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Understanding neighbourhood retail food-related environmental mechanisms influencing BMI in the Caribbean: a multilevel analysis from the Jamaica Health and Lifestyle Survey

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ABSTRACT

Objective To derive estimates of the associations between measures of the retail food environments and mean Body Mass Index (BMI) in Jamaica, a middle-income country with increasing prevalence of obesity.

Design Cross-sectional study

Setting Data from the Jamaica Health and Lifestyle Survey 2008 (JHLS II) a nationally representative population-based survey that recruited persons at their homes over a four-month period from all 14 parishes and 113 neighbourhoods defined as Enumeration Districts (EDs).

Participants A subsample of 2529 participants aged 18-74 years from the JHLS II who completed interviewer administered surveys, provided anthropometric measurements and whose addresses were geocoded.

Primary outcome measure Mean BMI, calculated as weight divided by height squared (kg/m^2)

Results There was significant clustering across neighbourhoods for mean BMI (Intraclass correlation coefficients = 4.16%). Fully adjusted models revealed increased mean BMI among women, with further distance away from supermarkets (β= 0.12; 95% CI = 8.20×10^{-3}, 0.24; *P*=0.036) and the absence of supermarkets within a 1 km buffer zone (β= 1.36; 95% CI 0.20, 2.52; *P*=0.022). A 10% increase in the distance from a supermarket was associated with a 1.7 kg/m^2 increase in mean BMI (95% CI 0.03, 0.32; *P*=0.020) in the middle class. No associations were detected with Fast Food Outlets or interaction by urbanicity.

Conclusions Increased mean BMI in Jamaicans may be partially explained by the presence of supermarkets and markets and differ by sex and social class. National efforts to curtail obesity in middle-income countries should consider interventions focused at the neighbourhood-level that not only target the location and density of supermarkets and markets but also consider sex and social class-specific factors that maybe influencing the associations.

Strengths and limitations of this study

- This study is the first in a Caribbean island to demonstrate the influence of the food retail environment on Body Mass Index (BMI) using geocoded data and multilevel modelling.
- This study provided a large sample size representative of Jamaicans 15 to 74 years.
- Individual geocoded addresses from a nationally representative survey were linked with specific objective GIS-based retail food environmental measures.
- Enumeration Districts (EDs) were used to define Jamaican neighbourhoods which are quite heterogeneous geographically in size, composition and context, and may not fully represent exposure to the food obesogenic environments
- The reliability and validity of the area-level environmental variables used were not ascertained for the local context and therefore they may not be the most effective in explaining any variance in BMI.

INTRODUCTION

Obesity has been increasing in the Caribbean [1,2] and in Jamaica is now a major public health problem [3]. Over the past five decades a rapid increase in obesity has been reported with women having consistently higher rates than men [4-6]. The Jamaica Health and Lifestyle Survey 2008 (JHLS II) [3], has documented increased prevalence over the earlier 2001 survey (JHLS I) [7], in obesity as well as the comorbid Chronic Non-communicable Disease (CNCD) conditions of diabetes mellitus (DM) and hypertension (HTN). Approximately 99 % of Jamaicans consumed below the daily recommended portions of fruits and vegetables and 30% of obese persons preferred fried protein in their diets [3].

The presence of supermarkets/markets has been thought to indicate better access to and intake of healthier foods, given its association with higher intake of fruit and vegetables [8] Toronto, those that lived in close proximity to a supermarket had decreased odds of being overweight or obese [12].

The presence of supermarkets has been shown to be inversely associated with neighbourhood SES in the US, whereby data have revealed greater poverty being associated with a decreased presence [13, 14]. With regards to sex differences, research by Wang et al [15] among 25 – 74 years old adults in California revealed that closer proximity to a supermarket and higher neighborhood density of small grocery stores were associated with higher BMI among women.

Fast food outlets (FFOs) have increased in many countries and thought to be associated with the global rise in obesity. Whilst there is no universally accepted agreement on what the definition of fast food is, most research include foods sold that are low cost, energy dense with high fat and/or sugar content and low nutrient content. Studies have found that frequent consumption of fast foods in areas with a high density of FFOs has been found to increase body weight [16,17] and a positive association of proximity to FFOs with measures of adiposity [18, 19].

The interaction between SES and the density of FFOs has also been investigated. In Australia it was found that persons with poor SES (based on median weekly income) had 2.5 times exposure to FFOs than persons in the wealthiest SES category [20]. Similar associations have been reported in the US [21, 22] and Great Britain [23]. In Europe, eating at restaurants (which included eating at FFOs) was positively associated with BMI among men [24]. On the other hand, in the US eating at FFOs was positively associated cross-sectionally with BMI among low- income women [25].

The limited body of research on environment influences on the Chronic Non-communicable Diseases (CNCDs) in Jamaica and the developing world, as well as the apparent lack of lifestyle changes despite health promotion programs targeting individual-level prevention, suggests that barriers to these changes may yet be unrecognized and accounted for in the traditional modelling of risk factors. The studies on obesity previously referenced [3,4,6,7] have only assessed geographical variations according to the dichotomized classification of urban/rural area of residence. Review of the literature has not revealed any local studies assessing geographical variations in obesity or other measures of adiposity such as mean BMI, using multilevel modelling (MLM) statistical techniques or Geographic Information Systems (GIS) to determine whether there are associations with the built environment in a middle-income country (MIC) context.

The aim of this study was to provide a unique and important opportunity to address these gaps in understanding the retail food-related environmental mechanisms influencing mean BMI in Jamaica, a small island MIC. Our objective was to derive estimates of the associations between measures of the retail food environments and mean BMI. We hypothesized that: a) there was variability in the mean BMI across Jamaican neighbourhoods, b) the pathway between greater presence/closer proximity to supermarkets/markets, mediated through healthy diet, would lead to lower mean BMI and would be stronger for those of higher SES, c) the pathway between greater presence/closer proximity to fast food outlets, mediated through unhealthy diet would lead to greater mean BMI and would be stronger for those of low SES and residing in urban areas, and d) there would be sex differences in these associations.

MATERIALS AND METHODS

Study design and sample

The JHLS II was a cross-sectional, interviewer-administered, island wide survey over a 4-month period between 2007 and 2008. The sample of 2848 15-74-year-olds represented approximately 70% of the predominantly (94%) Black Jamaican population [3]. A stratified random sample of clusters known as Enumeration Districts (EDs) was selected using a probability proportionate to the size of population of the parishes in the island in order to yield a nationally representative sample. Trained interviewers administered a structured questionnaire on diseases and lifestyle behaviours and performed anthropometry. Further details on the sampling technique are provided elsewhere [3].

A total of 2529 (or 89% of) participants from the JHLS II dataset were geocoded out of the original 2848 participants. Kreft [26] suggests a '30/30 rule' so that researchers should strive for a sample of at least 30 groups with 30 individuals per group. For this study, each of the 101 EDs (sampling units) had an average of 28 individuals, providing sufficient power for the proposed secondary multilevel analyses.

Patient and public involvement

No patients were involved in the study. The study participants were community residents and were not involved in the design, recruitment or the conduct of the study. The study findings will be disseminated to the Ministry of Health, Jamaica and general public, including the study participants.

Measures

Individual-level measures

The primary outcome was mean BMI, calculated as weight divided by height squared (kg/m^2). Weight was measured using calibrated electronic scales (Tanita® models HD 314 or 2204) to 0.1 kg precision and height measured using a portable stadiometer (Seca®) to 0.1 cm precision.

Individual-data included age, sex, educational attainment, occupation, urbanicity, diet, and perceived community safety. Named jobs were first categorised using the Jamaica Standardised Occupational Classification codes for 1991 [27] and collapsed into four groups: highly skilled/professional, skilled, unskilled and unemployed/other. Diet was examined as frequency of fruit and vegetable consumption, where an unhealthy diet (poor fruit and vegetable intake) was defined as consumption of < 2 servings of fruit per day or < 3 servings of vegetables per day. Perception of community safety was determined by asking each participant how safe he or she felt to walk in the community.

Household measures

The number of possessions owned (including but not exclusive to owning a radio, telephone, refrigerator, television, computer or car ownership) was used as a proxy for SES [3] and classification based on the following tertiles: 1^{st} tertile = lower class = ≤ 6 items, 2^{nd} tertile = middle class = 7-9 items, 3^{rd} tertile= upper class = 10-16 items.

Environment-level measures

Each observation was linked, through a geocoded residential address, to neighbourhood level proximity and density measures for supermarkets, markets and FFOs. Neighbourhood was defined as the Enumeration District (ED). The final choices of environment-level measures for investigation were based on a combination of previously derived GIS-based measures [28, 29], documented associations seen with the outcome of interest [28, 30] and data availability.

The locations of supermarkets/markets (*Figure 1, Panel A)* and FFOs (*Figure 1, Panel B)* were identified from Mona Geoinformatics Institute's (MonaGIS) proprietary JAMNAV database. The proximities and densities of supermarkets/markets and FFOs were estimated using application of Spatial Analyst tool in ArcGIS to data from MonaGIS proprietary JAMNAV database. Proximity of supermarkets and markets, combined to represent good sources of fresh fruit and vegetable, was determined as the straight-line distance (km) from each geocoded address to the closest supermarket or market. Two density variables created were supermarkets/markets per km^2 based which was converted to the number of supermarkets/markets per 1000 persons in the corresponding ED according to the 2011 census from the Statistical Institute of Jamaica (STATIN) [31].

FFOs were defined as places where high-caloric food could be obtained relatively quickly and excluded traditional cook shops, snack shops and sit-down restaurants. Proximity and density measures were created in a similar way as done for supermarkets/markets.

Zero-inflated variables

The absence of the environmental-level measure based on the participant's geocoded address was indicated by a large proportion of zero values for most density measures as shown in the Supplementary Table. New indicator variables (dummy variables) were subsequently created and the specific dummy variable included in regression models alongside the original quantitative forms of the respective retail food environmental-level explanatory variable. These dummy variables are also referenced as the zero-inflated form of the density measures.

Missing variables

Addresses for 11% of the JHLS II study participants could not be geocoded and contributed to missing data in subsequent analyses. The age/sex population of the dataset used for this JHLS II secondary analysis subsample was compared with that for the non-geocoded data and no key deviations were observed.

Geocoded and non-geocoded (missing) participants were compared with respect to age, sex, SES categories and the key outcome variables of mean BMI, mean WC and obesity, using mixed effect models, regression models accounting for survey design and regression models that ignored survey design. No associations were detected between the geocoded status (present or missing) and these other variables. This data analysis was done only on geocoded data, on the assumption that these participants were representative of the target population.

Statistical Analyses

A complex database was created that combined individual-level JHLS II data with contextual environment-level data.

Descriptive data analysis estimated sex-specific and total survey-weighted means, proportions and 95% confidence intervals (CIs) for the outcome, explanatory and confounding variables as well as age-adjusted mean BMI and prevalence of poor fruit and vegetable intake, a key cardiovascular disease (CVD) risk factor. Age-adjustment utilized direct standardization across the strata identified as 10-year age bands with weights being survey-weighted population proportions of the respective 10-year age groups, as estimated using the JHLS II data.

The adjusted Wald test and the Pearson's chi-squared test corrected for survey design were used to determine whether, respectively, the age-adjusted and unadjusted estimates differed with respect to sex.

Intraclass correlation coefficients (ICCs) from hierarchical models quantified the proportion of variation in mean BMI due to clustering at the ED level. An ICC ≥2% suggests a potential clustering effect worth examining in a multilevel framework [32].

To determine and account for the effect of clustering at the neighbourhood level, subsequent analyses used multilevel models based on EDs nested within parish and examined the stratum-specific estimates of the effect of the environment variables on mean BMI with and without adjustment for covariates. Strata were defined using the urbanicity, sex and SES variables and stratum-specific multilevel models estimated if terms for interaction between the environment and strata variables were statistically significant. The Akaike's Information Criterion (AIC) statistic was used to determine the final best models. Collinearity assessed using Goodman and Kruskal's gamma coefficient γ [33], was the basis for selection of models covariates. To assess the chance of false positive errors, *P*-values from these models were compared with the Bonferroni corrected significance level.

All analyses were conducted using STATA, versions 12 and 14 (StataCorp LP, College Station, Texas).

Ethical Approval

Ethical approval was received from the University of the West Indies/University Hospital of the West Indies Ethics Research Committee.

RESULTS

Sample characteristics

The weighted total and sex-specific summary statistics are shown in Table 1. Women had higher mean BMI than men and higher proportions in the highly skilled/professional, unskilled and unemployed categories and in both 1st and 2nd SES tertiles based on no. of possessions owned ($P < 0.001$). However, a greater proportion of men perceived their communities as unsafe (males = 86.29 %; 95% CI: 82.64, 89.94 vs. females = 80.38 %; 95% CI: 75.63, 85.13; $P < 0.012$). There were no sex differences in urbanicity, those who had not completed high school and poor fruit and vegetable intake.

There was clustering in mean BMI across neighbourhoods in Jamaica, with an ICC of 4.16%, the proportion of the variance in mean BMI explainable at the neighbourhood level. No associations were found between the retail food environment variables and mean BMI in unadjusted regression models. There was also no effect modification by urbanicity.

