between NSES and BMI. Two-way and three-way interaction terms were tested to examine moderation by FF outlets and PA facilities.

Results: Participants living in low NSES areas had a higher BMI than participants living in high (B [95% CI]: 0.76 [0.65 to 0.87]) or middle NSES areas (B [95% CI]: 0.40 [0.28 to 0.51]), independent of individual socioeconomic status. Although two- and three-way interactions between NSES, FF outlets, and PA facilities were significant, stratified analyses did not show consistent moderation patterns.

Conclusions: People living in lower NSES areas had a higher BMI, independent of their individual socioeconomic status. The study found no clear moderation of FF outlets and PA facilities. Environmental factors that may mitigate NSES differences in BMI should be the subject of future research.

INTRODUCTION

Overweight and obesity are risk factors for various chronic diseases and mortality [1] and contribute globally to rising health care costs [2, 3]. The combined prevalence rate of overweight and obesity among adults increased worldwide from 13% in 1975 to 39% in 2016 [4]. In the absence of effective health policies, this prevalence rate is predicted to increase even more in the future [5, 6]. Increasingly recognized as an explanation for the increase in overweight and obesity is the obesogenic (i.e., overweight- and obesity-promoting) environment [7–9]. Identifying obesogenic aspects of the environment could support population-level approaches to facilitate healthier lifestyles and reduce overweight and obesity [7].

Neighborhood socioeconomic status (NSES) may be an important aspect of the obesogenic environment [10]. Compared with higher NSES areas, lower NSES areas are generally characterized by a high level of unemployment and financial problems, a low level of income and education, poor housing [10], and a lack of community resources

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[11]. Mohammed et al. conducted a meta-analysis on the association between NSES and body mass index (BMI) and showed that people living in lower NSES areas have a higher BMI [10]. However, not all studies included in their meta-analysis sufficiently adjusted for individual socioeconomic status (SES) indicators such as income, education, occupational prestige, employment status, and financial strain. Consequently, associations in this meta-analysis may have been overestimated [10]. Furthermore, most studies investigating the association between NSES and BMI were conducted in the United States. This may hamper the generalizability of their results to European countries owing to between-country differences, such as variations in the magnitude of neighborhood socioeconomic differences and housing policies.

Moreover, there is a need to examine environmental moderators in the association between NSES and BMI. Knowledge about such moderating factors could improve our understanding of how different environmental characteristics interact with each other to affect BMI, and why NSES differences in BMI may be exacerbated in certain areas [12, 13]. This knowledge may in turn be used to design policy approaches to reduce NSES differences related to BMI, for instance by discouraging openings of fast-food (FF) outlets or promoting openings of pay-for-use physical activity (PA) facilities. To date, little research has investigated whether the availability of FF outlets and pay-for-use PA facilities plays a moderating role in neighborhood socioeconomic differences in BMI. The availability of FF outlets may increase neighborhood socioeconomic differences in BMI. FF outlets often offer highly caloric [14] and relatively cheap [15] meals that are quickly served. People from lower NSES areas may more often visit these FF outlets than people from higher NSES areas for several reasons. First, the relatively cheap FF meals may be especially attractive in low NSES areas where the incomes are generally lower and where financial strain is more common, making it more difficult to resist unhealthy food choices [16]. Second, social norms that are positive toward eating FF are more common in low NSES areas [17]. Third, people with a low individual SES, who more often live in low NSES areas, have fewer cooking skills [18] and a lower health literacy [19], generally eat less healthily [18], have lower self-efficacy regarding adopting healthy behaviors [20], and more often report making unhealthy food choices in an unhealthy food environment [18]. Furthermore, a greater availability of pay-for-use PA facilities (e.g., gyms, swimming pools) may exacerbate NSES differences in BMI for several reasons. First, pay-for-use PA facilities allow for PA behaviors; because users are required to pay an access fee, residents of high NSES areas are more likely to use them than people living in low NSES areas. A qualitative study found that people living in low NSES areas regard paying an access fee for PA facilities as a barrier to PA [21]. Second, people living in lower NSES areas may less often use pay-for-use PA facilities because lower NSES areas are less safe, discouraging them to go outdoors [10]. Third, in lower NSES areas, social norms toward physical inactivity may be more positive [10]. However, to our best knowledge, no previous study has investigated whether the availability of FF outlets or pay-for-use PA facilities moderates the association between NSES and BMI.

