EVIDENCE BASED PUBLIC HEALTH POLICY AND PRACTICE

Socioeconomic and food-related physical characteristics of the neighbourhood environment are associated with body mass index

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Objective: To determine whether socioeconomic and food-related physical characteristics of the neighbourhood are associated with body mass index (BMI; kg/m^2) independently of individual-level sociodemographic and behavioural characteristics.

Design and methods: Observational study using (1) individual-level data previously gathered in five cross-sectional surveys conducted by the Stanford Heart Disease Prevention Program between 1979 and 1990 and (2) neighbourhood-level data from (a) the census to describe socioeconomic characteristics and (b) data obtained from government and commercial sources to describe exposure to different types of retail food stores as measured by store proximity, and count of stores per square mile. Data were analysed using multilevel modelling procedures. The setting was 82 neighbourhoods in agricultural regions of California.

Participants: 7595 adults, aged 25–74 years.

Results: After adjusting for age, gender, ethnicity, individual-level socioeconomic status, smoking, physical activity and nutrition knowledge, it was found that (1) adults who lived in low socioeconomic neighbourhoods had a higher mean BMI than adults who lived in high socioeconomic neighbourhoods; (2) higher neighbourhood density of small grocery stores was associated with higher BMI among women; and (3) closer proximity to chain supermarkets was associated with higher BMI among women.

Conclusion: Living in low socioeconomic neighbourhoods, and in environments where healthy food is not readily available, is found to be associated with increased obesity risk. Unlike other studies which examined populations in other parts of the US, a positive association between living close to supermarkets and reduced obesity risk was not found in this study. A better understanding of the mechanisms by which neighbourhood physical characteristics influence obesity risk is needed.

The prevalence of obesity has been increasing rapidly in the US.[1 2] Sedentary lifestyles, larger food portion sizes, the ready availability of high sugar beverage and food products, and poor diet quality are factors that have been implicated in the country's obesity crisis.[3] Lower socioeconomic groups have been affected to a greater extent,[4] and there is growing evidence that the social and physical characteristics of neighbourhoods may play a role in the development of obesity.

Neighbourhood social characteristics such as median income have been linked to obesity risk in studies of adults living in Europe[5–7] and North America.[8 9] However, neighbourhood physical characteristics, such as the geographic distribution of fast food restaurants and various types of retail food stores, have been examined in relation to obesity risk in only a few studies. A recent study found no association between living close to fast food restaurants and body mass index (BMI) in Americans,[10] even though frequent fast food consumption may increase obesity risk.[10 11] By contrast, the presence of supermarkets in the neighbourhood was observed to be associated with lower obesity risk in another study of Americans.[12] In the US, supermarkets invariably carry a wide variety of foods at discounted prices and are presumed to be an important source of fresh produce and other healthy foods. Despite the availability of healthy foods in American supermarkets, only a few studies have observed associations between living close to supermarkets and increased fruit and vegetable intake or diet quality.[13–15]

In the US, neighbourhood social and physical characteristics are inter-related. It has been reported that supermarkets are found less frequently, whereas small grocery stores and convenience stores (often carrying mostly less healthy foods and at higher prices than supermarkets) are found more frequently in low socioeconomic neighbourhoods.[16–18] This observation is not necessarily applicable to societies outside of the US—for example, in the UK, Cummins found no differences in food price or food availability between deprived and affluent areas.[19 20]

The primary objective of this investigation is to determine, in the context of the US, whether social and physical characteristics of the neighbourhood environment are associated with obesity risk indicated by BMI (kg/m^2). Socioeconomic characteristics of the neighbourhood may affect social capital (defined to include mutual relations, social interactions and networks within a community),[21] which in turn may influence norms and values about food and body size. Physical characteristics of the neighbourhood may affect the accessibility of more healthy versus less healthy foods. Since others have observed gender differences in the relationship between neighbourhood environment and health,[22] we also examine interactions with gender. We hypothesise the following:

1. Proximity to, and geographic density of, fast food restaurants and each type of food store will vary by neighbourhood socioeconomic characteristics.
2. Residents living in lower socioeconomic neighbourhoods will have higher BMI. These effects will be independent of individual-level risk factors, specifically age, ethnicity,

Abbreviations: BMI, body mass index; SES, socioeconomic status; SHDPP, Stanford Heart Disease Prevention Program

socioeconomic status (SES), smoking, physical activity and nutrition knowledge, and will vary by gender.