Sex-specific regression models

There was interaction between sex and the following variables in their relationship with mean BMI: supermarkets proximity (*P* =0.023), absence of supermarkets within a 1 km buffer zone (*P* =0.008) and fast food outlets proximity (*P* =0.031). Figure 2 reveals that for women, in fully-adjusted models, a 10% increase in proximity (km) to supermarkets was associated with a 1.20 kg/m^2 increase in mean BMI (95% CI 8.20 $x10^{-3}$, 0.24; *P*=0.036); the absence of supermarkets within a 1 km buffer zone was associated with a 1.36 kg/m^2 increase in mean BMI (95% CI 0.20, 2.52; *P*=0.022).

SES- tertile-specific regression models

There was interaction between SES of a participant and a few retail food environment variables in their relationship with mean BMI. These included supermarkets proximity (*P*=0.015), absence of supermarkets/1000 people/ ED (*P*=0.033) and fast food outlets proximity (*P* =0.045). Figure 3 reveals that a 10% increase in the distance from a supermarket was consistently associated with an increase in mean BMI for all models for persons within the middle class, with a 1.7 kg/m^2 increase in mean BMI (95% CI 0.03, 0.32; *P*=0.020) in the final model. Among persons in the upper class, the absence of supermarkets/ 1000 people/ ED was associated with a 2.00 kg/m^2 increase in mean BMI (95% CI 0.08, 3.92; *P*=0.041) only in age-adjusted models. Proximity to FFOs was not associated with mean BMI in any of the SES classes.

DISCUSSION

This study is the first to examine the impact of the retail food-related environment on obesity-related outcomes in a small Caribbean island. Our finding of ≥ 2.0% of the variance in mean BMI being explainable by environmental influences outside of the individual or at the neighbourhood level is like that reported by Harrington et al for Canada [34] and by Masood and Reidpath [35] for many of the countries that participated in the 2003 World Health Survey. We also found that further distance away from supermarkets and markets, and their absence within a 1 km buffer zone from residences, were associated with increased mean BMI in women; and further proximity to supermarkets associated with mean BMI for the middle class. There was no association with proximity to or density of FFOs, nor urban-rural differences.

Table 1. Total and sex-specific weighted sample characteristics (95% CI) for Jamaicans (JHLS II, 2008)

Variable	Men (n=796)	Women (n=1731)	Total (n=2527)	*P* value
Individual -level measures				
Mean Age in years (%)	37.00 (36.33, 37.13)	36.73 (36.64, 37.36)	36.87 (36.54, 37.20)	0.158
Urban Residence (%)	53.53 (43.84,62.28)	53.17 (45.11,61.74)	53.35 (44.87,61.64)	0.890
< High School Education (%)	31.75 (27.17, 36.33)	29.13 (25.69, 32.56)	30.43 (26.96, 33.90)	0.208
Occupation (%)				<0.0001
Highly skilled/Professional	38.87 (34.41, 43.34)	52.54 (49.02, 56.06)	45.73 (42.73, 48.72)	
Skilled	40.33 (35.19, 45.48)	8.21 (6.19, 10.23)	24.23 (21.29, 27.16)	
Unskilled	9.75 (6.66, 12.84)	18.13 (15.20, 21.06)	13.95 (11.33, 16.57)	
Unemployed/Other	11.05 (8.22, 13.88)	21.11 (18.17, 24.06)	16.10 (14.12, 18.07)	
Possessions owned (%)				<0.001
Lower class ≤ 6 items	34.09 (29.03, 39.14)	41.51 (37.45, 45.57)	37.82 (33.96, 41.68)	
Middle class 7-9 items	29.92 (25.99, 33.85)	31.17, (28.45, 33.89)	30.55 (27.89, 33.20)	
Upper class 10-16 items	36.00 (30.68, 41.31)	27.32 (22.99, 31.65)	31.63 (27.45, 35.82)	
Perception of unsafe community (%)	86.29 (82.64, 89.94)	80.38 (75.63, 85.13)	83.32 (79.77, 86.86)	0.012
Poor fruit & vegetable (%)	99.50 (98.84, 100.00)	99.83 (99.64, 100.00)	99.57 (99.34, 100.00)	0.340
Mean BMI□ (kg/m^2)	24.83(24.28, 25.38)	28.40 (27.90, 28.89)	26.64 (26.21, 27.07)	<0.001
Neighbourhood -level measures† [Mean (95% CI)]				
Supermarkets§ proximity (km)	3.61 (2.69, 4.54)	3.64 (2.78, 4.49)	3.63 (2.77, 4.48)	0.978
Supermarkets§ / km^2	1.60 (0.84, 2.36)	1.57 (0.96, 2.19)	1.59 (0.91, 2.26)	0.895
Supermarkets§ /1000 people/ ED	0.65 (0.27, 1.04)	0.63 (0.20, 1.07)	0.64 (0.26, 1.03)	0.922
FFO proximity (km)	4.56 (3.54, 5.58)	4.68(3.60, 5.76)	4.62 (3.62, 5.62)	0.747
FFO / km^2	0.57 (0.33, 0.81)	0.52 (0.32, 0.72)	0.55 (0.33, 0.76)	0.266
FFO / 1000 people/ ED	0.35 (0.10, 0.60)	0.21 (0.07, 0.35)	0.28 (0.10, 0.46)	0.104

† Age-adjusted

§Includes supermarkets and markets

CI – Confidence Interval; JHLS II, Jamaica Health and Lifestyle Survey II; BMI, Body Mass Index; ED – Enumeration District; FFO - Fast Food Outlets

P values for difference between means (men versus women)

Our study findings corroborate previous research conducted in developed countries that indicate closer proximity to supermarkets/markets [12, 19, 20] and increased density of supermarkets/markets [9-11, 16, 36, 37] are associated with less obesity-related outcomes in adults and children. Of note however, Wang and colleagues found higher neighbourhood density of small grocery stores associated with higher BMI among a sample of US women [15], while our study found increased BMI for women being associated with further distance from supermarkets/markets (inclusive of small grocery stores). Although the geographic variables are somewhat dissimilar (a density versus proximity measure), the difference in direction of the associations raises the question as to whether presence of grocery stores, supermarkets and markets across different geographical contexts, including small island states like Jamaica, each represent the same degree of accessibility, availability and ultimate consumption of healthy foods. For example, we found no urban-rural differences as hypothesized, perhaps due to PAL, diet or some other unknown confounder masking the association. Living a greater distance away from supermarkets/markets was positively associated with mean BMI in the middle class in our study, however many other studies found this association in the lower class [38]. We are unclear as to the reasons for the association observed among the middle-class participants. We surmise this could possibly be due to the influence of diet or lower PAL in this group, the latter perhaps being influenced by car ownership and/or greater use of motorized transport [39]. PAL, diet and motorized transport were not adjusted for in the food environment regression models. These omissions may have suppressed associations.

It is also unclear why associations between FFO proximity and mean BMI were not seen in the SES-specific models. This may be an indication that demonstration of associations may depend on which obesogenic food environment variable or outcome measure of adiposity is chosen for the regression models. For example, Menke et al in analysing the 3rd US National Health and Nutrition Examination Survey conducted, found that waist circumference maintained a stronger association with CVD risk factors than the other measures of adiposity [40]. Further work is needed on assessing the quality and utility of the measures used in this study as well as the development of new ones for the Jamaican and developing world context.

The major strength of this study is that it represents pioneering work in a small island developing country context. We linked individually geocoded addresses from a nationally representative survey, with specific objective GIS-based retail food environmental measures and provided empirical evidence using MLM to explore the association between objective neighbourhood-level retail food environment measures and BMI.

Despite strengths, there are limitations that deserve mention, including the inability to make causal inferences given the cross-sectional design of the JHLS II and our definition of neighbourhood. Using EDs to represent a Jamaican neighbourhood could be deemed inadequate as they i) are quite heterogeneous geographically in size, composition and context, and ii) may not fully represent exposure to the obesogenic environments being investigated. Additionally, although the outcome was objectively assessed, the risk factors included self-reported data on a single individual representing a household, which may introduce information bias. Furthermore, there was temporal mismatch of the data collected from individual JHLS II participants with that for most of the food environment level variables, most of which were collected in and after the year 2010, which was after the MonaGIS's end of data collection for the JHLS II in 2008. This may have biased the results as individual exposures may have varied after the survey period, although food consumption behaviours are believed to be relatively stable over time. Lastly, the reliability and validity of the area-level environmental variables were untested locally and therefore uncertainty remains as to whether they were most effective in explaining any variance in the obesity-related outcomes.

In conclusion, we found that further distance away from supermarkets and markets and their absence within a 1 km buffer zone from residences were associated with increased mean BMI, with important and unexpected sex and social class differences. There has been an increase in the prevalence of obesity in Jamaica (3) despite the implementation of policies and programmes to ameliorate its impact on the continuum towards CNCDs (41). Based on our findings, we recommend that national strategic and operational plans crafted for prevention and control of CNCDs, for which obesity is a key risk factor, should place greater emphasis on policies, programmes and interventions that are focused on the neighborhood-level effects and not only on individual-level determinants. They should also be tailored to address sex and social class differences.

STATEMENTS

Contributors CC-M and KT conceived the study. LG and PL-A geocoded the data. CC-M, NY-C and KT analysed and interpreted the data. RW supervised the research. CC-M wrote the manuscript. PL-A, KT and RW edited the manuscript. All authors provided critical intellectual contributions and read and approved the final manuscript.

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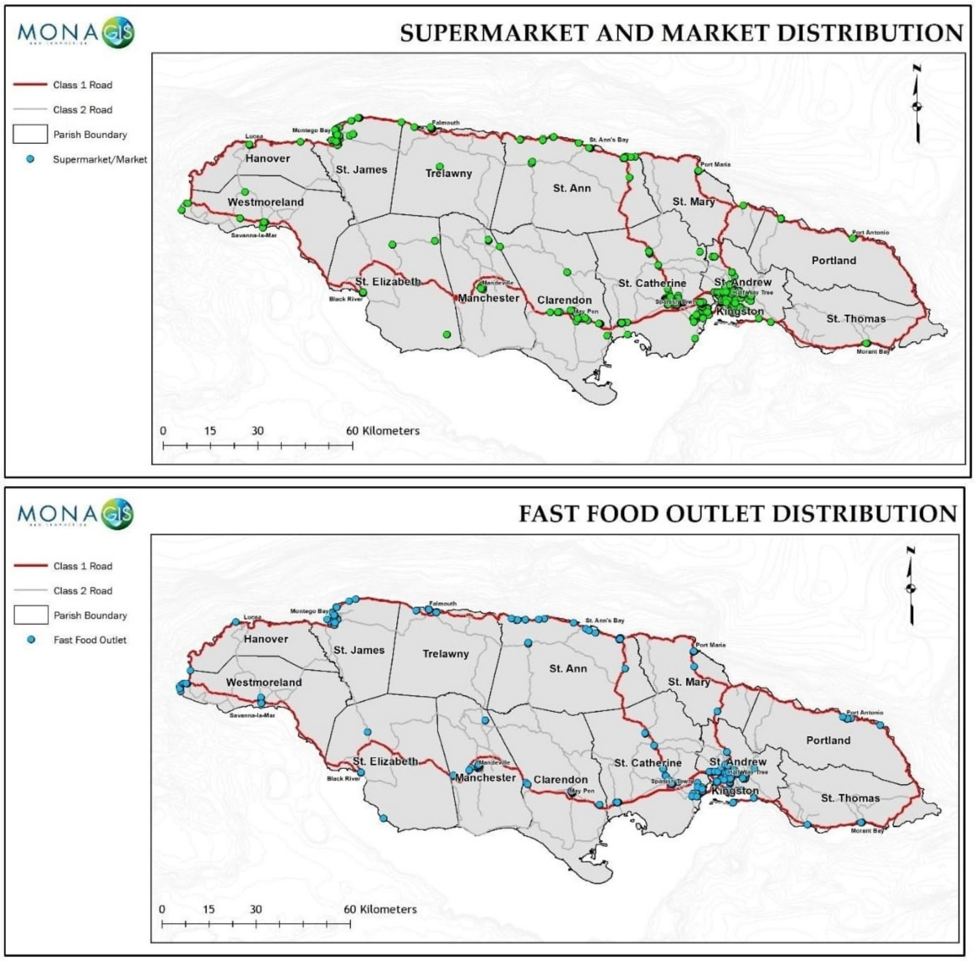
Figure 1. Spatial Distribution of Supermarket/markets (A) and Fast Food Outlets in Jamaica (B)

Figure 2. Sex-specific unadjusted and adjusted β Coefficients for the association of retail food environments with mean Body Mass Index

ǂ Dummy variable for zero inflated predictor
CI – Confidence Interval
Model 1 - unadjusted
Model 2 - age adjusted
Model 3 - adjusted for age and no. of possessions
Model 4 - adjusted for age, no. of possessions, urban, occupation, education, perception of unsafe community
*p < 0.05

Figure 3. SES-specific unadjusted and adjusted β Coefficients for the association of retail food environments with mean Body Mass Index

CI – Confidence Interval; ED – Enumeration District
ǂ Dummy variable for zero inflated predictor
Model 1 - unadjusted
Model 2 - age adjusted
Model 3 - adjusted for age and sex
Model 4 - adjusted for age, sex, urban, occupation, education, perception of unsafe community
*$p < 0.05$, ** $p < 0.01$