Study Importance

What is already known?

- Previous studies have found that people living in areas with a lower neighborhood socioeconomic status have a higher BMI. However, these studies contain the risk of confounding by the socioeconomic status of the individuals and have not taken into account the moderating role of the availability of fast-food outlets and pay-for-use physical activity facilities.

What does this study add?

- This study highlights that people living in lower neighborhood socioeconomic status areas have a higher BMI, independent of the individual socioeconomic status indicators income, education, occupational prestige, financial strain, and employment status.
- The authors found no clear role for fast-food outlets and pay-for-use physical activity facilities within neighborhood socioeconomic differences in BMI.

How might these results change the direction of research?

- Environmental factors that may mitigate neighborhood socioeconomic status differences in BMI should be the subject of future research.

We therefore investigated the association between NSES and BMI in adults and to what extent this association is moderated by the availability of FF outlets and pay-for-use PA facilities. We hypothesized that people living in lower NSES have a higher BMI than people living in higher NSES areas (hypothesis 1). We also hypothesized that the NSES differences in BMI widen with a greater availability of FF outlets (hypothesis 2) and a greater availability of pay-for-use PA facilities (hypothesis 3).

METHODS

Study population

For this cross-sectional study we used adult baseline data from the Lifelines Cohort Study [22]. Lifelines is a multidisciplinary, prospective, population-based cohort study examining in a unique three-generation design the health and health-related behaviors of 167,729 persons living in the North of the Netherlands. It employs a broad range of investigative procedures in assessing the biomedical, sociodemographic, behavioral, physical, and psychological factors that contribute

to the health and disease of the general population, with a special focus on multimorbidity and complex genetics. Recruitment of participants took place between 2006 and 2013 (with 86.2% recruited between 2010 and 2013) through general practitioners, online registrations, and family members of participants. Further details about Lifelines are available elsewhere [22]. Participants' residential addresses were obtained using a nationwide address registry ("Basisadministratie Adressen en Gebouwen") and geocoded [23].

For this study we excluded nursing home residents, as they are not likely to interact with their neighborhood environment. We also excluded pregnant women (currently or in the past year) because their BMI is affected by the pregnancy and it does not accurately reflect their weight status. Furthermore, we excluded participants with missing data on the outcome measurement (BMI) or with >30% data points missing on potential confounders [24].

Exposure

Lifelines participants' residential neighborhood codes were linked to Statistics Netherlands neighborhood data from 2012 [25]. Statistics Netherlands provides annual freely available data on demographic characteristics and socioeconomic resources at the neighborhood level. Statistics Netherlands defines neighborhoods by official administrative boundaries [26]. The three provinces of the Northern Netherlands (i.e., Groningen, Friesland, Drenthe) where Lifelines was conducted have 1984 neighborhoods, covering a median (range) surface of 156 (3-12,403) hectares and containing a median (range) of 616.5 (0-6,108) residents. We used data from the year 2012, as close as possible to the median recruitment month of Lifelines baseline participants (March 2012).

Based on the linkage with Statistics Netherlands, we computed NSES as a composite score based on the following: 1) percentage of persons aged 15 to 65 years not receiving social assistance benefits, 2) average household income, 3) average value of a house in the neighborhood, and 4) percentage owner-occupied houses. These indicators reflect the general financial (1 and 2), occupational (2), and housing (3 and 4) status of a neighborhood. Similar to existing literature [10], we used principal component analysis to aggregate these indicators into a single NSES variable. Loadings of separate indicators on the NSES variable were all greater than 0.79 and explained 72.1% of the total variance. We categorized the NSES variable into tertiles (low, middle, and high).