3. Residents living in neighbourhoods where convenience and less healthy foods are more readily available (eg, through fast food restaurants, convenience stores, small grocery stores and ethnic markets) will have higher BMI. These effects will be independent of neighbourhood socioeconomic characteristics, age, ethnicity, SES, smoking, physical activity and nutrition knowledge, and will vary by gender.
4. Residents living in neighbourhoods where healthy foods, specifically fresh produce, are more readily available (eg, through supermarkets) will have lower BMI. These effects will be independent of neighbourhood socioeconomic characteristics, age, ethnicity, SES, smoking, physical activity and nutrition knowledge, and will vary by gender.

METHODS

Data sources

We used (1) individual-level clinical and sociodemographic data gathered from 7595 women and men, aged 25–74 years, who had participated in one of five cross-sectional surveys conducted between 1979 and 1990 by the Stanford Heart Disease Prevention Program (SHDPP), (2) US census data to describe social characteristics of the neighbourhood and (3) historical food store data obtained from government and commercial sources to describe physical characteristics of the neighbourhood.

Relevant data obtained from the SHDPP were BMI, gender, age, ethnicity, family income, education, smoking, physical activity and nutrition knowledge. The SHDPP was a community-based cardiovascular disease risk intervention study conducted in four California cities: Monterey, Salinas, Modesto and San Luis Obispo.[23–25] Persons, aged 12–74 years, who resided in randomly selected households and were English or Spanish speaking were eligible to participate. The respondents represented a stable population who mostly had lived in their communities for a relatively long period of time: 74% for $\geq$5 years and only 7% for $<$1 year.[26] The SHDPP 6-year intervention was comprehensive, but the net treatment effects for cardiovascular disease risk factors including weight gain were modest or negligible, amounting to a difference of about 0.6 kg in the mean weight gain between intervention and control communities.[27 28]

Historical data relating to the social environment were obtained from the 1980 and 1990 census, whereas data quantifying the food-related aspects of the physical environment were obtained from the California State Board of Equalization and telephone business directories for the relevant years (1979–90). All research was approved by the ethics committees at Stanford University, School of Medicine and/or the University of California at Berkeley, and conforms to the principles of the Declaration of Helsinki.

Definition of neighbourhoods

Neighbourhood was primarily defined by a combination of census tracts and/or block groups.[29] To determine whether these census-defined boundaries corresponded to the boundaries of actual neighbourhoods, they were verified against archival neighbourhood maps and with city planners. As a result, 82 neighbourhoods were defined in all four cities. For 70 neighbourhoods, the boundaries corresponded to individual census tracts or block groups. For the remaining 12 neighbourhoods, a combination of census tracts or blocks groups was used to represent boundaries better. The same neighbourhood boundaries were used in all five surveys.[30] Although data were clustered by neighbourhood, the intraclass correlation was low (0.05), indicating that one person's BMI was unlikely to affect another person's BMI in the same neighbourhood. Table 1 provides summary data on the size of the 82 neighbourhoods. The boundaries of the 82 neighbourhoods were used to define the neighbourhood of each participant's geocoded address. The geocoding service used was assessed to be 95–98% accurate; further methodological details have been published.[26 30 31]

Variable definition

Neighbourhood-level variables

Social characteristics of the neighbourhood were quantified using socioeconomic indicators available from the 1980 and 1990 census. Principal components analysis was used to identify those census variables that loaded highly on the same component to develop an index of the neighbourhood socioeconomic environment (neighbourhood SES). The final index was derived from five census variables (median family income, median housing value, percentage having blue collar workers, percentage of unemployed and percentage of less than high-school education) that explained 72% of the total variance. It was then used to categorise neighbourhood SES into survey-specific tertiles, with the highest, middle and lowest tertiles considered the high, middle and low socioeconomic neighbourhoods, respectively. Because census data were available only for 1980 and 1990, neighbourhood SES index was obtained by linear interpolation for the second, third and fourth cross-sectional surveys, which were conducted between 1980 and 1990.

Food-related physical characteristics of the neighbourhood were indicated by proximity to and density of fast food restaurants and various types of retail food stores. For the purposes of our study, we defined fast food restaurants as those nationally recognised chains that sell inexpensive, quickly served foods such as hamburgers, pizza and fried chicken, and adapted the North American Industry Classification System (http://www.census.gov/epcd/www/naics.html) and the Food Marketing Institute (http://www.fmi.org) definitions of retail food stores, which we classified as chain convenience stores, small grocery stores, ethnic markets, specialised markets, medium-sized independent grocery stores and chain supermarkets. (table 2) The classification of food stores was based on chain name and ethnic name recognition, and on interviews with long-term residents or owners/managers of existing independent grocery stores. Medium-sized independent grocery stores and specialised markets were excluded from the analysis. Only 1% of SHDPP participants lived in neighbourhoods with a medium-sized independent grocery store, and while 12% of SHDPP participants lived in neighbourhoods with specialised markets, the types of food sold by specialised markets varied greatly, making the data difficult to interpret.