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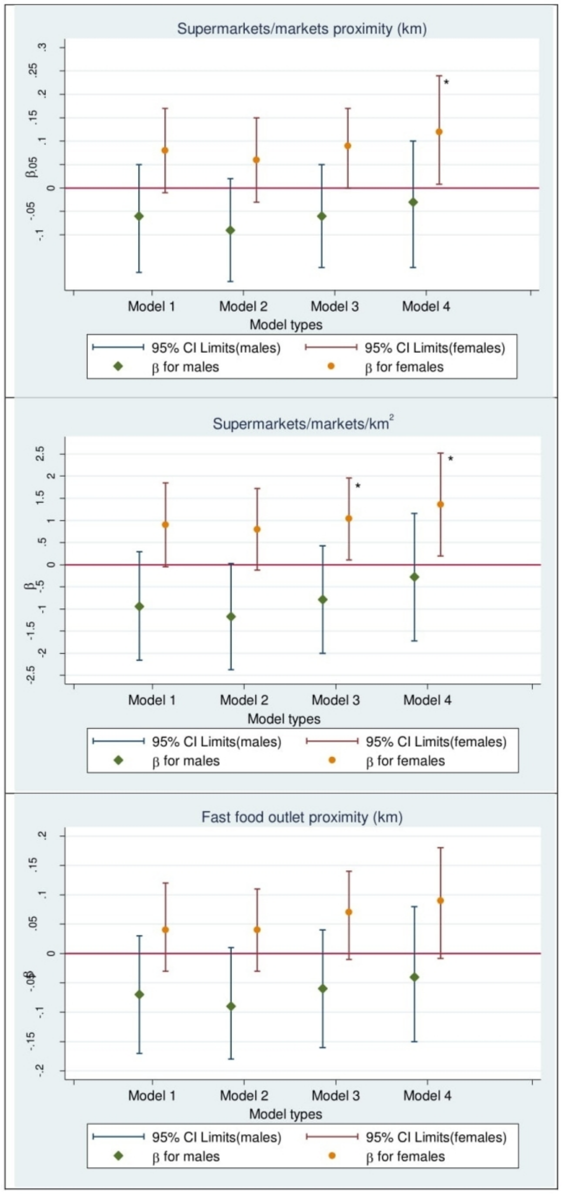

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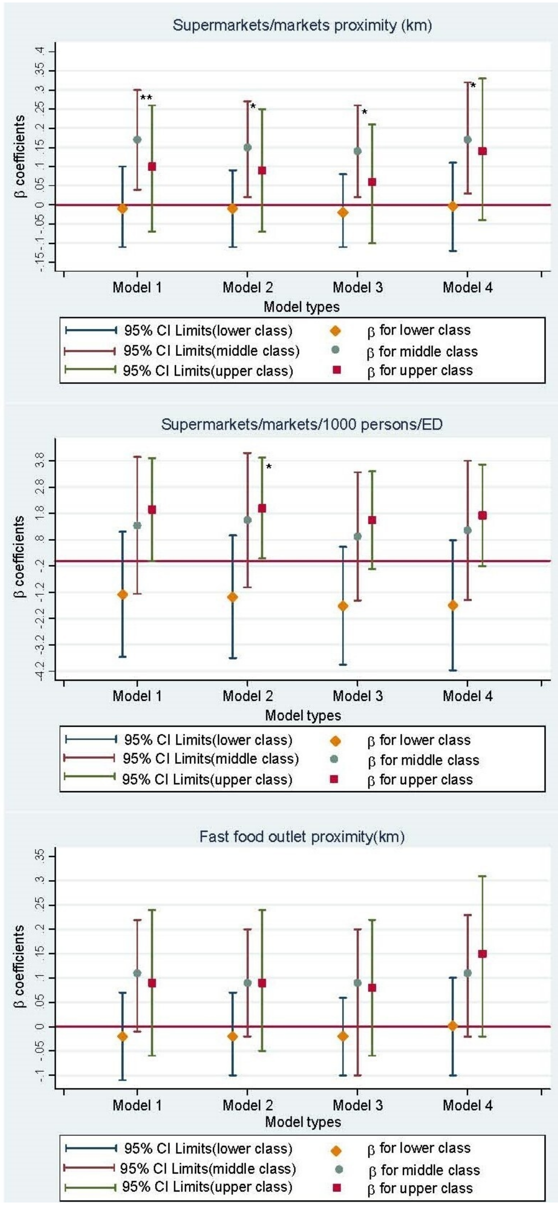

211x441mm (96 x 96 DPI)

Supplementary Table. Proportion of zero-valued observations for geographic variables

Retail Food Environments	Frequency (%) N=2527
Supermarkets/markets proximity (km)	0
Supermarkets/markets / km^2	61.30
Supermarkets/markets /1000 people/ ED	92.13
FFO proximity (km)	0
FFO / km^2	68.22
FFO / 1000 people/ ED	94.46

ED – Enumeration District; FFO - Fast Food Outlets

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **[Within the title page 1 and methods section of the abstract page 2]**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **[See methods and results sections of abstract page 2]**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **[pages 4-5]**
Objectives	3	State specific objectives, including any prespecified hypotheses **[page 5]**
Methods		
Study design	4	Present key elements of study design early in the paper **[page 5-6]**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **[pages 6-8]**
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants **[pages 5- 6]**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. **[pages 6-9]** Give diagnostic criteria, if applicable **[N/A]**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **[pages 6-9]**
Bias	9	Describe any efforts to address potential sources of bias **[pages 5-6, 8-9]**
Study size	10	Explain how the study size was arrived at **[page 5-6]**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **[pages 8-9]**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **[pages 8-9]**
		(*b*) Describe any methods used to examine subgroups and interactions **[page 9]**
		(*c*) Explain how missing data were addressed **[page 8]**
		(*d*) If applicable, describe analytical methods taking account of sampling strategy **[page 9]**
		(*e*) Describe any sensitivity analyses **[N/A]**
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **[N/A]**
		(b) Give reasons for non-participation at each stage **[N/A]**
		(c) Consider use of a flow diagram **[N/A]**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **[page 9; Table 1]**
		(b) Indicate number of participants with missing data for each variable of interest **[N/A]**
Outcome data	15*	Report numbers of outcome events or summary measures **[page 9; Table 1]**

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). **[pages 9-10; Figures 2-3]** Make clear which confounders were adjusted for and why they were included **[page 6, Figures 2-3]**
		(*b*) Report category boundaries when continuous variables were categorized **[page 10, Table 1]**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **[N/A]**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **[pages 9-10]**
Discussion		
Key results	18	Summarise key results with reference to study objectives **[page 10]**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **[page 13]**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **[pages 12-13]**
Generalisability	21	Discuss the generalisability (external validity) of the study results **[page 13]**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **[page 14]**

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Understanding neighbourhood retail food environmental mechanisms influencing BMI in the Caribbean: a multilevel analysis from the Jamaica Health and Lifestyle Survey: a cross-sectional study

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Key words: Body mass index, retail food environment, neighbourhood, geocoding, multilevel modelling, developing country.

ABSTRACT

Objective To derive estimates of the associations between measures of the retail food environments and mean Body Mass Index (BMI) in Jamaica, a middle-income country with increasing prevalence of obesity.

Design Cross-sectional study

Setting Data from the Jamaica Health and Lifestyle Survey 2008 (JHLS II) a nationally representative population-based survey that recruited persons at their homes over a four-month period from all 14 parishes and 113 neighbourhoods defined as Enumeration Districts (EDs).

Participants A subsample of 2529 participants aged 18-74 years from the JHLS II who completed interviewer administered surveys, provided anthropometric measurements and whose addresses were geocoded.

Primary outcome measure Mean BMI, calculated as weight divided by height squared (kg/m^2)

Results There was significant clustering across neighbourhoods for mean BMI (Intraclass correlation coefficients = 4.16%). Fully adjusted models revealed higher mean BMI among women, with further distance away from supermarkets (β= 0.12; 95% CI = 8.20×10^{-3}, 0.24; *P*=0.036) and the absence of supermarkets within a 1 km buffer zone (β= 1.36; 95% CI 0.20, 2.52; *P*=0.022). A 10km increase in the distance from a supermarket was associated with a 1.7 kg/m^2 higher mean BMI (95% CI 0.03, 0.32; *P*=0.020) in the middle class. No associations were detected with Fast Food Outlets or interaction by urbanicity.

Conclusions Higher mean BMI in Jamaicans may be partially explained by the presence of supermarkets and markets and differ by sex and social class. National efforts to curtail obesity in middle-income countries should consider interventions focused at the neighbourhood-level that not only target the location and density of supermarkets and markets but also consider sex and social class-specific factors that maybe influencing the associations.

Strengths and limitations of this study

- This study is the first in a Caribbean island to demonstrate the influence of the retail food environment on Body Mass Index (BMI) using geocoded data and multilevel modelling.
- This study provided a large sample size representative of Jamaicans 15 to 74 years.
- Individual geocoded addresses from a nationally representative survey were linked with specific objective GIS-based retail food environmental measures.
- Enumeration Districts (EDs) were used to define Jamaican neighbourhoods which are quite heterogeneous geographically in size, composition and context, and may not fully represent exposure to the food obesogenic environments
- The reliability and validity of the area-level environmental variables used were not ascertained for the local context and therefore they may not be the most effective in explaining any variance in BMI.

INTRODUCTION

Obesity has been increasing in the Caribbean [1,2] and in Jamaica is now a major public health problem [3]. Over the past five decades a rapid increase in obesity has been reported with women having consistently higher rates than men [4-6]. The Jamaica Health and Lifestyle Survey 2008 (JHLS II) [3], has documented increased prevalence over the earlier 2001 survey (JHLS I) [7], in obesity as well as the comorbid Chronic Non-communicable Disease (NCD) conditions of diabetes mellitus (DM) and hypertension (HTN). Approximately 99 % of Jamaicans consumed below the daily recommended portions of fruits and vegetables and 30% of obese persons preferred fried protein in their diets [3].

The presence of supermarkets/markets has been thought to indicate better access to and intake of healthier foods, given its association with higher intake of fruit and vegetables [8] and inversely associated with obesity [9-11]. For example, among Canadian children residing in Toronto, those that lived in close proximity to a supermarket had decreased odds of being overweight or obese [12].

The presence of supermarkets has been shown to be inversely associated with neighbourhood SES in the US, whereby data have revealed greater poverty being associated with a decreased presence [13, 14]. With regards to sex differences, research by Wang et al [15] among 25 – 74 years old adults in California revealed that closer proximity to a supermarket and higher neighborhood density of small grocery stores were associated with higher BMI among women.

Fast food outlets (FFOs) have increased in many countries and thought to be associated with the global rise in obesity. Whilst there is no universally accepted agreement on what the definition of fast food is, most research include foods sold that are low cost, energy dense with high fat and/or sugar content and low nutrient content. Studies have found that frequent consumption of fast foods in areas with a high density of FFOs has been found to increase body weight [16,17] and a positive association of proximity to FFOs with measures of adiposity [18, 19].

The interaction between SES and the density of FFOs has also been investigated. In Australia it was found that persons with poor SES (based on median weekly income) had 2.5 times exposure to FFOs than persons in the wealthiest SES category [20]. Similar associations have been reported in the US [21, 22] and Great Britain [23]. In Europe, eating at restaurants (which included eating at FFOs) was positively associated with BMI among men [24]. On the other hand, in the US eating at FFOs was positively associated cross-sectionally with BMI among low- income women [25].

The limited body of research on environment influences on the chronic NCDs in Jamaica and the developing world, as well as the apparent lack of lifestyle changes despite health promotion programs targeting individual-level prevention, suggests that barriers to these changes may yet be unrecognized and accounted for in the traditional modelling of risk factors. The studies on obesity previously referenced [3,4,6,7] have only assessed geographical variations according to the dichotomized classification of urban/rural area of residence. Within the Caribbean and Latin American regions, there are a limited number of studies assessing geographical variations in obesity or other measures of adiposity such as mean BMI, using multilevel modelling (MLM) statistical techniques and/or Geographic Information Systems (GIS) to determine whether there are associations with the built environment in a middle-income country (MIC) or small island developing state (SIDS) context [26-28].

The aim of this study was to provide a unique and important opportunity to address these gaps in understanding the retail food environmental mechanisms influencing mean BMI in Jamaica, a small island MIC. Our objective was to derive estimates of the associations between measures of the retail food environments and mean BMI, using a combination of MLM and GIS-based methods for contextualizing the national survey data and calculating objective community exposures.

We hypothesized that: a) there was variability in the mean BMI across Jamaican neighbourhoods, b) the pathway between greater presence/closer proximity to supermarkets/markets, and lower mean BMI would be stronger for those of higher SES, c) the pathway between greater presence/closer proximity to fast food outlets and greater mean BMI would be stronger for those of low SES and residing in urban areas, and d) there would be sex differences in these associations.

MATERIALS AND METHODS

Study design and sample

The JHLS II was a cross-sectional, interviewer-administered, island wide survey over a 4-month period between 2007 and 2008. The sample of 2848 15-74-year-olds represented approximately 70% of the predominantly (94%) Black Jamaican population [3]. A stratified random sample of clusters known as Enumeration Districts (EDs) was selected using a probability proportionate to the size of population of the parishes in the island in order to yield a nationally representative sample. Trained interviewers administered a structured questionnaire on diseases and lifestyle behaviours and performed anthropometry. Further details on the sampling technique are provided elsewhere [3].