Outcome

The primary outcome, BMI, was calculated as weight in kilograms divided by height in meters squared, based on objective weight and height measurements made by trained medical staff at Lifelines research centers. Additionally, we computed waist to height ratio by dividing waist circumference (in centimeters) by height (in centimeters) [27]. Waist circumference (in centimeters) was measured objectively by placing a SECA 200 measuring tape around the body in between the lower rib margin and iliac crest while the participant was in a standing position [28].

Moderators

We established a linkage between participants' geocoded residential addresses and LISA (Dutch: Landelijk Informatiesysteem van Arbeidsplaatsen; English: Nationwide Information System of Workplaces; www.lisa.nl) [29], a Dutch database containing locations where paid work is performed for at least 1 hour per month and including FF outlets and pay-for-use PA facilities. This allowed us to compute the number of FF outlets and pay-for-use PA facilities within 1 km of participants' residential addresses. We defined FF outlets as outlets offering food that was the following: 1) paid for at the counter, 2) meant to be eaten directly, and 3) unhealthy, highly caloric, and prepared in mass volume (Supporting Information Table S1). We defined pay-for-use PA facilities as facilities for recreational PA, such as gyms and swimming pools, that require a user to pay a fee (Supporting Information Table S1). We used LISA data from 2012, because these were as close as possible to the median recruitment month of Lifelines baseline participants (March 2012). Further details about the linkage and justification for the 1-km density measure are provided elsewhere [30].

We defined the availability of FF outlets and pay-for-use PA facilities as the number of each of these outlets within a straight-line distance of 1 km from the participants' residential address. We divided the number of FF outlets and the number of pay-for-use PA facilities into having no, one, and at least two within 1 km. These groups reflect availability versus no availability and allow for further assessment when multiple FF outlets or pay-for-use PA facilities are available. The availability of these outlets and facilities was computed using address points in Quantum Geographic Information System (QGIS) version 3.4.2.

Potential confounders

Neighborhood address density (number of addresses per kilometer squared) was used as a potential confounder at neighborhood level [7]. Potential individual-level confounders not reflecting SES included age (in years), sex, and partner status (having a partner or no partner). Individual-level potential confounders reflecting SES included income, education, occupational prestige, financial strain, and employment status. Income was measured as the net monthly household income (categorized into <750 euros, 750-1000 euros, 1000-1500 euros, 1500-2000 euros, 2000-2500 euros, 2500-3000 euros, 3000-3500 euros, and >3500 euros) divided by the square root of the number of people in the household living on that income [31]. Education was measured as the highest level of education attained and categorized according to the International Standard Classification of Education into low (no primary, primary, and lower secondary education), middle (upper secondary and postsecondary nontertiary education), and high (short-cycle tertiary, bachelor's degree or equivalent,

TABLE 1 Baseline characteristics for total study sample and separately for participants with low, middle, and high NSES