In the US, convenience and small grocery stores primarily carry non-perishables (such as processed and canned foods, high in sugar, salt and/or fat), and seldom stock fresh fruits and vegetables.[17 32] Chain supermarkets invariably carry fresh fruits and vegetables. There are few reports on the types of food generally carried by ethnic markets.

Table 1 Description of 82 selected neighbourhoods from 4 California cities, 1980 and 1990

	Median (range)
Area (square miles)	0.8 (0.2–116.7)
Population (1980)	363 (16–1308)
Population (1990)	4251 (525–12 153)

Table 2: Definitions of retail food stores

Store type	Definition
Chain convenience store	Self-service grocery stores offering a limited line of high-convenience items, open long hours and provide easy access
Small grocery stores	Independently owned grocery stores that sell beverages, tobacco and a limited selection of convenience foods
Ethnic markets	Independently owned stores that have an ethnic name (presumed to carry ethnic foods)
Specialised markets	Stores that sell only specific food items such as seafood or fresh produce
Medium-sized independent grocery stores	Independently owned grocery stores that carry a range of products generating an annual sales volume of <$2 million
Chain supermarkets	Chain self-service grocery stores generating an annual sales volume of ⩾$2 million

Geographic store density in a neighbourhood was calculated by dividing the number of stores located in an area comprising the neighbourhood and a surrounding 0.5-mile buffer zone, by the area of the neighbourhood. The creation of a buffer zone allows the inclusion of stores that lie just outside neighbourhood boundaries. Proximity was defined as the shortest straight line distance to a fast food restaurant or a type of food store from a participant's home.

Individual-level variables

Gender, age, ethnicity, individual SES, smoking, physical activity and nutrition knowledge were treated as individual-level variables. Gender and age were assessed from self-reports. Ethnicity was defined as non-Hispanic white or Hispanic; individuals of other races/ethnicities (about 6% of the sample) were excluded from analysis as they varied considerably in ethnic heritage. Individual SES was a composite measure

Table 3 Characteristics of participants by neighbourhood socioeconomic status*

	Neighbourhood SES tertile†		
Characteristics	**High (n = 3993)**	**Middle (n = 2372)**	**Low (n = 1230)**
BMI (kg/m^2)	25.4 (4.6; 14.6–67.9)	25.7 (4.9; 13.3–55.6)	27.3 (5.4; 14.3–54.4)
Age (years)	45.6 (14.0; 25–74)	43.9 (14.2; 25–74)	45.0 (14.3; 25–74)
Gender			
Women	2142 (53.6%)	1298 (54.7%)	718 (58.4%)
Men	1151 (46.4%)	1074 (45.3%)	512 (41.6%)
Race/ethnicity			
Non-Hispanic white	3819 (95.6%)	2119 (89.3%)	710 (65.8%)
Hispanic	174 (4.4%)	253 (10.7%)	420 (34.2%)
Household income ($)			
<10 000	306 (8.2%)	296 (13.4%)	263 (24.1%)
10 000–19 999	674 (18.1%)	530 (24.1%)	347 (31.9%)
20 000–29 999	896 (24.0%)	561 (25.5%)	233 (21.4%)
30 000–39 999	710 (19.0%)	384 (17.4%)	132 (12.1%)
40 000–49 999	482 (12.9%)	244 (11.1%)	61 (5.6%)
>50 000	661 (17.7%)	187 (8.50%)	53 (4.9%)
Education (years)	14.4 (2.9; 0–25)	13.3 (3.0; 0–26)	10.3 (4.1; 0–23)
Individual SES‡	2.8 (0.8; 1–4)	2.5 (0.8; 1–4)	1.8 (0.8; 1–4)
Marital status			
Currently married	2748 (68.8%)	1593 (67.2%)	861 (70.1%)
Previously married	778(19.5%)	506 (21.3%)	287 (23.4%)
Never married	466 (11.7%)	273 (11.5%)	80 (6.5%)
Language spoken at home			
English only or mostly English	961 (94.8%)	540 (85.9%)	217 (43.9%)
English and Spanish equally	27 (2.7%)	39 (6.2%)	66 (13.4%)
Mostly Spanish or Spanish only	26 (2.6%)	50 (8.0%)	211 (42.7%)
Non-smokers	1792 (45.3%)	1032 (43.8%)	509 (41.5%)
Physical activity§	4.53 (1.55; 1–7)	4.46 (1.61; 1–7)	4.37 (1.68; 1–7)
Nutrition knowledge (above median)¶	2596 (65.0%)	1386 (58.4%)	561 (45.6%)