A total of 2529 (or 89% of) participants from the JHLS II dataset were geocoded out of the original 2848 participants. Kreft [29] suggests a '30/30 rule' so that researchers should strive for a sample of at least 30 groups with 30 individuals per group. For this study, each of the 101 EDs (sampling units) had an average of 28 individuals, providing sufficient power for the proposed secondary multilevel analyses. Furthermore, we also calculated power to detect a difference in BMI from 2 to 10 units based on differences in food environment exposure, at alpha = 0.05 and power of 80%, with a design effect employed ranging from an ICC of 2% to 10% and in all scenarios our sample and number of groups were sufficient to detect this difference in BMI.

Patient and public involvement

No patients were involved in the study. The study participants were community residents and were not involved in the design, recruitment or the conduct of the study. The study findings will be disseminated to the Ministry of Health, Jamaica and general public, including the study participants.

Measures

Individual-level measures

The primary outcome was mean BMI, calculated as weight divided by height squared (kg/m^2). Weight was measured using calibrated electronic scales (Tanita® models HD 314 or 2204) to 0.1 kg precision and height measured using a portable stadiometer (Seca®) to 0.1 cm precision.

Additional covariates included age, sex, educational attainment, occupation, urbanicity, and perceived community safety, and were examined as potential confounders; sex and urbanicity were also examined as effect modifiers, based on *a priori* theory. Named jobs were first categorised using the Jamaica Standardised Occupational Classification codes for 1991 [30] comprised of 16 categories. These were collapsed into four groups: a) highly skilled/professional (Legislators, Senior Officials and managers, Professionals/ Technicians & Associate Professionals, Clerks, Service Workers & Shop and Market Sales Workers), b) skilled (Skilled Agricultural & Fishery Workers, Craft and Related Trade Workers, Plant and Machine Operators & Assemblers, c) unskilled (Elementary Occupations) and d) unemployed/other (Armed Forces, Retired, Unemployed, Housewife, Self-employed, Student and Unclassified).

Perception of community safety was determined by asking each participant how safe he or she felt to walk in the community.

Household-level measures

The number of possessions owned (including but not exclusive to owning a radio, telephone, refrigerator, television, computer or car ownership) was used as a proxy for SES [3] and classification based on the following tertiles: 1st tertile = lower class = ≤ 6 items, 2nd tertile = middle class = 7-9 items, 3rd tertile= upper class = 10-16 items. The tertile categorization was based on the distribution of ownership of these items. SES, using this definition, was examined as a potential confounder or effect modifier, based on *a priori* theory.

Environment-level measures

Each observation was linked, through a geocoded residential address, to neighbourhood level proximity and density measures for supermarkets, markets and FFOs. Neighbourhood was defined as the Enumeration District (ED). The final choices of environment-level measures for investigation were based on a combination of previously derived GIS-based measures [31, 32], documented associations seen with the outcome of interest [31, 33] and data availability.

The locations of supermarkets/markets (*Figure 1, Panel A)* and FFOs (*Figure 1, Panel B)* were identified from Mona Geoinformatics Institute's (MonaGIS) proprietary JAMNAV database, and were collected in 2009. The proximities and densities of supermarkets/markets and FFOs were estimated using application of Spatial Analyst tool in ArcGIS to data from MonaGIS proprietary JAMNAV database. Proximity of supermarkets and markets, combined to represent good sources of fresh fruit and vegetable, was determined as the straight-line distance (km) from each geocoded address to the closest supermarket or market. Two density variables were created. The first was supermarkets/markets per km^2, and the second density variable, the number of supermarkets/markets per 1000 persons in the corresponding ED according to the 2011 census from the Statistical Institute of Jamaica (STATIN) [34]. Buffer zones were set at 1 km to reflect a short walking distance that could be completed in about 10-15 minutes [35].

FFOs were defined as places where high-caloric food could be obtained relatively quickly and excluded traditional cook shops, snack shops and sit-down restaurants. Proximity and density measures were created in a similar way as done for supermarkets/markets.

The above-mentioned retail food environments excluded informal food spaces (for e.g. street vendors).

Zero-inflated variables

The absence of the environmental-level measure based on the participant's geocoded address was indicated by a large proportion of zero values for most density measures as shown in the Supplementary Table. New indicator variables (dummy variables) were subsequently created and the specific dummy variable included in regression models alongside the original quantitative forms of the respective retail food environmental-level explanatory variable. These dummy variables are also referenced as the zero-inflated form of the density measures.

Missing variables

Addresses for 11% of the JHLS II study participants could not be geocoded and contributed to missing data in subsequent analyses. The age/sex population of the dataset used for this JHLS II secondary analysis subsample was compared with that for the non-geocoded data and no key deviations were observed.

Geocoded and non-geocoded (missing) participants were compared with respect to age, sex, SES categories and the key outcome variables of mean BMI, mean WC and obesity, using mixed effect models, regression models accounting for survey design and regression models that ignored survey design. No associations were detected between the geocoded status (present or missing) and these other variables. This data analysis was done only on geocoded data, on the assumption that these participants were representative of the target population.

Statistical Analyses

A complex database was created that combined individual-level JHLS II data with contextual environment-level data.

Descriptive data analysis estimated sex-specific and total survey-weighted means, proportions and 95% confidence intervals (CIs) for the outcome, explanatory and confounding variables as well as age-adjusted mean BMI and prevalence of poor fruit and vegetable intake, a key cardiovascular disease (CVD) risk factor. Age-adjustment utilized direct standardization across the strata identified as 10-year age bands with weights being survey-weighted population proportions of the respective 10-year age groups, as estimated using the JHLS II data.

The adjusted Wald test and the Pearson's chi-squared test corrected for survey design were used to determine whether, respectively, the age-adjusted and unadjusted estimates differed with respect to sex.

Intraclass correlation coefficients (ICCs) from hierarchical models quantified the proportion of variation in mean BMI potentially explainable at the ED level.

To determine and account for the effect of clustering at the neighbourhood level, subsequent analyses used multilevel models based on EDs nested within parish and examined the stratum-specific estimates of the effect of the environment variables on mean BMI with and without adjustment for covariates. Strata were defined using the urbanicity, sex and SES variables and stratum-specific multilevel models estimated if terms for interaction between the environment and strata variables were statistically significant. The Akaike's Information Criterion (AIC) statistic was used to determine the final best models. Collinearity assessed using Goodman and Kruskal's gamma coefficient γ [36], was the basis for selection of models covariates. To assess the chance of false positive errors, *P*-values from these models were compared with the Bonferroni corrected significance level.

All analyses were conducted using STATA, versions 12 and 14 (StataCorp LP, College Station, Texas).

Ethical Approval

Ethical approval was received from the University of the West Indies/University Hospital of the West Indies Ethics Research Committee.

RESULTS

Sample characteristics

The weighted total and sex-specific summary statistics are shown in Table 1. Women had higher mean BMI than men and higher proportions in the highly skilled/professional, unskilled and unemployed categories and in both 1st and 2nd SES tertiles based on no. of possessions owned ($P < 0.001$). However, a greater proportion of men perceived their communities as unsafe (males = 86.29 %; 95% CI: 82.64, 89.94 vs. females = 80.38 %; 95% CI: 75.63, 85.13; $P < 0.012$). There were no sex differences in urbanicity nor among those who had not completed high school.

There was clustering in mean BMI across neighbourhoods in Jamaica, with an ICC of 4.16%, the proportion of the variance in mean BMI that can be accounted for by the neighbourhood level [29,37]. No associations were found between the retail food environment variables and mean BMI in unadjusted regression models. There was also no effect modification by urbanicity.

Sex-specific regression models

There was interaction between sex and the following variables in their relationship with mean BMI: supermarkets proximity (P =0.023), absence of supermarkets within a 1 km buffer zone (P =0.008) and fast food outlets proximity (P =0.031). Figure 2 reveals that for women, in fully-adjusted models, a 10 km increase in distance from supermarkets (or further proximity) was associated with a 1.20 kg/m^2 higher mean BMI (95% CI 8.20 x10^{-3}, 0.24; P=0.036); the absence of supermarkets within a 1 km buffer zone was associated with a 1.36 kg/m^2 higher mean BMI (95% CI 0.20, 2.52; P=0.022). Proximity to FFOs was not associated with mean BMI in any sex.

SES- tertile-specific regression models

There was interaction between SES of a participant and a few retail food environment variables in their relationship with mean BMI. These included supermarkets proximity (P=0.015), absence of supermarkets/1000 people/ ED (P=0.033) and fast food outlets proximity (P =0.045). Figure 3 reveals that a kilometre increase in the distance from a supermarket was consistently associated with higher mean BMI for all models for persons within the middle class, with a 0.17 kg/m^2 higher mean BMI (95% CI 0.03, 0.32; *P*=0.020) in the final model. Among persons in the upper class, the absence of supermarkets/ 1000 people/ ED was associated with a 2.00 kg/m^2 higher mean BMI

Table 1. Total and sex-specific weighted sample characteristics (95% CI) for Jamaicans (JHLS II, 2008)

Variable	Men (n=796)	Women (n=1731)	Total (n=2527)	*P* value
Individual -level measures				
Mean Age in years (%)	37.00 (36.33, 37.13)	36.73 (36.64, 37.36)	36.87 (36.54, 37.20)	0.158
Urban Residence (%)	53.53 (43.84,62.28)	53.17 (45.11,61.74)	53.35 (44.87,61.64)	0.890
< High School Education (%)	31.75 (27.17, 36.33)	29.13 (25.69, 32.56)	30.43 (26.96, 33.90)	0.208
Occupation (%)				<0.0001
Highly skilled/Professional	38.87 (34.41, 43.34)	52.54 (49.02, 56.06)	45.73 (42.73, 48.72)	
Skilled	40.33 (35.19, 45.48)	8.21 (6.19, 10.23)	24.23 (21.29, 27.16)	
Unskilled	9.75 (6.66, 12.84)	18.13 (15.20, 21.06)	13.95 (11.33, 16.57)	
Unemployed/Other	11.05 (8.22, 13.88)	21.11 (18.17, 24.06)	16.10 (14.12, 18.07)	
Possessions owned (%)				<0.001
Lower class ≤ 6 items	34.09 (29.03, 39.14)	41.51 (37.45, 45.57)	37.82 (33.96, 41.68)	
Middle class 7-9 items	29.92 (25.99, 33.85)	31.17, (28.45, 33.89)	30.55 (27.89, 33.20)	
Upper class 10-16 items	36.00 (30.68, 41.31)	27.32 (22.99, 31.65)	31.63 (27.45, 35.82)	
Perception of unsafe community (%)	86.29 (82.64, 89.94)	80.38 (75.63, 85.13)	83.32 (79.77, 86.86)	0.012
Mean BMI□ (kg/m^2)	24.83(24.28, 25.38)	28.40 (27.90, 28.89)	26.64 (26.21, 27.07)	<0.001
Neighbourhood -level measures† [Mean (95% CI)]				
Supermarkets§ proximity (km)	3.61 (2.69, 4.54)	3.64 (2.78, 4.49)	3.63 (2.77, 4.48)	0.978
Supermarkets§ / km^2	1.60 (0.84, 2.36)	1.57 (0.96, 2.19)	1.59 (0.91, 2.26)	0.895
Supermarkets§ /1000 people/ ED	0.65 (0.27, 1.04)	0.63 (0.20, 1.07)	0.64 (0.26, 1.03)	0.922
FFO proximity (km)	4.56 (3.54, 5.58)	4.68(3.60, 5.76)	4.62 (3.62, 5.62)	0.747
FFO / km^2	0.57 (0.33, 0.81)	0.52 (0.32, 0.72)	0.55 (0.33, 0.76)	0.266
FFO / 1000 people/ ED	0.35 (0.10, 0.60)	0.21 (0.07, 0.35)	0.28 (0.10, 0.46)	0.104

† Age-adjusted

§Includes supermarkets and markets

CI – Confidence Interval; JHLS II, Jamaica Health and Lifestyle Survey II; BMI, Body Mass Index; ED – Enumeration District; FFO - Fast Food Outlets

P values for difference between means (men versus women)

(95% CI 0.08, 3.92; *P*=0.041) only in age-adjusted models. Proximity to FFOs was not associated with mean BMI in any of the SES classes.

DISCUSSION

This study is the first to examine the impact of the retail food environment on obesity-related outcomes in a small Caribbean island. While we observed no significant associations between the retail food environment variables and mean BMI in unadjusted regression models, results revealed significant sex differences in the impact of the food environment, particularly for supermarkets. The further distance away from supermarkets and markets, and their absence within a 1 km buffer zone from residences, were associated with higher mean BMI in women; and further proximity to supermarkets associated with higher mean BMI for the middle class. There was no association with proximity to or density of FFOs, nor urban-rural differences.

We also observed clustering of BMI at the community level, with approximately4.0% of the variance in mean BMI potentially explainable by environmental influences outside of the individual or at the neighbourhood level. This is similar to those reported by Harrington et al in a Canadian sample [38] and by Masood and Reidpath [39] for many of the countries that participated in the 2003 World Health Survey. It is also similar to ICC by neighborhood seen for obesity-related outcomes among adolescents in the U.S. as part of the National Health and Nutrition Survey (NHANES) [40].