	Total, *N* = 146,629	Low NSES, *N* = 47,308 (32.2%)	Middle NSES, *N* = 46,801 (31.9%)	High NSES, *N* = 47,062 (32.1%)
Age (y), mean (SD)	44.9 (13.0)	43.4 (13.7)	44.8 (12.9)	46.3 (12.3)
Sex				
Female, *N* (%)	84,016 (57.3)	27,620 (58.4)	26,686 (57.0)	26,616 (56.6)
Having a partner, *N* (%)	123,840 (84.5)	37,062 (78.4)	40,083 (85.7)	41,864 (89.0)
Highest education, *N* (%)				
Low	44,349 (30.9)	15,951 (34.5)	14,759 (32.2)	12,103 (26.3)
Middle	56,754 (39.6)	18,033 (39.0)	18,693 (40.8)	17,707 (38.4)
High	42,377 (29.5)	12,277 (26.5)	12,347 (27.0)	16,243 (35.3)
Occupational prestige, median (IQR)	42.8 (31.0-52.4)	42.2 (29.8-50.9)	42.8 (31.0-51.0)	44.0 (33.0-54.1)
Net monthly income, median (IQR)	1588 (1125-1877)	1375 (1010-1875)	1588 (1125-1875)	1625 (1237-1945)
Neighborhood address density[a], median (IQR)	616 (209-1157)	1155 (726-1720)	471 (184-830)	394 (103-832)
Financial strain, *N* (%)				
No financial strain	114,804 (82.5)	34,641 (78.5)	37,371 (83.8)	38,458 (85.2)
Some financial strain	20,685 (14.9)	7856 (17.8)	6209 (13.9)	5808 (12.9)
Much financial strain	3659 (2.6)	1646 (3.7)	1028 (2.3)	851 (1.9)
Employment status, *N* (%)				
Unemployed	36,599 (25.0)	13,174 (27.8)	11,228 (24.0)	10,919 (23.2)
Working 1-11 hours	8357 (5.7)	2888 (6.1)	2682 (5.7)	2426 (5.2)
Working 12-19 hours	11,525 (7.9)	3458 (7.3)	3937 (8.4)	3679 (7.8)
Working 20-31 hours	26,406 (18.0)	7801 (16.5)	8649 (18.5)	9040 (19.2)
Working ≥32 hours	63,742 (43.5)	19,987 (42.2)	20,305 (43.4)	20,998 (44.6)
Number of pay-for-use PA facilities[b], *N* (%)				
Null pay-for-use PA facilities	45,831 (31.3)	6898 (14.6)	16,146 (34.5)	18,931 (40.2)
One pay-for-use PA facility	27,887 (19.0)	7648 (16.2)	10,616 (22.7)	8858 (18.8)
At least two pay-for-use PA facilities	72,991 (49.7)	32,762 (69.3)	20,039 (42.8)	19,273 (41.0)
Number of FF outlets[b], *N* (%)				
Null FF outlets	33,002 (22.5)	1903 (4.0)	9316 (19.9)	17,947 (38.1)
One FF outlet	19,736 (13.5)	3587 (7.6)	8699 (18.6)	6832 (14.5)
At least two FF outlets	93,891 (64.0)	41,818 (88.4)	*28,786* (61.5)	22,283 (47.3)
BMI (kg/m^2), mean (SD)	26.1 (4.3)	26.3 (4.6)	26.1 (4.3)	25.8 (4.1)
Waist-to-height ratio, mean (SD)	0.52 (0.07)	0.52 (0.07)	0.52 (0.07)	0.51 (0.07)
Normal weight (BMI < 25.0), *N* (%)	66,247 (45.2)	21,050 (44.5)	20,685 (44.2)	22,036 (46.8)
Pre-obesity (BMI 25.0-30.0), *N* (%)	57,565 (39.3)	17,867 (37.8)	18,764 (40.1)	18,738 (39.8)
Obesity (BMI ≥ 30.0), *N* (%)	22,817 (15.6)	8391 (17.7)	7352 (15.7)	6288 (13.4)

Note: Baseline characteristics are based on non-imputed data. Presented percentages concern valid percentages.
Abbreviations: FF, fast food; NSES, neighborhood socioeconomic status; PA, physical activity.
[a]Number of addresses per kilometer squared.
[b]Within 1 km of the residential address.

master's degree or equivalent, and doctoral degree or equivalent) [32]. Occupational prestige was measured with the Standard International Occupational Prestige Scale [33]. Financial strain was measured with the Long-term Difficulties Inventory [34] and categorized into having no, some, or much financial strain in the past year. Employment status was categorized into being unemployed (including unemployment due to retirement or disability), working 1 to 11 hours, working 12 to 19 hours, working 20 to 31 hours, and working ≥32 hours per week.