BMI, body mass index; SES, socioeconomic status.
*Values for continuous variables are expressed as Mean (SD; range); values for categorical variables are expressed as count (%). Non-significance for each variable varies because of missing values.
†Neighbourhood SES index was derived from census information on median family income, median housing value, percentage of blue collar workers, percentage of unemployed and percentage having less than high-school education. Participants were categorised into survey-specific tertiles by their neighbourhood SES.
‡Individual SES was derived from annual household income and educational attainment.
§Participants were asked to rate their activity level relative to others of their age on a scale of 1–7.
¶A dichotomous variable derived from 17 questions was developed to assess nutrition knowledge. The median score, 4/17, was the cut-off point used to create this dichotomous variable.

Table 4 Proximity to, and density of, fast food restaurants and various types of food stores by neighbourhood socioeconomic status*

Store type‡		Neighbourhood SES tertile† High (n = 3993)	Middle (n = 2372)	Low (n = 1230)	Significant pairwise comparisons§
Proximity (mean closest distance to participant's home, in miles)	Fast food	0.897 (0.631; 0.014–5.081)	0.613 (0.372; 0.011–2.256)	0.853 (0.555; 0.039–2.905)	All ($p<0.05$)
	Convenience	0.960 (0.654; 0.008–4.827)	0.556 (0.382; 0.007–2.492)	0.501 (0.301; 0.004–1.827)	All ($p<0.01$)
	Small grocery	1.046 (0.883; 0.011–5.562)	0.787 (0.420; 0.021–2.754)	0.481 (0.333; 0.012–1.817)	All ($p<0.001$)
	Ethnic market	1.398 (1.131; 0.000–5.486)	1.044 (0.877; 0.000–4.073)	1.321 (0.966; 0.027–4.374)	All ($p<0.05$)
	Supermarket	1.050 (0.613; 0.019–4.753)	0.731 (0.454; 0.017–3.549)	0.822 (0.528; 0.019–2.740)	All ($p<0.001$)
Store type‡		**High (n = 25)**	**Middle (n = 25)**	**Low (n = 29)**	
Store density (count per square mile) in neighbourhood and buffer zone¶,**	Fast food	4.39 (4.41; 0–13.15)	5.27 (4.39; 0–15.16)	2.76 (3.63; 0–14.33)	NS
	Convenience	3.16 (4.75; 0–17.53)	3.85 (3.23; 0–13.72)	3.94 (3.26; 0.40–14.34)	NS
	Small grocery	3.48 (3.96; 0–13.15)	2.82 (3.22; 0–12.30)	5.54 (5.47; 0–20.74)	NS
	Ethnic market	0.61 (1.13; 0–3.53)	0.83 (1.23; 0–4.20)	2.77 (3.74; 0–14.51)	L vs M, H ($p<0.01$)
	Supermarket	1.19 (1.54; 0–5.00)	1.21 (1.62; 0–6.38)	1.29 (1.67; 0–7.33)	NS

H, high, L, low; M, medium; NS, not significant; SES, socioeconomic status.
*Values shown represent mean (SD; range). Values for proximity are obtained by averaging the closest distances of each type of store for all participants (n = 7595) by neighbourhood SES tertile. Values for store density are obtained by averaging the density of each type of store by neighbourhood SES tertile.
†Neighbourhood SES index derived from census information on median family income, median housing value, percentage of blue collar workers, percentage of unemployed and percentage having less than high-school education. Tertiles were created from survey-specific data, explaining why NS for all tertiles are not equal.
‡Definitions of store types are given in table 2.
§Pairwise comparisons were assessed using Bonferroni's test at a 5% procedure-wise error rate.
¶Neighbourhood buffer includes neighbourhood and a 0.5 mile surrounding radius.
**Using data from Survey 5.

calculated from annual household income and educational attainment, coded as ordinal variables with values ranging from 1 to 4 (income as a percentage of the Federal Poverty Level: 0–200%, 201–400%, 401–600% and ⩾601%, and education as the number of years of formal education: <12 years, 12 years, 13–15 years and ⩾16 years). Smoking was defined by a categorical variable (current smoker, past smoker and never smoked). Physical activity was assessed by asking each participant to rate his/her level of activity (on a scale of 1–7) relative to others of his/her age. Nutrition knowledge was assessed using a dichotomous variable created from responses to 17 questions (the median score, 4 correct out of 17, was used to define the cut point).