Our study findings corroborate previous research conducted in developed countries that indicate closer proximity to supermarkets/markets [12, 19, 20] and increased density of supermarkets/markets [9-11, 16, 41, 42] are associated with less obesity-related outcomes in adults and children. Of note however, Wang and colleagues found higher neighbourhood density of small grocery stores associated with higher BMI among a sample of US women [15], while our study found higher BMI for women being associated with further distance from supermarkets/markets (inclusive of small grocery stores). There are potential explanations for this sex-specific difference as some studies have found that residential environments have a greater effect on women's health [43]. For example, women as primary food providers may depend more on neighbourhood sources for food than men do, which may in turn have an effect on their health outcomes, such as BMI. However, the influence of gender specific roles in the provision of food supplies for families was not the focus of our study and so additional studies would be needed to better understand the differences observed. Although the geographic variables are somewhat dissimilar (a density versus proximity measure), the difference in direction of the associations raises the question as to whether presence of grocery stores, supermarkets and markets across different geographical contexts, including small island states like Jamaica, each represent the same degree of accessibility, availability and ultimate consumption of healthy foods. For example, we found no urban-rural differences as hypothesized, perhaps due to Physical Activity Levels (PALs), diet or some other unknown confounder masking the association. For example, it is quite possible that the presence or absence of supplementary food sources, utilized in rural communities and not captured in the environmental-level variables used in our study, for e.g. small produce plots or seasonal vegetable/fruits that supplement diets, may have played a role in the lack of urban-rural differences seen.

Living a greater distance away from supermarkets/markets was positively associated with mean BMI in the middle class in our study, however many other studies found this association in the lower class [44]. We are unclear as to the reasons for the association observed among the middle-class participants. We surmise this could possibly be due to the influence of shopping preferences in terms of location. For example, a study conducted in low income neighbourhoods in Philadelphia USA found that many residents did most of their shopping outside of the neighbourhood [45]. Other possible influences could be cost, types of food purchased, or lower PALs in this group, the latter perhaps being influenced by car ownership and/or greater use of motorized transport. Inagami et al [46] found in a study conducted in the Los Angeles area of California, USA that BMI was higher a) where persons frequented grocery stores located in more disadvantaged neighbourhoods, which usually have higher availability of relatively inexpensive, energy-dense foods and b) among those who owned cars and travelled farther to their grocery stores. However, other studies reveal inconsistencies, with mixed findings across various neighbourhood food retail contexts which may be due to the heterogeneity in defining neighbourhoods using socioeconomic status [47,48] and methodological limitations in measuring the interrelatedness of neighbourhood residence, determinants of purchasing choices within and outside of the residential neighbourhood and issues such as dietary preferences [49]. In our study, PAL, motorized transport and diet were not adjusted for in the regression models. These omissions may have suppressed associations.

It is also unclear why associations between FFO proximity and mean BMI were neither seen in the sex-specific nor SES-specific models. This may be an indication that demonstration of associations may depend on which obesogenic retail food environment variable or outcome measure of adiposity is chosen for the regression models. For example, Menke et al in analysing the 3rd US National Health and Nutrition Examination Survey conducted, found that waist circumference maintained a stronger association with CVD risk factors than the other measures of adiposity [50]. Further work is needed on assessing the quality and utility of the measures used in this study as well as the development of new ones for the Jamaican and developing world context.

The major strength of this study is that it represents pioneering work in a small island developing country context. We linked individually geocoded addresses from a nationally representative survey, with specific objective GIS-based retail food environment measures and provided empirical evidence using MLM to explore the association between objective neighbourhood-level retail food environment measures and BMI. Additionally, the sample characteristics that differed significantly with sex, were also included as covariates in the final models in order to minimize over or underestimation of the true strength of the associations detected between the neighbourhood food retail environment measures and BMI.

Despite strengths, there are limitations that deserve mention, including the inability to make causal inferences given the cross-sectional design of the JHLS II and our definition of neighbourhood. Using EDs to represent a Jamaican neighbourhood could be deemed inadequate as they i) are quite heterogeneous geographically in size, composition and context, and ii) may not fully represent exposure to the obesogenic environments being investigated. Additionally, although the outcome was objectively assessed, the risk factors included self-reported data on a single individual representing a household, which may introduce information bias. Furthermore, there was temporal mismatch of the data collected from individual JHLS II participants with that for the retail food environment-level variables, most of which were collected by MonaGIS in and after the year 2009, subsequent to the end of data collection for the JHLS II in 2008. This may have biased the results as individual exposures may have varied after the survey period, although food consumption behaviours are believed to be relatively stable over time. Lastly, the reliability and validity of the area-level environmental variables were untested locally and therefore uncertainty remains as to whether they were most effective in explaining any variance in the obesity-related outcomes. For example, a study conducted in a low-income neighborhood in Spain found a mismatch between GIS-based measures of the food environment and resident's perceptions of the environment [51]. Another challenge faced in Jamaica with accurately characterizing the neighbourhood retail food environment relates to the presence of and patronage of the foods provided by many itinerant vendors which are often energy-dense foods. The use of mixed-methods approaches in future research within small island developing states similar to Jamaica, may improve understanding on the associations with observed health-related behaviours such as food purchases (cost and locations) and dietary choices with BMI.

In conclusion, we found that further distance away from supermarkets and markets and their absence within a 1 km buffer zone from residences were associated with higher mean BMI, with important sex and social class differences. There has been an increase in the prevalence of obesity in Jamaica [3] despite the implementation of policies and programmes to ameliorate its impact on the continuum towards NCDs [52]. Higher mean BMI in Jamaicans may be partially explained by the presence of supermarkets and markets and differ by sex and social class. National efforts to curtail obesity in SIDS, like Jamaica should consider the inclusion of interventions and future studies focused at the neighbourhood-level that not only target the location and density of supermarkets and markets but also those that consider sex and social class-specific factors that maybe influencing the associations.

STATEMENTS

Contributors CC-M and KT conceived the study. LG and PL-A geocoded the data. CC-M, NY-C and KT analysed and interpreted the data. RW supervised the research. CC-M wrote the manuscript. PL-A, KT and RW edited the manuscript. All authors provided critical intellectual contributions and read and approved the final manuscript.

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Figure 1. Spatial Distribution of Supermarket/markets (A) and Fast Food Outlets in Jamaica (B)

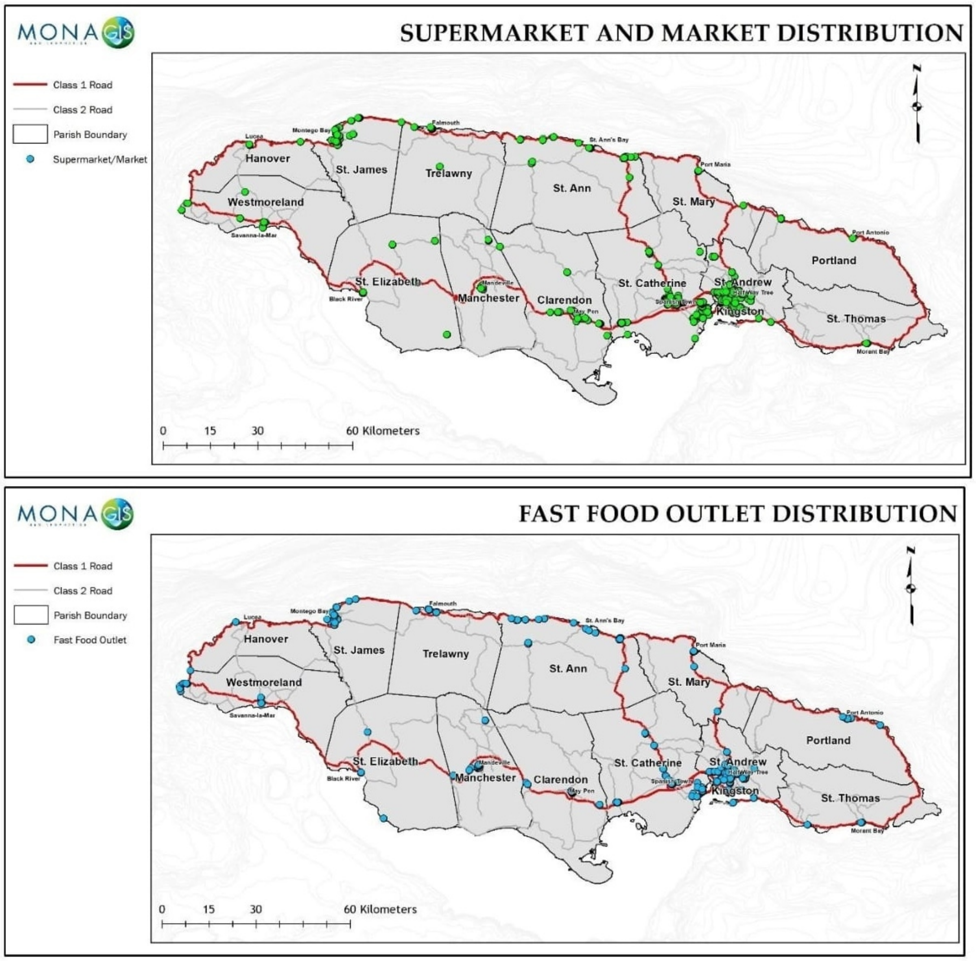
Figure 2. Sex-specific unadjusted and adjusted β Coefficients for the association of retail food environments with mean Body Mass Index

ǂ Dummy variable for zero inflated predictor
CI – Confidence Interval
Model 1 - unadjusted
Model 2 - age adjusted
Model 3 - adjusted for age and no. of possessions
Model 4 - adjusted for age, no. of possessions, urban, occupation, education, perception of unsafe community
*$p < 0.05$

Figure 3. SES-specific unadjusted and adjusted β Coefficients for the association of retail food environments with mean Body Mass Index

CI – Confidence Interval; ED – Enumeration District

‡ Dummy variable for zero inflated predictor
Model 1 - unadjusted
Model 2 - age adjusted
Model 3 - adjusted for age and sex
Model 4 - adjusted for age, sex, urban, occupation, education, perception of unsafe community
*$p < 0.05$, ** $p < 0.01$



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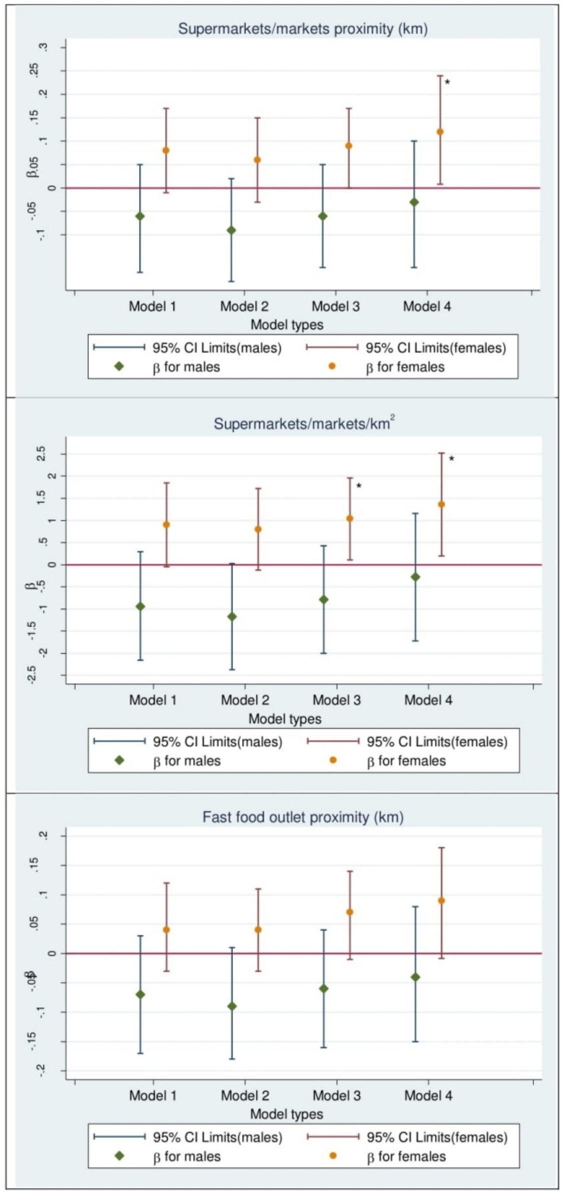

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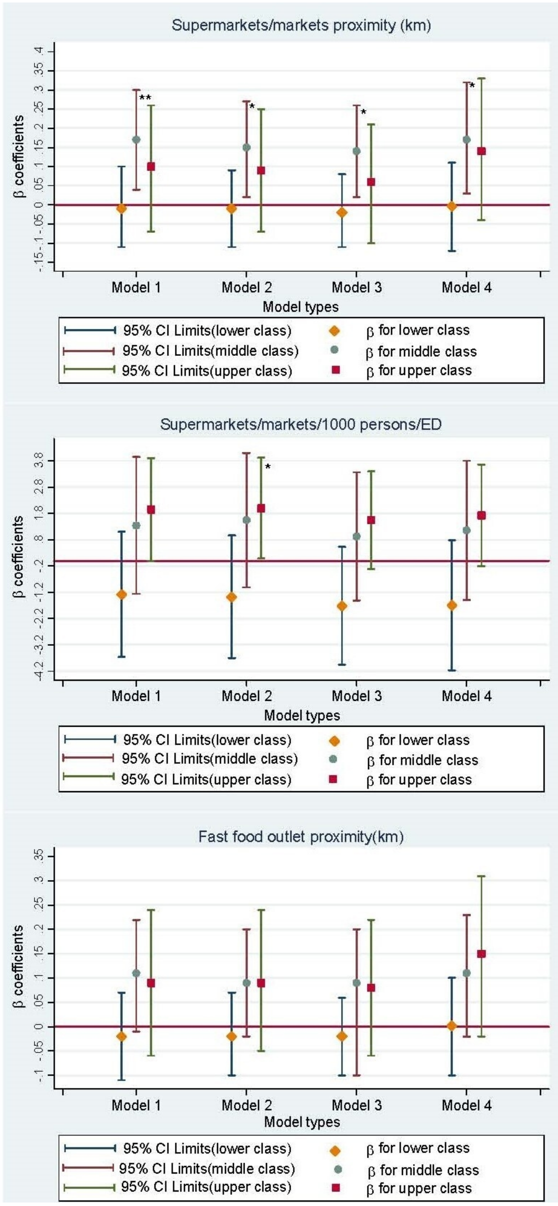