Statistical analyses

Multiple Imputation by Chained Equations was used to impute missing data and to create 13 imputed data sets [35] (Supporting Information Table S2 provides frequencies of missing data per variable). Pooled estimates were subsequently presented.

To examine the association between NSES and BMI, we performed multivariable multilevel linear regression analysis with random intercepts

TABLE 2 Association between NSES and BMI

	N (%)	Model 1[a], B (95% CI)	Model 2[b], B (95% CI)	Model 3[c], B (95% CI)	Model 4[d], B (95% CI)
Low NSES[e]	48,355 (32.9)	0.26 (0.15 to 0.37)**	0.88 (0.76 to 1.00)**	1.00 (0.88 to 1.11)**	0.76 (0.65 to 0.87)**
Middle NSES[e]	48,672 (33.2)	0.26 (0.14 to 0.39)**	0.40 (0.30 to 0.49)**	0.47 (0.37 to 0.57)**	0.37 (0.27 to 0.46)**
Low NSES[f]	48,355 (32.9)	0.00 (−0.13 to 0.14)	0.49 (0.36 to 0.61)**	0.53 (0.40 to 0.65)**	0.40 (0.28 to 0.51)**

Abbreviation: NSES, neighborhood socioeconomic status.
[a]Unadjusted model.
[b]Model 1 with adjustment for neighborhood address density.
[c]Model 2 with additional adjustment for age, sex, and partner status.
[d]Model 3 with additional adjustment for the highest level of education attained, occupational prestige, financial strain, employment status, and net monthly income.
[e]With reference group high NSES.
[f]With reference group middle NSES.
**$p < 0.001$.

and random slopes to account for clustered data within neighborhoods. First, we estimated an unadjusted model (model 1). Subsequently, we adjusted for address density (model 2) and additionally for individual-level potential confounders not reflecting SES (model 3), as well as for potential confounders reflecting individual SES (model 4). No multicollinearity was observed in model 4 (variance inflation factor < 4).

To assess moderation by FF outlets and pay-for-use PA facilities in the association between NSES and BMI, we added two-way interaction terms between NSES and FF outlets and between NSES and pay-for-use PA facilities to model 4 of the aforementioned analysis. We also tested three-way interaction terms between NSES, FF outlets, and pay-for-use PA facilities on BMI. In cases where interaction terms had a *p* value below 0.05, we stratified analyses for availability of FF outlets and/or pay-for-use PA facilities. We performed all analyses in RStudio version 3.5.2.

Sensitivity analysis

To evaluate the robustness of results, we repeated the analyses with waist to height ratio instead of BMI as outcome. Although BMI is the most commonly used measure of overweight and obesity because of its relatively easy assessment, waist to height ratio more accurately predicts chronic diseases [27] and all-cause mortality [36].

Ethics approval

The Lifelines Cohort Study complies with the Declaration of Helsinki. The protocol was approved by the Medical Ethical Committee of the University Medical Center Groningen (number 1007/152). All Lifelines participants provided informed consent.

RESULTS

Study population

After excluding 5,551 participants (994 nursing home residents, 4159 pregnant women, and 398 participants owing to missing data), 146,629 participants were eligible for this study. Among those eligible, the mean (SD) age was 44.9 (13.0) years and 57.3% were female (Table 1). Participants had a mean (SD) BMI of 26.1 (4.3) kg/m^2. Compared with participants living in middle or high NSES areas, those living in low NSES areas were younger, more often had a low educational level and were unemployed, had a lower occupational prestige and a lower income, and more often experienced financial strain. Also, low NSES areas had a higher address density and, in relation to this, a higher density of FF outlets and pay-for-use PA facilities.