Statistical analysis

Means and SDs, and frequency distributions of relevant variables at the individual- and neighbourhood levels were examined, and inter-relationships among the predictor variables were tested for possible collinearities. To test our first hypothesis, we applied analysis of variance and Bonferroni's test at a 5% procedure-wise error rate for pairwise comparisons to data gathered in the final cross-sectional survey. To test our other hypotheses, we built regression models by progressively including relevant variables. We started with a model that included individual-level sociodemographic variables:

$$BMI = f(\text{gender, age, ethnicity, individual SES, city and time of survey}).$$

Table 5 Neighbourhood socioeconomic characteristics and body mass index

	Model 1* (individual sociodemographic factors)		Model 2* (individual sociodemographic and behavioural factors)		Model 3* (individual sociodemographic and behavioural factors, and neighbourhood SES)	
	Regression coefficient (SE)	p Value	Regression coefficient (SE)	p Value	Regression coefficient (SE)	p Value
Individual factors						
Age (year)†	0.063 (0.004)	<0.001	0.061 (0.004)	<0.001	0.061 (0.004)	<0.001
Individual SES†,‡	−0.566 (0.069)	<0.001	−0.589 (0.069)	<0.001	−0.532 (0.072)	<0.001
Hispanic ethnicity	1.619 (0.188)	<0.001	1.533 (0.188)	<0.001	1.393 (0.192)	<0.001
Gender (men vs women)	1.321 (0.109)	<0.001	1.599 (0.111)	<0.001	1.596 (0.110)	<0.001
Smoking§	—	—				
Current			−1.022 (0.133)	<0.001	−1.022 (0.133)	<0.001
Past			−0.061 (0.130)	NS	−0.070 (0.130)	NS
Physical activity¶	—	—	−0.570 (0.034)	<0.001	−0.571 (0.034)	<0.001
Nutrition knowledge**	—	—	−0.238 (0.133)	<0.05	−0.233 (0.113)	<0.05
Neighbourhood SES††						
Low tertile	—	—	—	—	0.647 (0.196)	<0.01
Middle tertile	—	—	—	—	0.0171 (0.139)	NS

NS, not significant; SES, socioeconomic status.
*Survey year and city were also included in these regressions.
†Centred around the mean.
‡Individual SES was a composite variable derived from annual household income and educational attainment.
§Smoking was defined by a categorical variable (current smoker, past smoker, never smoker).
¶Physical activity was assessed by asking participants to rate their level of physical activity relative to others of their age on a scale of 1–7 (higher scores indicate higher levels of activity).
**A dichotomous variable derived from 17 questions was developed to assess nutrition knowledge. The median score, 4/17, was the cut-off point used to create this dichotomous variable.
††Defined by the neighbourhood SES index, which was derived from census information on median family income, median housing value, percentage of blue collar workers, percentage of unemployed and percentage having less than high-school education, and categorised into survey-specific tertiles, compared with high tertile.

Table 6 Effects of proximity† to fast food restaurants and various types of food stores‡,§ on body mass index as an outcome variable, independent of individual-level factors and neighbourhood socioeconomic characteristics

	Regression coefficient (SE) with BMI (kg/m^2) as the outcome variable†				
Independent variables	**Fast food restaurant**	**Convenience store**	**Small grocery store**	**Ethnic market**	**Supermarket**
Individual factors					
Age (year)	0.061 (0.004)****	0.060 (0.004)****	0.061 (0.004)****	0.060 (0.004)****	0.061 (0.004)****
Hispanic ethnicity	1.393 (0.192)****	1.344 (0.179)****	1.395 (0.192)****	1.380 (0.192)****	1.386 (0.192)****
Individual SES¶	−0.532 (0.072)****	−0.538 (0.072)****	−0.536 (0.072)****	−0.529 (0.072)****	−0.527 (0.072)****
Smoking**					
Current	−1.024 (0.133)****	−1.022 (0.133)****	−1.023 (0.133)****	−1.025 (0.133)****	−1.019 (0.133)****
Past	NS	NS	NS	NS	NS
Physical activity††	−0.571 (0.034)****	−0.569 (0.034)****	−0.569 (0.033)****	−0.571 (0.034)****	−0.571 (0.034)****
Nutrition knowledge‡‡	−0.233 (0.113)*	−0.234 (0.113)*	−0.232 (0.113)*	−0.226 (0.113)**	−0.230 (0.113)*
Neighbourhood SES§§					
Low tertile	0.649 (0.197)**	0.684 (0.197)**	0.706 (0.204)**	0.639 (0.196)*	0.621 (0.196)*
Middle tertile	NS	NS	NS	NS	NS
Geographic accessibility to store					
Proximity†,¶¶ (miles)					
Men	NS	NS	NS	NS	NS
Women	NS	NS	NS	−0.157 (0.079)*	−0.300 (0.131)*