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Supplementary Table. Proportion of zero-valued observations for geographic variables

Retail Food Environments	Frequency (%) N=2527
Supermarkets/markets proximity (km)	0
Supermarkets/markets / km^2	61.30
Supermarkets/markets /1000 people/ ED	92.13
FFO proximity (km)	0
FFO / km^2	68.22
FFO / 1000 people/ ED	94.46

ED – Enumeration District; FFO - Fast Food Outlets

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **[Within the title page 1 and methods section of the abstract page 2]**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **[See methods and results sections of abstract page 2]**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **[pages 4-5]**
Objectives	3	State specific objectives, including any prespecified hypotheses **[page 5]**
Methods		
Study design	4	Present key elements of study design early in the paper **[page 5-6]**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **[pages 6-8]**
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants **[pages 5- 6]**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. **[pages 6-9]** Give diagnostic criteria, if applicable **[N/A]**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **[pages 6-9]**
Bias	9	Describe any efforts to address potential sources of bias **[pages 5-6, 8-9]**
Study size	10	Explain how the study size was arrived at **[page 5-6]**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **[pages 8-9]**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **[pages 8-9]**
		(*b*) Describe any methods used to examine subgroups and interactions **[page 9]**
		(*c*) Explain how missing data were addressed **[page 8]**
		(*d*) If applicable, describe analytical methods taking account of sampling strategy **[page 9]**
		(*e*) Describe any sensitivity analyses **[N/A]**
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **[N/A]**
		(b) Give reasons for non-participation at each stage **[N/A]**
		(c) Consider use of a flow diagram **[N/A]**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **[page 9; Table 1]**
		(b) Indicate number of participants with missing data for each variable of interest **[N/A]**
Outcome data	15*	Report numbers of outcome events or summary measures **[page 9; Table 1]**

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). **[pages 9-10; Figures 2-3]** Make clear which confounders were adjusted for and why they were included **[page 6, Figures 2-3]**
		(*b*) Report category boundaries when continuous variables were categorized **[page 10, Table 1]**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **[N/A]**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **[pages 9-10]**
Discussion		
Key results	18	Summarise key results with reference to study objectives **[page 10]**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **[page 13]**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **[pages 12-13]**
Generalisability	21	Discuss the generalisability (external validity) of the study results **[page 13]**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **[page 14]**

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Understanding neighbourhood retail food environmental mechanisms influencing BMI in the Caribbean: a multilevel analysis from the Jamaica Health and Lifestyle Survey: a cross-sectional study

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Understanding neighbourhood retail food environmental mechanisms influencing BMI in the Caribbean: a multilevel analysis from the Jamaica Health and Lifestyle Survey: a cross-sectional study

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ABSTRACT

Objective To derive estimates of the associations between measures of the retail food environments and mean Body Mass Index (BMI) in Jamaica, a middle-income country with increasing prevalence of obesity.

Design Cross-sectional study

Setting Data from the Jamaica Health and Lifestyle Survey 2008 (JHLS II) a nationally representative population-based survey that recruited persons at their homes over a four-month period from all 14 parishes and 113 neighbourhoods defined as Enumeration Districts (EDs).

Participants A subsample of 2529 participants aged 18-74 years from the JHLS II who completed interviewer administered surveys, provided anthropometric measurements and whose addresses were geocoded.

Primary outcome measure Mean BMI, calculated as weight divided by height squared (kg/m^2)

Results There was significant clustering across neighbourhoods for mean BMI (Intraclass correlation coefficients = 4.16%). Fully adjusted models revealed higher mean BMI among women, with further distance away from supermarkets (β= 0.12; 95% CI = 8.20×10^{-3}, 0.24; *P*=0.036) and the absence of supermarkets within a 1 km buffer zone (β= 1.36; 95% CI 0.20, 2.52; *P*=0.022). A 10km increase in the distance from a supermarket was associated with a 1.7 kg/m^2 higher mean BMI (95% CI 0.03, 0.32; *P*=0.020) in the middle class. No associations were detected with Fast Food Outlets or interaction by urbanicity.

Conclusions Higher mean BMI in Jamaicans may be partially explained by the presence of supermarkets and markets and differ by sex and social class. National efforts to curtail obesity in middle-income countries should consider interventions focused at the neighbourhood-level that not only target the location and density of supermarkets and markets but also consider sex and social class-specific factors that maybe influencing the associations.

Strengths and limitations of this study

- This study is the first in a Caribbean island to demonstrate the influence of the retail food environment on Body Mass Index (BMI) using geocoded data and multilevel modelling.
- This study provided a large sample size representative of Jamaicans 15 to 74 years.
- Individual geocoded addresses from a nationally representative survey were linked with specific objective GIS-based retail food environmental measures.
- Enumeration Districts (EDs) were used to define Jamaican neighbourhoods which are quite heterogeneous geographically in size, composition and context, and may not fully represent exposure to the food obesogenic environments
- The reliability and validity of the area-level environmental variables used were not ascertained for the local context and therefore they may not be the most effective in explaining any variance in BMI.

INTRODUCTION

Obesity has been increasing in the Caribbean [1,2] and in Jamaica is now a major public health problem [3]. Over the past five decades a rapid increase in obesity has been reported with women having consistently higher rates than men [4-6]. The Jamaica Health and Lifestyle Survey 2008 (JHLS II) [3], has documented increased prevalence over the earlier 2001 survey (JHLS I) [7], in obesity as well as the comorbid Chronic Non-communicable Disease (NCD) conditions of diabetes mellitus (DM) and hypertension (HTN). Approximately 99 % of Jamaicans consumed below the daily recommended portions of fruits and vegetables and 30% of obese persons preferred fried protein in their diets [3].

The presence of supermarkets/markets has been thought to indicate better access to and intake of healthier foods, given its association with higher intake of fruit and vegetables [8] and inversely associated with obesity [9-11]. For example, among Canadian children residing in Toronto, those that lived in close proximity to a supermarket had decreased odds of being overweight or obese [12].

The presence of supermarkets has been shown to be inversely associated with neighbourhood SES in the US, whereby data have revealed greater poverty being associated with a decreased presence [13, 14]. With regards to sex differences, research by Wang et al [15] among 25 – 74 years old adults in California revealed that closer proximity to a supermarket and higher neighborhood density of small grocery stores were associated with higher BMI among women.

Fast food outlets (FFOs) have increased in many countries and thought to be associated with the global rise in obesity. Whilst there is no universally accepted agreement on what the definition of fast food is, most research include foods sold that are low cost, energy dense with high fat and/or sugar content and low nutrient content. Studies have found that frequent consumption of fast foods in areas with a high density of FFOs has been found to increase body weight [16,17] and a positive association of proximity to FFOs with measures of adiposity [18, 19].

The interaction between SES and the density of FFOs has also been investigated. In Australia it was found that persons with poor SES (based on median weekly income) had 2.5 times exposure to FFOs than persons in the wealthiest SES category [20]. Similar associations have been reported in the US [21, 22] and Great Britain [23]. In Europe, eating at restaurants (which included eating at FFOs) was positively associated with BMI among men [24]. On the other hand, in the US eating at FFOs was positively associated cross-sectionally with BMI among low- income women [25].

The limited body of research on environment influences on the chronic NCDs in Jamaica and the developing world, as well as the apparent lack of lifestyle changes despite health promotion programs targeting individual-level prevention, suggests that barriers to these changes may yet be unrecognized and accounted for in the traditional modelling of risk factors. The studies on obesity previously referenced [3,4,6,7] have only assessed geographical variations according to the dichotomized classification of urban/rural area of residence. Within the Caribbean and Latin American regions, there are a limited number of studies assessing geographical variations in obesity or other measures of adiposity such as mean BMI, using multilevel modelling (MLM) statistical techniques and/or Geographic Information Systems (GIS) to determine whether there are associations with the built environment in a middle-income country (MIC) or small island developing state (SIDS) context [26-28].

The aim of this study was to provide a unique and important opportunity to address these gaps in understanding the retail food environmental mechanisms influencing mean BMI in Jamaica, a small island MIC. Our objective was to derive estimates of the associations between measures of the retail food environments and mean BMI, using a combination of MLM and GIS-based methods for contextualizing the national survey data and calculating objective community exposures.

We hypothesized that: a) there was variability in the mean BMI across Jamaican neighbourhoods, b) the pathway between greater presence/closer proximity to supermarkets/markets, and lower mean BMI would be stronger for those of higher SES, c) the pathway between greater presence/closer proximity to fast food outlets and greater mean BMI would be stronger for those of low SES and residing in urban areas, and d) there would be sex differences in these associations.

MATERIALS AND METHODS

Study design and sample

The JHLS II was a cross-sectional, interviewer-administered, island wide survey over a 4-month period between 2007 and 2008. The sample of 2848 15-74-year-olds represented approximately

70% of the predominantly (94%) Black Jamaican population [3]. A stratified random sample of clusters known as Enumeration Districts (EDs) was selected using a probability proportionate to the size of population of the parishes in the island in order to yield a nationally representative sample. Trained interviewers administered a structured questionnaire on diseases and lifestyle behaviours and performed anthropometry. Further details on the sampling technique are provided elsewhere [3].

A total of 2529 (or 89% of) participants from the JHLS II dataset were geocoded out of the original 2848 participants. Kreft [29] suggests a '30/30 rule' so that researchers should strive for a sample of at least 30 groups with 30 individuals per group. For this study, each of the 101 EDs (sampling units) had an average of 28 individuals, providing sufficient power for the proposed secondary multilevel analyses. Furthermore, we also calculated power to detect a difference in BMI from 2 to 10 units based on differences in food environment exposure, at alpha = 0.05 and power of 80%, with a design effect employed ranging from an ICC of 2% to 10% and in all scenarios our sample and number of groups were sufficient to detect this difference in BMI.

Patient and public involvement

No patients were involved in the study. The study participants were community residents and were not involved in the design, recruitment or the conduct of the study. The study findings will be disseminated to the Ministry of Health, Jamaica and general public, including the study participants.

Measures

Individual-level measures

The primary outcome was mean BMI, calculated as weight divided by height squared (kg/m^2). Weight was measured using calibrated electronic scales (Tanita® models HD 314 or 2204) to 0.1 kg precision and height measured using a portable stadiometer (Seca®) to 0.1 cm precision.

Additional covariates included age, sex, educational attainment, occupation, urbanicity, and perceived community safety, and were examined as potential confounders; sex and urbanicity were also examined as effect modifiers, based on *a priori* theory. Named jobs were first categorised using the Jamaica Standardised Occupational Classification codes for 1991 [30] comprised of 16 categories. These were collapsed into four groups: a) highly skilled/professional

(Legislators, Senior Officials and managers, Professionals/ Technicians & Associate Professionals, Clerks, Service Workers & Shop and Market Sales Workers), b) skilled (Skilled Agricultural & Fishery Workers, Craft and Related Trade Workers, Plant and Machine Operators & Assemblers, c) unskilled (Elementary Occupations) and d) unemployed/other (Armed Forces, Retired, Unemployed, Housewife, Self-employed, Student and Unclassified).

Perception of community safety was determined by asking each participant how safe he or she felt to walk in the community.

Household-level measures

The number of possessions owned (including but not exclusive to owning a radio, telephone, refrigerator, television, computer or car ownership) was used as a proxy for SES [3] and classification based on the following tertiles: 1st tertile = lower class = ≤ 6 items, 2nd tertile = middle class = 7-9 items, 3rd tertile= upper class = 10-16 items. The tertile categorization was based on the distribution of ownership of these items. SES, using this definition, was examined as a potential confounder or effect modifier, based on *a priori* theory.

Environment-level measures

Each observation was linked, through a geocoded residential address, to neighbourhood level proximity and density measures for supermarkets, markets and FFOs. Neighbourhood was defined as the Enumeration District (ED). The final choices of environment-level measures for investigation were based on a combination of previously derived GIS-based measures [31, 32], documented associations seen with the outcome of interest [31, 33] and data availability.

The locations of supermarkets/markets (*Figure 1, Panel A)* and FFOs (*Figure 1, Panel B)* were identified from Mona Geoinformatics Institute's (MonaGIS) proprietary JAMNAV database, and were collected in 2009. The proximities and densities of supermarkets/markets and FFOs were estimated using application of Spatial Analyst tool in ArcGIS to data from MonaGIS proprietary JAMNAV database. Proximity of supermarkets and markets, combined to represent good sources of fresh fruit and vegetable, was determined as the straight-line distance (km) from each geocoded address to the closest supermarket or market. Two density variables were created. The first was supermarkets/markets per km^2, and the second density variable, the number of supermarkets/markets per 1000 persons in the corresponding ED according to the 2011 census from the Statistical Institute of Jamaica (STATIN) [34]. Buffer zones were set at 1 km to reflect a short walking distance that could be completed in about 10-15 minutes [35].