Association between NSES and BMI

Results on the association between NSES and BMI are presented in Table 2. In the final most adjusted model (model 4), participants living in low or middle NSES areas had, on average, a higher BMI than participants living in high NSES areas (unstandardized effect size (B) [95% confidence interval (CI)]: 0.76 [0.65 to 0.87]; and B [95% CI]: 0.37 [0.27 to 0.46], respectively), independent of their individual SES. Also, participants living in low NSES areas had a higher BMI than participants living in middle NSES areas (B [95% CI]: 0.40 [0.28 to 0.51]), independent of their individual SES.

Association between NSES and BMI, stratified by the availability of FF outlets and/or pay-for-use PA facilities

Because we found significant interaction terms ($p < 0.05$) between NSES and FF outlets (two-way interaction), NSES and pay-for-use PA facilities (two-way interaction), and NSES, FF outlets, and pay-for-use PA facilities (three-way interaction), we performed stratified analyses for the availability of FF outlets and/or pay-for-use PA facilities.

In analyses stratified by the availability of FF outlets, we found no clear moderation effect across levels of FF outlets, and in all strata, we found that differences in BMI remained between the low, middle, and high NSES groups (Table 3). Furthermore, we found no clear

TABLE 3 Associations between NSES and BMI for the whole study sample, stratified for the number of FF outlets (null, one, at least two) and stratified for the number of pay-for-use PA facilities (null, one, at least two) using model 4[a]

Study population	*N* (%)	Low NSES[b], B (95% CI)	Middle NSES[b], B (95% CI)	Low NSES[c], B (95% CI)
Total study sample	146,629 (100.0)	0.76 (0.65 to 0.87)**	0.37 (0.27 to 0.46)**	0.40 (0.28 to 0.51)**
Number of FF outlets within 1 km				
Null FF outlets	33,002 (22.5)	0.95 (0.61 to 1.29)**	0.40 (0.28 to 0.51)**	0.58 (0.23 to 0.93)**
One FF outlet	19,736 (13.5)	0.93 (0.65 to 1.22)**	0.30 (0.10 to 0.51)**	0.63 (0.33 to 0.93)**
At least two FF outlets	93,891 (64.0)	0.71 (0.59 to 0.84)**	0.36 (0.23to 0.49)**	0.35 (0.23 to 0.48)**
Number of pay-for-use PA facilities within 1 km				
Null pay-for-use PA facilities	45,831 (31.3)	0.77 (0.58 to 0.97)**	0.32 (0.19 to 0.46)**	0.45 (0.25 to 0.66)**
One pay-for-use PA facility	27,887 (19.0)	0.90 (0.67 to 1.12)**	0.32 (0.14 to 0.50)**	0.58 (0.36 to 0.79)**
At least two pay-for-use PA facilities	72,911 (49.7)	0.78 (0.64 to 0.92)**	0.45 (0.30 to 0.59)**	0.31 (0.19 to 0.47)**

Abbreviations: FF, fast food; NSES, neighborhood socioeconomic status; PA, physical activity.
[a]Model 4: Adjusted for neighborhood address density, age, sex, partner status, the highest level of education attained, occupational prestige, financial strain, employment status, and net monthly income.
[b]Reference group high NSES.
[c]Reference group middle NSES.
**$p < 0.001$.

TABLE 4 Associations between NSES and BMI stratified for both the number of FF outlets and pay-for-use PA facilities using model 4[a]