BMI, body mass index; NS, not significant; SES, socioeconomic status.
*p<0.05; **p<0.01; ***p<0.001; ****p<0.0001.
†The closest distance to a fast food restaurant or a type of food store from a participant's residence.
‡The table shows regression coefficient (SE) derived from multilevel modelling procedures constructed for each store type with BMI as the outcome variable; city and survey year were also included in the regression equations.
§Definitions of store types (table 2).
¶A composite variable derived from annual household income and educational attainment.
**Smoking was defined by a categorical variable (current smoker, past smoker, never smoker).
††Physical activity was assessed by asking participants to rate their level of physical activity relative to others of their age on a scale of 1–7 (higher scores indicate higher levels of activity).
‡‡A dichotomous variable derived from 17 questions was developed to assess nutrition knowledge. The median score, 4/17, was the cut-off point used to create this dichotomous variable.
§§Neighbourhood SES index was derived from census information on median family income, median housing value, percentage of blue collar workers, percentage of unemployed and percentage having less than high-school education and categorised into survey-specific tertiles compared with high tertile.
¶¶Interactions between sex and food store characteristics of the neighbourhood were observed; hence, the regression coefficients are presented separately for men and women.

Individual-level behavioural factors—namely nutrition knowledge, smoking and physical activity—were then added to the regression equation, followed in turn by neighbourhood SES and food-related neighbourhood physical characteristics. As the cross-sectional nature of the data did not allow us to determine whether the individual-level variables were intervening or confounding, these individual-level factors were left in the final regression.

Because the study involved individuals nested within neighbourhoods, we used multilevel modelling procedures, which allow for the inclusion of both individual and environmental variables to investigate associations with individual-level outcomes.[33 34] To properly apply multilevel modelling procedures, we centred individual SES around a grand mean to remove potential correlations between individual SES and neighbourhood SES. The SAS procedure PROC MIXED was used to conduct iterative maximum likelihood estimation regression analyses. The final model estimated fixed effect coefficients for individual-level and neighbourhood-level variables while adjusting for random intercepts between neighbourhoods:

$$BMI_{ij} = \beta_{n1}(N_1)_j + \beta_{n2}(N_2)_j + \ldots\ldots\ldots \beta_{nk}(N_k)_j + \beta_{i1}(I_1)_{ij} + \beta_{i2}(I_2)_{ij} + \ldots\ldots \beta_{il}(I_l)_{ij} + \beta_{0j}$$

(k Neighbourhood variables; l Individual variables)

RESULTS

Summary measures of participant characteristics are shown by neighbourhood SES in table 3. In table 4, we note that proximity to various types of food stores varied by neighbourhood SES. Residents of low socioeconomic neighbourhoods lived closest to small grocery stores and convenience stores, while residents of middle socioeconomic neighbourhoods lived closest to fast food restaurants, ethnic markets and supermarkets, compared with residents of other neighbourhoods. Density of all store types, except ethnic markets, varied in a pattern that was somewhat consistent with that observed for the proximity measure; however, few of the differences were statistically significant.

In table 5, we show associations of neighbourhood socioeconomic characteristics with BMI. Neighbourhood SES was significantly associated with BMI (model 3); participants living in low socioeconomic neighbourhoods had an adjusted mean BMI that was about 0.6 kg/m^2 higher than that of participants living in high socioeconomic neighbourhoods ($p<0.01$).

In tables 6 and 7, we show that a few food-related aspects of the physical environment are associated with BMI, independent of neighbourhood SES and individual-level factors, but only among women: closer proximity to ethnic markets and supermarkets, and higher density of small grocery stores are associated with higher BMI. We found no evidence of interaction effects between neighbourhood socioeconomic and physical characteristics, after controlling for individual-level sociodemographic and behavioural factors. All individual-level factors examined were associated with BMI.