FFOs were defined as places where high-caloric food could be obtained relatively quickly and excluded traditional cook shops, snack shops and sit-down restaurants. Proximity and density measures were created in a similar way as done for supermarkets/markets.

The above-mentioned retail food environments excluded informal food spaces (for e.g. street vendors).

Zero-inflated variables

The absence of the environmental-level measure based on the participant's geocoded address was indicated by a large proportion of zero values for most density measures as shown in the Supplementary Table. New indicator variables (dummy variables) were subsequently created and the specific dummy variable included in regression models alongside the original quantitative forms of the respective retail food environmental-level explanatory variable. These dummy variables are also referenced as the zero-inflated form of the density measures.

Missing variables

Addresses for 11% of the JHLS II study participants could not be geocoded and contributed to missing data in subsequent analyses. The age/sex population of the dataset used for this JHLS II secondary analysis subsample was compared with that for the non-geocoded data and no key deviations were observed.

Geocoded and non-geocoded (missing) participants were compared with respect to age, sex, SES categories and the key outcome variables of mean BMI, mean WC and obesity, using mixed effect models, regression models accounting for survey design and regression models that ignored survey design. No associations were detected between the geocoded status (present or missing) and these other variables. This data analysis was done only on geocoded data, on the assumption that these participants were representative of the target population.

Statistical Analyses

A complex database was created that combined individual-level JHLS II data with contextual environment-level data.

Descriptive data analysis estimated sex-specific and total survey-weighted means, proportions and 95% confidence intervals (CIs) for the outcome, explanatory and confounding variables as well as age-adjusted mean BMI and prevalence of poor fruit and vegetable intake, a key cardiovascular disease (CVD) risk factor. Age-adjustment utilized direct standardization across the strata identified as 10-year age bands with weights being survey-weighted population proportions of the respective 10-year age groups, as estimated using the JHLS II data.

The adjusted Wald test and the Pearson's chi-squared test corrected for survey design were used to determine whether, respectively, the age-adjusted and unadjusted estimates differed with respect to sex.

Intraclass correlation coefficients (ICCs) from hierarchical models quantified the proportion of variation in mean BMI potentially explainable at the ED level.

To determine and account for the effect of clustering at the neighbourhood level, subsequent analyses used multilevel models based on EDs nested within parish and examined the stratum-specific estimates of the effect of the environment variables on mean BMI with and without adjustment for covariates. Strata were defined using the urbanicity, sex and SES variables and stratum-specific multilevel models estimated if terms for interaction between the environment and strata variables were statistically significant. The Akaike's Information Criterion (AIC) statistic was used to determine the final best models. Collinearity assessed using Goodman and Kruskal's gamma coefficient γ [36], was the basis for selection of models covariates. To assess the chance of false positive errors, *P*-values from these models were compared with the Bonferroni corrected significance level.

All analyses were conducted using STATA, versions 12 and 14 (StataCorp LP, College Station, Texas).

Ethical Approval

Ethical approval was received from the University of the West Indies/University Hospital of the West Indies Ethics Research Committee.

RESULTS

Sample characteristics

The weighted total and sex-specific summary statistics are shown in Table 1. Women had higher mean BMI than men and higher proportions in the highly skilled/professional, unskilled and unemployed categories and in both 1st and 2nd SES tertiles based on no. of possessions owned (*P* < 0.001). However, a greater proportion of men perceived their communities as unsafe (males = 86.29 %; 95% CI: 82.64, 89.94 vs. females = 80.38 %; 95% CI: 75.63, 85.13; *P* < 0.012). There were no sex differences in urbanicity nor among those who had not completed high school.

There was clustering in mean BMI across neighbourhoods in Jamaica, with an ICC of 4.16%, the proportion of the variance in mean BMI that can be accounted for by the neighbourhood level [29,37]. No associations were found between the retail food environment variables and mean BMI in unadjusted regression models. There was also no effect modification by urbanicity.

Sex-specific regression models

There was interaction between sex and the following variables in their relationship with mean BMI: supermarkets proximity (*P* =0.023), absence of supermarkets within a 1 km buffer zone (*P* =0.008) and fast food outlets proximity (*P* =0.031). Figure 2 reveals that for women, in fully-adjusted models, a 10 km increase in distance from supermarkets (or further proximity) was associated with a 1.20 kg/m^2 higher mean BMI (95% CI 8.20 $x10^{-3}$, 0.24; *P*=0.036); the absence of supermarkets within a 1 km buffer zone was associated with a 1.36 kg/m^2 higher mean BMI (95% CI 0.20, 2.52; *P*=0.022). Proximity to FFOs was not associated with mean BMI in any sex.

SES- tertile-specific regression models

There was interaction between SES of a participant and a few retail food environment variables in their relationship with mean BMI. These included supermarkets proximity (*P*=0.015), absence of supermarkets/1000 people/ ED (*P*=0.033) and fast food outlets proximity (*P* =0.045). Figure 3 reveals that a kilometre increase in the distance from a supermarket was consistently associated with higher mean BMI for all models for persons within the middle class, with a 0.17 kg/m^2 higher mean BMI (95% CI 0.03, 0.32; *P*=0.020) in the final model. Among persons in the upper class, the absence of supermarkets/ 1000 people/ ED was associated with a 2.00 kg/m^2 higher mean BMI

Table 1. Total and sex-specific weighted sample characteristics (95% CI) for Jamaicans (JHLS II, 2008)

Variable	Men (n=796)	Women (n=1731)	Total (n=2527)	*P* value
Individual -level measures				
Mean Age in years (%)	37.00 (36.33, 37.13)	36.73 (36.64, 37.36)	36.87 (36.54, 37.20)	0.158
Urban Residence (%)	53.53 (43.84,62.28)	53.17 (45.11,61.74)	53.35 (44.87,61.64)	0.890
< High School Education (%)	31.75 (27.17, 36.33)	29.13 (25.69, 32.56)	30.43 (26.96, 33.90)	0.208
Occupation (%)				<0.0001
Highly skilled/Professional	38.87 (34.41, 43.34)	52.54 (49.02, 56.06)	45.73 (42.73, 48.72)	
Skilled	40.33 (35.19, 45.48)	8.21 (6.19, 10.23)	24.23 (21.29, 27.16)	
Unskilled	9.75 (6.66, 12.84)	18.13 (15.20, 21.06)	13.95 (11.33, 16.57)	
Unemployed/Other	11.05 (8.22, 13.88)	21.11 (18.17, 24.06)	16.10 (14.12, 18.07)	
Possessions owned (%)				<0.001
Lower class ≤ 6 items	34.09 (29.03, 39.14)	41.51 (37.45, 45.57)	37.82 (33.96, 41.68)	
Middle class 7-9 items	29.92 (25.99, 33.85)	31.17, (28.45, 33.89)	30.55 (27.89, 33.20)	
Upper class 10-16 items	36.00 (30.68, 41.31)	27.32 (22.99, 31.65)	31.63 (27.45, 35.82)	
Perception of unsafe community (%)	86.29 (82.64, 89.94)	80.38 (75.63, 85.13)	83.32 (79.77, 86.86)	0.012
Mean BMI□ (kg/m^2)	24.83(24.28, 25.38)	28.40 (27.90, 28.89)	26.64 (26.21, 27.07)	<0.001
Neighbourhood -level measures† [Mean (95% CI)]				
Supermarkets§ proximity (km)	3.61 (2.69, 4.54)	3.64 (2.78, 4.49)	3.63 (2.77, 4.48)	0.978
Supermarkets§ / km^2	1.60 (0.84, 2.36)	1.57 (0.96, 2.19)	1.59 (0.91, 2.26)	0.895
Supermarkets§ /1000 people/ ED	0.65 (0.27, 1.04)	0.63 (0.20, 1.07)	0.64 (0.26, 1.03)	0.922
FFO proximity (km)	4.56 (3.54, 5.58)	4.68(3.60, 5.76)	4.62 (3.62, 5.62)	0.747
FFO / km^2	0.57 (0.33, 0.81)	0.52 (0.32, 0.72)	0.55 (0.33, 0.76)	0.266
FFO / 1000 people/ ED	0.35 (0.10, 0.60)	0.21 (0.07, 0.35)	0.28 (0.10, 0.46)	0.104

† Age-adjusted

§Includes supermarkets and markets

CI – Confidence Interval; JHLS II, Jamaica Health and Lifestyle Survey II; BMI, Body Mass Index; ED – Enumeration District; FFO - Fast Food Outlets

P values for difference between means (men versus women)

(95% CI 0.08, 3.92; *P*=0.041) only in age-adjusted models. Proximity to FFOs was not associated with mean BMI in any of the SES classes.

DISCUSSION

This study is the first to examine the impact of the retail food environment on obesity-related outcomes in a small Caribbean island. While we observed no significant associations between the retail food environment variables and mean BMI in unadjusted regression models, results revealed significant sex differences in the impact of the food environment, particularly for supermarkets. The further distance away from supermarkets and markets, and their absence within a 1 km buffer zone from residences, were associated with higher mean BMI in women; and further proximity to supermarkets associated with higher mean BMI for the middle class. There was no association with proximity to or density of FFOs, nor urban-rural differences.

We also observed clustering of BMI at the community level, with approximately4.0% of the variance in mean BMI potentially explainable by environmental influences outside of the individual or at the neighbourhood level. This is similar to those reported by Harrington et al in a Canadian sample [38] and by Masood and Reidpath [39] for many of the countries that participated in the 2003 World Health Survey. It is also similar to ICC by neighborhood seen for obesity-related outcomes among adolescents in the U.S. as part of the National Health and Nutrition Survey (NHANES) [40].

Our study findings corroborate previous research conducted in developed countries that indicate closer proximity to supermarkets/markets [12, 19, 20] and increased density of supermarkets/markets [9-11, 16, 41, 42] are associated with less obesity-related outcomes in adults and children. Of note however, Wang and colleagues found higher neighbourhood density of small grocery stores associated with higher BMI among a sample of US women [15], while our study found higher BMI for women being associated with further distance from supermarkets/markets (inclusive of small grocery stores). There are potential explanations for this sex-specific difference as some studies have found that residential environments have a greater effect on women's health [43]. For example, women as primary food providers may depend more on neighbourhood sources for food than men do, which may in turn have an effect on their health outcomes, such as BMI. However, the influence of gender specific roles in the provision of food supplies for families was not the focus of our study and so additional studies would be needed to better understand the differences observed. Although the geographic variables are somewhat dissimilar (a density versus proximity measure), the difference in direction of the associations raises the question as to whether presence of grocery stores, supermarkets and markets across different geographical contexts, including small island states like Jamaica, each represent the same degree of accessibility, availability and ultimate consumption of healthy foods. For example, we found no urban-rural differences as hypothesized, perhaps due to Physical Activity Levels (PALs), diet or some other unknown confounder masking the association. For example, it is quite possible that the presence or absence of supplementary food sources, utilized in rural communities and not captured in the environmental-level variables used in our study, for e.g. small produce plots or seasonal vegetable/fruits that supplement diets, may have played a role in the lack of urban-rural differences seen.

Living a greater distance away from supermarkets/markets was positively associated with mean BMI in the middle class in our study, however many other studies found this association in the lower class [44]. We are unclear as to the reasons for the association observed among the middle-class participants. We surmise this could possibly be due to the influence of shopping preferences in terms of location. For example, a study conducted in low income neighbourhoods in Philadelphia USA found that many residents did most of their shopping outside of the neighbourhood [45]. Other possible influences could be cost, types of food purchased, or lower PALs in this group, the latter perhaps being influenced by car ownership and/or greater use of motorized transport. Inagami et al [46] found in a study conducted in the Los Angeles area of California, USA that BMI was higher a) where persons frequented grocery stores located in more disadvantaged neighbourhoods, which usually have higher availability of relatively inexpensive, energy-dense foods and b) among those who owned cars and travelled farther to their grocery stores. However, other studies reveal inconsistencies, with mixed findings across various neighbourhood food retail contexts which may be due to the heterogeneity in defining neighbourhoods using socioeconomic status [47,48] and methodological limitations in measuring the interrelatedness of neighbourhood residence, determinants of purchasing choices within and outside of the residential neighbourhood and issues such as dietary preferences [49]. In our study, PAL, motorized transport and diet were not adjusted for in the regression models. These omissions may have suppressed associations.

It is also unclear why associations between FFO proximity and mean BMI were neither seen in the sex-specific nor SES-specific models. This may be an indication that demonstration of associations may depend on which obesogenic retail food environment variable or outcome measure of adiposity is chosen for the regression models. For example, Menke et al in analysing the 3rd US National Health and Nutrition Examination Survey conducted, found that waist circumference maintained a stronger association with CVD risk factors than the other measures of adiposity [50]. Further work is needed on assessing the quality and utility of the measures used in this study as well as the development of new ones for the Jamaican and developing world context.

The major strength of this study is that it represents pioneering work in a small island developing country context. We linked individually geocoded addresses from a nationally representative survey, with specific objective GIS-based retail food environment measures and provided empirical evidence using MLM to explore the association between objective neighbourhood-level retail food environment measures and BMI. Additionally, the sample characteristics that differed significantly with sex, were also included as covariates in the final models in order to minimize over or underestimation of the true strength of the associations detected between the neighbourhood food retail environment measures and BMI.