Number of FF outlets within 1 km	Number of PA facilities within 1 km	*N*	Low NSES[b], B (95% CI)	Middle NSES[b], B (95% CI)	Low NSES[c], B (95% CI)
Null	Null	21,011	1.07 (0.62 to 1.51)**	0.36 (0.16 to 0.55)**	0.71 (0.25 to 1.17)*
Null	One	6,427	1.10 (0.37 to 1.82)*	0.48 (0.16 to 0.80)*	0.62 (−0.12 to 1.35)
Null	At least two	5564	0.53 (0.01 to 1.05)*	0.37 (0.01 to 0.74)*	0.16 (−0.41 to 0.73)
One	Null	8876	0.85 (0.44 to 1.26)**	0.25 (−0.03 to 0.52)	0.60 (0.18 to 1.02)*
One	One	5434	1.08 (0.61 to 1.56)**	0.33 (−0.02 to 0.69)	0.75 (0.28 to 1.21)*
One	At least two	5426	1.07 (0.61 to 1.52)**	0.40 (0.02 to 0.78)*	0.66 (0.17 to 1.16)*
At least two	Null	15,826	0.54 (0.27 to 0.81)**	0.20 (−0.06 to 0.46)	0.34 (0.06 to 0.61)*
At least two	One	15,991	0.76 (0.50 to 1.03)**	0.22 (−0.04 to 0.47)	0.55 (0.29 to 0.80)**
At least two	At least two	61,587	0.77 (0.62 to 0.92)**	0.44 (0.28 to 0.60)**	0.33 (0.18 to 0.48)**

Abbreviations: FF, fast food; NSES, neighborhood socioeconomic status; PA, physical activity.
[a]Adjusted for neighborhood address density, age, sex, partner status, the highest level of education attained, occupational prestige, financial strain, employment status, and net monthly income.
[b]Reference group high NSES.
[c]Reference group middle NSES.
*$p < 0.05$.
**$p < 0.001$.

moderation pattern in analyses stratified by availability of pay-for-use PA facilities (Table 3).

In stratified analyses by availability of *both* FF outlets and pay-for-use PA facilities, a clear moderation pattern was also lacking, and we observed differences in BMI between the three NSES groups in all strata with a few exceptions (Table 4). Participants with low NSES did not differ in BMI from participants with middle NSES when null FF outlets and at least one pay-for-use PA facility were available within 1 km. Also, participants with middle NSES did not differ in BMI from participants with high NSES when at least two FF outlets and fewer than two pay-for-use PA facilities were available within 1 km.

Sensitivity analysis

The analysis using waist to height ratio did not alter the outcomes of the analysis using BMI (Supporting Information Tables S3 and S4).

DISCUSSION

In accordance with our hypothesis 1, we found that people living in low NSES areas have a higher BMI than people living in high NSES areas, independent of their individual SES. Overall, participants living in low NSES areas had a 0.76 higher BMI than participants with high

NSES; this indicates a 2.33 kg higher weight for an average-height adult in the Netherlands (i.e., 1.75 m for females and males combined [37]). However, we found no evidence for hypotheses 2 and 3 that NSES differences in BMI would be larger with a greater availability of FF outlets or pay-for-use PA facilities.

In line with hypothesis 1, participants living in lower NSES areas had a higher BMI than participants living in higher NSES areas. This may be because lower NSES areas have less social capital [11] and fewer social norms that promote healthy behaviors [38]. The association between NSES and BMI in our study was not as strong as reported in the meta-analysis of Mohammed et al. [10]. This may be explained by our extensive adjustment for individual SES indicators. Many studies in the meta-analysis of Mohammed et al. did not do this, possibly overestimating the association between NSES and BMI. Between-country differences may also explain the weaker association between NSES and BMI in our study compared with those reported in the meta-analysis of Mohammed et al. [10], as the studies included in this meta-analysis were performed predominantly in the United States, where socioeconomic differences are generally more pronounced than in Europe [39].