DISCUSSION

Neighbourhood food-related physical characteristics may influence food choices, and hence obesity risk. Yet, it can be argued that higher SES individuals are more likely to own cars and are hence less dependent on neighbourhood stores for food, whereas the reverse is true for individuals with lower SES. (According to the 1990 US census, nearly 30% of adults from

Table 7 Effects of density† of fast food restaurant and various types of food stores‡,§ on body mass index as an outcome variable, independent of individual-level factors and neighbourhood socioeconomic characteristics

	Regression coefficient (SE) with BMI (kg/m^2) as the outcome variable				
Independent variables	**Fast food restaurant**	**Convenience store**	**Small grocery store**	**Ethnic market**	**Supermarket**
Individual factors					
Age (year)	0.061 (0.004)****	0.061 (0.004)****	0.061 (0.004)****	0.061 (0.004)****	0.061 (0.004)****
Hispanic ethnicity	1.386 (0.192)****	1.393 (0.192)****	1.377 (0.192)****	1.386 (0.192)****	1.388 (0.192)****
Individual SES¶	−0.530 (0.072)****	−0.531 (0.072)****	−0.528 (0.072)****	−0.530 (0.072)****	−0.531 (0.072)****
Smoking**					
Current	−1.022 (0.133)****	−1.021 (0.133)****	−1.015 (0.133)****	−1.022 (0.133)****	−1.017 (0.133)****
Past	NS	NS	NS	NS	NS
Physical activity††	0.569 (0.034)****	−0.571 (0.034)****	−0.569 (0.034)****	−0.569 (0.034)****	−0.571 (0.034)****
Nutrition knowledge‡‡	0.231 (0.113)*	−0.230 (0.113)*	−0.233 (0.113)*	−0.231 (0.113)*	−0.232 (0.113)*
Neighbourhood SES§§					
Low tertile	0.631 (0.200)*	0.624 (0.198)*	0.574 (0.206)*	0.631 (0.200)*	0.619 (0.199)*
Middle tertile	NS	NS	NS	NS	NS
Geographic accessibility to store					
Store density†, ¶¶					
Men	NS	NS	NS	NS	NS
Women	NS	NS	0.053 (0.023)*	NS	NS

BMI, body mass index; NS, not significant; SES, socioeconomic status.
*p<0.05; **p<0.01; ***p<0.001; ****p<0.0001
†Store density was estimated by dividing the number of stores in an area by the number of stores located in an area comprising the neighbourhood and a 0.5 mile buffer zone (expressed as number of stores per square mile).
‡The table shows regression coefficient (SE) derived from multilevel modelling procedures constructed for each store type with BMI as the outcome variable; city and survey year were also included in the regression equations.
§Definitions of store types (table 2).
¶A composite variable derived from annual household income and educational attainment.
**Smoking was defined by a categorical variable (current smoker, past smoker, never smoker).
††Physical activity was assessed by asking participants to rate their level of physical activity relative to others of their age on a scale of 1–7 (higher scores indicate higher levels of activity).
‡‡A dichotomous variable derived from 17 questions was developed to assess nutrition knowledge. The median score, 4/17, was the cut-off point used to create this dichotomous variable.
§§Neighbourhood SES index was derived from census information on median family income, median housing value, percentage of blue collar workers, percentage of unemployed and percentage having less than high-school education and categorised into survey-specific tertiles, compared with high tertile.
¶¶Interactions between sex and food store characteristics of the neighbourhood were observed; therefore, the regression coefficients are presented separately for men and women. Interactions between neighbourhood SES and store density were not observed for any store type.

poor households did not own a car compared with 10% of the overall population.)[35] In our study, we observed that proximity to various types of food stores was associated with neighbourhood SES. Residents of low socioeconomic neighbourhoods lived closest to small grocery stores and convenience stores, and residents of middle socioeconomic neighbourhoods lived closest to supermarkets and fast food restaurants, as well as ethnic markets, compared with residents of other neighbourhoods. Others have reported that there are relatively more fast food restaurants, small grocery stores and convenience stores in poor neighbourhoods.[16 18 36 37] In our study, differences in store density by neighbourhood SES were significant only for ethnic markets—the density of ethnic markets was highest in low socioeconomic neighbourhoods. As we also noted that residents of middle socioeconomic neighbourhoods lived closest to ethnic markets, we speculate that ethnic markets may be located in areas straddling low and middle socioeconomic neighbourhoods, near to where ethnic minority populations live.

In examining the contributions of neighbourhood social characteristics to BMI, we found, as reported by others,[5–9] higher BMI among residents of low socioeconomic neighbourhoods after adjusting for individual-level factors. Since individual-level behavioural factors may be intervening rather than confounding variables, the magnitude of the neighbourhood socioeconomic effect may actually be greater than that reported in this study.