Despite strengths, there are limitations that deserve mention, including the inability to make causal inferences given the cross-sectional design of the JHLS II and our definition of neighbourhood. Using EDs to represent a Jamaican neighbourhood could be deemed inadequate as they i) are quite heterogeneous geographically in size, composition and context, and ii) may not fully represent exposure to the obesogenic environments being investigated. Additionally, although the outcome was objectively assessed, the risk factors included self-reported data on a single individual representing a household, which may introduce information bias. Furthermore, there was temporal mismatch of the data collected from individual JHLS II participants with that for the retail food environment-level variables, most of which were collected by MonaGIS in and after the year 2009, subsequent to the end of data collection for the JHLS II in 2008. This may have biased the results as individual exposures may have varied after the survey period, although food consumption behaviours are believed to be relatively stable over time. Lastly, the reliability and validity of the area-level environmental variables were untested locally and therefore uncertainty remains as to whether they were most effective in explaining any variance in the obesity-related outcomes. For example, a study conducted in a low-income neighborhood in Spain found a mismatch between GIS-based measures of the food environment and resident's perceptions of the environment [51]. Another challenge faced in Jamaica with accurately characterizing the neighbourhood retail food environment relates to the presence of and patronage of the foods provided by many itinerant vendors which are often energy-dense foods. The use of mixed-methods approaches in future research within small island developing states similar to Jamaica, may improve understanding on the associations with observed health-related behaviours such as food purchases (cost and locations) and dietary choices with BMI.

In conclusion, we found that further distance away from supermarkets and markets and their absence within a 1 km buffer zone from residences were associated with higher mean BMI, with important sex and social class differences. There has been an increase in the prevalence of obesity in Jamaica [3] despite the implementation of policies and programmes to ameliorate its impact on the continuum towards NCDs [52]. Higher mean BMI in Jamaicans may be partially explained by the presence of supermarkets and markets and differ by sex and social class. National efforts to curtail obesity in SIDS, like Jamaica should consider the inclusion of interventions and future studies focused at the neighbourhood-level that not only target the location and density of supermarkets and markets but also those that consider sex and social class-specific factors that maybe influencing the associations.

STATEMENTS

Contributors CC-M and KT conceived the study. LG and PL-A geocoded the data. CC-M, NY and KT analysed and interpreted the data. RW supervised the research. CC-M wrote the manuscript. PL-A, KT and RW edited the manuscript. All authors provided critical intellectual contributions and read and approved the final manuscript.

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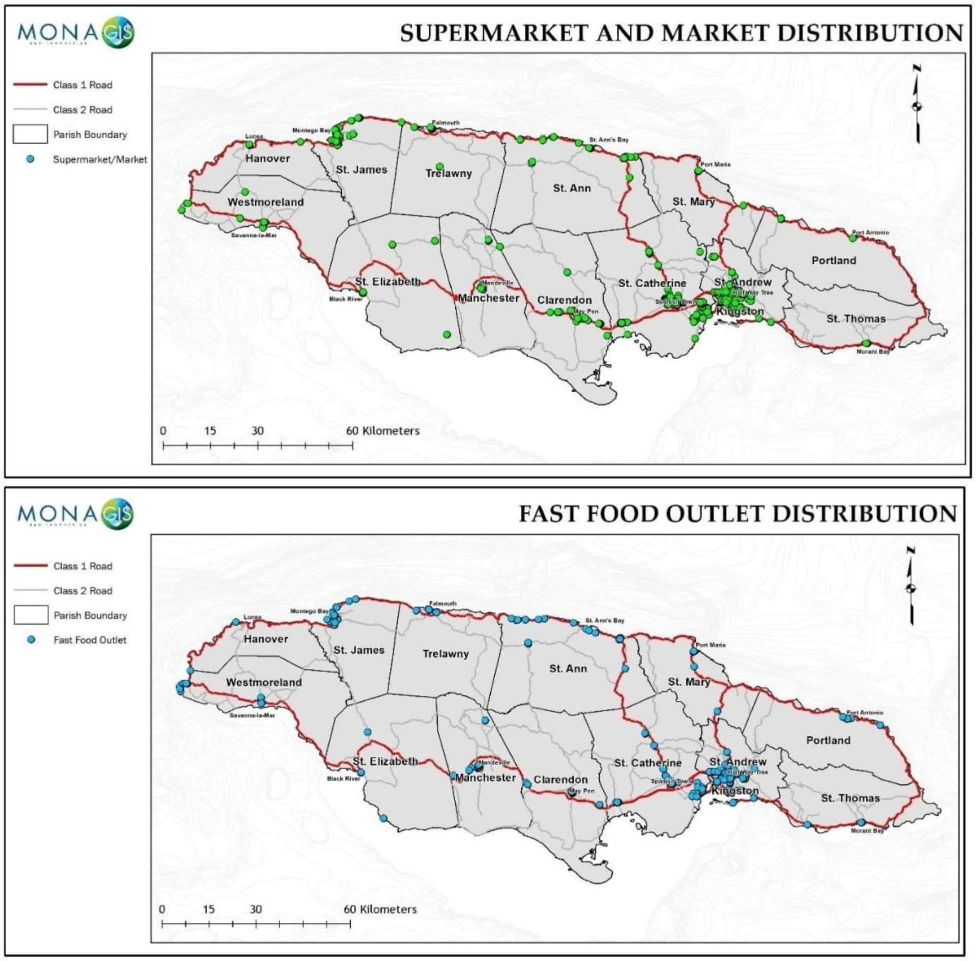
Figure 1. Spatial Distribution of Supermarket/markets (A) and Fast Food Outlets in Jamaica (B)

Figure 2. Sex-specific unadjusted and adjusted β Coefficients for the association of retail food environments with mean Body Mass Index

ǂ Dummy variable for zero inflated predictor
CI – Confidence Interval
Model 1 - unadjusted
Model 2 - age adjusted
Model 3 - adjusted for age and no. of possessions
Model 4 - adjusted for age, no. of possessions, urban, occupation, education, perception of unsafe community
*$p < 0.05$

Figure 3. SES-specific unadjusted and adjusted β Coefficients for the association of retail food environments with mean Body Mass Index

CI – Confidence Interval; ED – Enumeration District
ǂ Dummy variable for zero inflated predictor
Model 1 - unadjusted
Model 2 - age adjusted
Model 3 - adjusted for age and sex
Model 4 - adjusted for age, sex, urban, occupation, education, perception of unsafe community
*p < 0.05, ** p < 0.01



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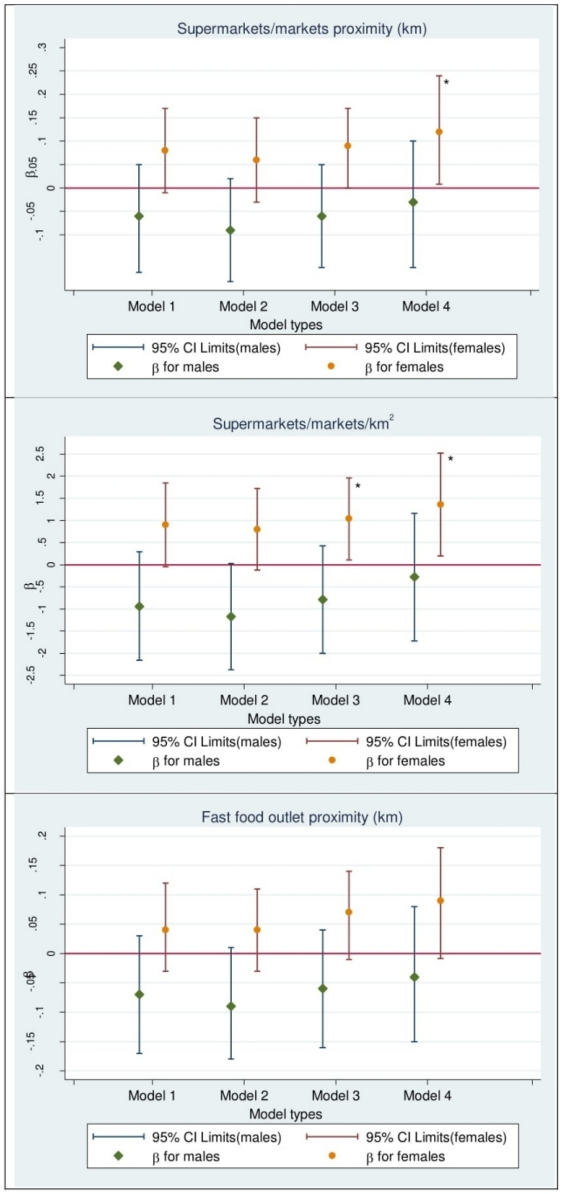

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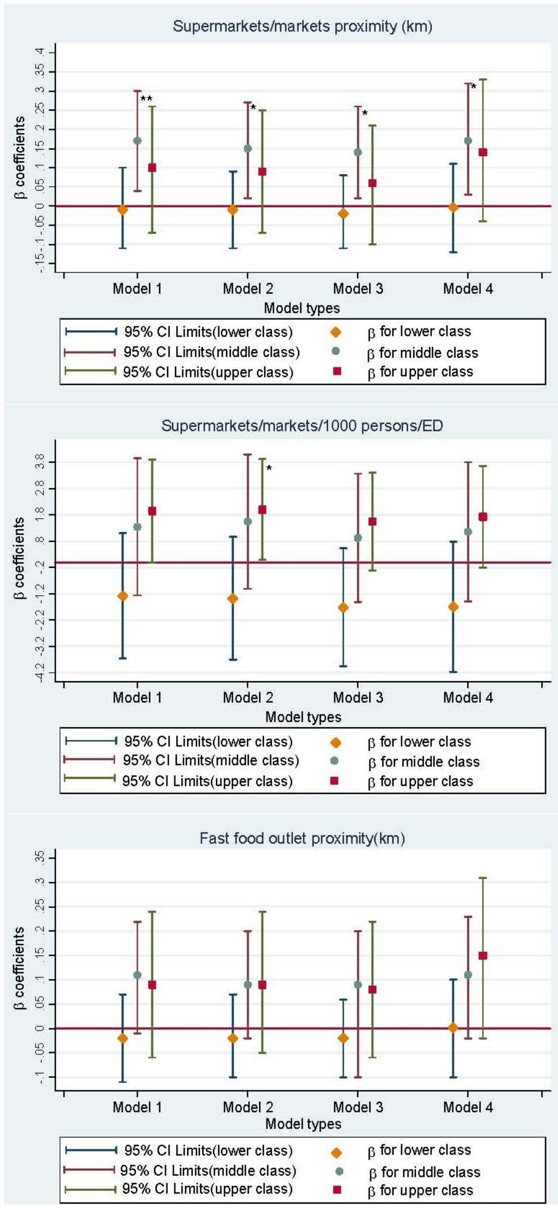

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Supplementary Table. Proportion of zero-valued observations for geographic variables

Retail Food Environments	**Frequency (%) N=2527**
Supermarkets/markets proximity (km)	0
Supermarkets/markets / km^2	61.30
Supermarkets/markets /1000 people/ ED	92.13
FFO proximity (km)	0
FFO / km^2	68.22
FFO / 1000 people/ ED	94.46

ED – Enumeration District; FFO - Fast Food Outlets

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract **[Within the title page 1 and methods section of the abstract page 2]**
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found **[See methods and results sections of abstract page 2]**
Introduction		
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported **[pages 4-5]**
Objectives	3	State specific objectives, including any prespecified hypotheses **[page 5]**
Methods		
Study design	4	Present key elements of study design early in the paper **[page 5-6]**
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection **[pages 6-8]**
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants **[pages 5- 6]**
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. **[pages 6-9]** Give diagnostic criteria, if applicable **[N/A]**
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group **[pages 6-9]**
Bias	9	Describe any efforts to address potential sources of bias **[pages 5-6, 8-9]**
Study size	10	Explain how the study size was arrived at **[page 5-6]**
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why **[pages 8-9]**
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding **[pages 8-9]**
		(*b*) Describe any methods used to examine subgroups and interactions **[page 9]**
		(*c*) Explain how missing data were addressed **[page 8]**
		(*d*) If applicable, describe analytical methods taking account of sampling strategy **[page 9]**
		(*e*) Describe any sensitivity analyses **[N/A]**
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed **[N/A]**
		(b) Give reasons for non-participation at each stage **[N/A]**
		(c) Consider use of a flow diagram **[N/A]**
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders **[page 9; Table 1]**
		(b) Indicate number of participants with missing data for each variable of interest **[N/A]**
Outcome data	15*	Report numbers of outcome events or summary measures **[page 9; Table 1]**

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). **[pages 9-10; Figures 2-3]** Make clear which confounders were adjusted for and why they were included **[page 6, Figures 2-3]**
		(*b*) Report category boundaries when continuous variables were categorized **[page 10, Table 1]**
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period **[N/A]**
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses **[pages 9-10]**
Discussion		
Key results	18	Summarise key results with reference to study objectives **[page 10]**
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias **[page 13]**
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence **[pages 12-13]**
Generalisability	21	Discuss the generalisability (external validity) of the study results **[page 13]**
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based **[page 14]**

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.