Contrary to our hypotheses 2 and 3, NSES differences in BMI were not larger with a greater availability of FF outlets and/or pay-for-use PA facilities. Although interaction terms between NSES, FF outlets, and pay-for-use PA facilities were significant, stratified analyses showed no consistent moderation pattern, that is, we found no evidence supporting moderation. Other aspects of the built environment (rather than FF outlets and pay-for-use PA facilities), such as greenspace or other food outlets (for instance healthy food outlets), may play a more important role in the association between NSES and BMI. Moreover, a higher exposure to FF outlets could also represent higher exposure to health-promoting neighborhood resources, such as healthy food outlets or transportation facilities. Such health-promoting neighborhood resources could also have an impact on BMI by promoting healthier diets or physical activity. The notion that higher exposure to FF outlets may simultaneously represent higher exposure to health-promoting neighborhood resources makes it difficult to study the moderating role of FF outlets in the association between NSES and BMI in isolation. Also, we reasoned that exposure to pay-for-use PA facilities would exacerbate NSES differences in BMI because the access fee would be a barrier for using such facilities in low NSES areas [21]. However, the moderation effect of pay-for-use PA facilities in the association between NSES and BMI may have been underestimated because low NSES residents may be physically active in other places such as parks, at home, or at the workplace [40] where they need not pay what is, for them, a costly access fee.

The strengths of this study include its large and representative study sample [41], the objective measurement of BMI, FF outlets, and pay-for-use PA facilities, and the comprehensive assessment of potential confounding variables. The study also had a number of limitations. For instance, because of its cross-sectional nature, reverse causation cannot be excluded: people with a higher BMI are at increased risk of mental and physical health problems [42], possibly resulting in a lower income [42] and subsequently a lower NSES. Furthermore, as NSES and the availability of FF outlets and pay-for-use PA facilities were measured in 2012 and the BMI of Lifelines participants was measured between 2006 and 2013, potential misclassification cannot be excluded, even though 86.2% of the participants in Lifelines were recruited between 2010 and 2013. Another consideration is that, for computing NSES, a measure of the general level of education within the neighborhood was not available; however, housing, financial, and occupational status were used to compute NSES, and these factors tend to correlate highly with educational level. Finally, for measuring the availability of FF outlets and pay-for-use PA facilities within 1 km of the residential address, we were able to use only straight-line rather than street-network distances because street-network distances were not available in the data. A UK study found that measures based on straight-line and street-network distances correlate highly [43], yet this correlation may be weaker in rural areas where part of the Lifelines participants reside as rural areas contain a relatively low street connectivity. Moreover, we had no data available on whether participants used these FF outlets and pay-for-use PA facilities within 1 km of their residential address. Also, our results may have been affected by the inclusion of rural areas (i.e., areas with a low address density), despite adjustment for address density (i.e., residual confounding). High and middle NSES areas were relatively often present in rural areas and people from rural areas have, on average, a higher BMI than people from urban areas [30]. This may have weakened our finding that people from lower NSES have a higher BMI. Besides, rural and urban areas may differ substantially in exposure to local destinations such as FF outlets and pay-for-use PA facilities. Still, we chose not to exclude rural areas as it would remove a large part of the variation in NSES, BMI, and exposure to FF outlets and pay-for-use PA facilities.

This study highlights the role of neighborhood socioeconomic conditions in BMI. Our results do not support a major role for targeting FF outlets and pay-for-use PA facilities in neighborhood socioeconomic differences in BMI. Future longitudinal studies on the association between NSES and changes in BMI are needed. Next, environmental factors that may mitigate NSES differences in BMI should be the subject of future research. In this respect, researchers could assess the role of *using* FF outlets and pay-for-use PA facilities in the association between NSES and BMI. Also, the interplay between NSES and PA facilities for which no fee is necessary (e.g., public sports courts) and between NSES and healthy food outlets should be investigated. Besides, future studies should investigate the potentially mediating role of FF outlets in the association between NSES and BMI. Such an investigation is warranted because FF outlets are more ubiquitous in low NSES areas than in high NSES areas in our data as well as in previous research [44]. Moreover, the role of other aspects of the built environment (e.g., as greenspace) deserves more attention.

CONCLUSION

People living in low NSES areas had, on average, a higher BMI than people living in higher NSES areas, independent of their individual SES. This pattern was not consistently more pronounced with greater availability of FF outlets and/or pay-for-use PA facilities. Environmental

factors that may mitigate NSES differences in BMI should be the subject of future research.O

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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