Our findings regarding associations between neighbourhood physical characteristics and BMI varied depending on the measure (proximity or density) used. We hypothesised that living close to ethnic markets, small grocery stores and convenience stores would be associated with higher BMI. We found such an association only with ethnic markets, and only among women. Based on work by others,[12 14 15] we had further hypothesised that living close to supermarkets would be associated with lower BMI. Instead, we found the opposite. Given the wide availability of heavily marketed high-fat and high-sugar processed foods,[38] it could be inferred that living close to retail food stores of any kind, including supermarkets, implies greater exposure to these foods, and that nutrition knowledge, while not sufficient to initiate behavioural change, is important for helping individuals make healthy food choices. Indeed, we observed an association between increased nutrition knowledge and lower BMI. In our examination of the relationships between store density and BMI, we found that only density of small grocery stores was associated with BMI in women. We conclude that living in neighbourhoods with a higher density of small grocery stores is associated with increased overweight risk in women.

The gender differences in the associations between neighbourhood physical characteristics and BMI parallel the observations of researchers in the UK[22]; several explanations are plausible. Women may depend more on neighbourhood goods, services and resources than men do, and hence be exposed to the effects of the neighbourhood to a greater extent.[22] Also, women may perceive the neighbourhood environment differently from men[39]; perceptions of neighbourhood environment have been observed to be associated with health.[40]

This study has several limitations. First, owing to the historical nature of the food store data collected, we were unable to verify that the food stores were accurately classified—for example, ethnic stores may include stores that sell mostly convenience foods and those that sell fruits and vegetables. Second, over the course of the SHDPP study, it is likely that the

Policy implications

- In the US, local efforts are being made to develop environment-based programmes that aim to increase access to fresh fruits and vegetables, especially in low-income neighbourhoods.
- Our findings suggest that changing behaviour may involve more than just removing environmental barriers to behavioural change. While education-based intervention efforts have mostly proven ineffective in changing food behaviour,[28 44] education may continue to play an important role in the development of environment-based interventions.
- Our findings also suggest that women may be more sensitive to the effects of the neighbourhood environment; it may be worthwhile to explore the effectiveness of interventions that incorporate environmental approaches and educational strategies tailored to women, who often influence food consumption of the family.

What this paper adds

- Residents of low socioeconomic neighbourhoods have increased obesity risk.
- In the US, there is a higher density of small grocery and convenience stores in low socioeconomic neighbourhoods. As these stores seldom carry fresh and healthy foods, the assumption is that living close to these stores increases obesity risk, and, conversely, living close to supermarkets, which invariably carry fresh produce and healthy foods, lowers obesity risk.
- Our findings suggest that living in neighbourhoods with a high density of small grocery stores is associated with increased BMI. However, living close to supermarkets is not associated with a lower risk of obesity.
- We conclude that living in an environment where healthy food is not readily available is associated with increased obesity risk. The mechanisms by which the food-related characteristics of the neighbourhood environment influence obesity risk should be further examined and elucidated.

mix of foods offered by the different types of food stores changed. Between 1972 and 1992, processed food sales increased from $242 to $342 billion.[41] To address this limitation, survey year was included as a term in the statistical models. Third, despite the large sample size, our findings relate to small to mid-sized cities in agricultural regions in ethnically diverse California. In less ethnically diverse regions, ethnic markets may play a lesser role. In large cities, where different socioeconomic groups may live closer to each other, factors other than proximity to various types of retail food stores may influence food purchasing and consumption patterns. Fourth, the cross-sectional nature of our data precludes a conclusion regarding causal relationships. Further, other factors that may influence where people shop for food—such as transportation—need to be examined.[42] Finally, several multilevel regression models were analysed, but adjustment for multiple comparisons was not made. Rothman[43] has argued that adjustments for multiple comparisons are not always necessary for large bodies of data involving actual observations.

To our knowledge, this is one of the first studies in the US to simultaneously document the contributions of both social and physical aspects of the neighbourhood environment to obesity risk. Although these two aspects of the neighbourhood environment are inter-related, they seem to show independent associations with BMI.

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APHORISM OF THE MONTH

A fish is the last one to see the water

The rediscovery of the obvious is a central part of public health. Poverty, squalor, tobacco, alcohol, inequality, violence, greed – these things surround us and contribute in great part to the inequalities in health with which we are all too familiar. Vested interests spend vast amounts of resources diverting us from focussing on the water that surrounds us.

Lowell Levin and JRA