Associations between the traditional and novel neighbourhood built environment metrics and weight status among Canadian men and women.

Abstract:

Objectives: Neighbourhood characteristics can impact the health of residents. This study investigated associations between objectively-derived neighbourhood characteristics, including novel space syntax metrics, and self-reported body mass index (BMI) among Canadian men and women.

Methods: Our study included survey data collected from a random cross-section of adults residing in Calgary, Alberta (n=1,718). The survey, conducted in 2007/2008 captured participant's sociodemographic characteristics, health, and weight status (BMI). Participant's household postal codes were geocoded and 1600m lined-based network buffers estimated. Using Geographical Information System, we estimated neighbourhood characteristics within each buffer including *business destination density*, *street intersection density*, *sidewalk length, and population density*. Using space syntax, we estimated *street integration* and walkability (*street integration* plus *population density*) within each buffer. Using adjusted regression models, we estimated associations between neighbourhood characteristics and BMI (continuous) and BMI categories (healthy weight versus overweight including obese). Gender-stratified analysis was also performed.

Results: *Business destination density* was negatively associated with BMI and the odds of being overweight. Among men, *street intersection density* and *sidewalk length* were negatively associated with BMI and *street intersection density, business destination density, street integration*, and *space syntax walkability* were negatively associated with odds of being overweight. Among women, *business destination density* was negatively associated with BMI.

Conclusion: Urban planning policies that impact neighbourhood design has the potential to influence weight among adults living in urban Canadian settings. Some characteristics may have a differential association with weight among men and women and should be considered in urban planning and in neighbourhood-focussed public health interventions.

Keywords: neighbourhood, built environment, space syntax, walkability, obesity, body mass index.

Introduction:

Overweight and obesity are major public health issues in high-income, middle-income, and low-income countries (WHO, 2019). Despite efforts to tackle obesity, the prevalence of overweight or obesity continue to increase among different countries (NCD-RisC, 2017). Notably, the prevalence of obesity in Canada increased from 23.1% in 2004 to 26.7% in 2015 (Canadian Community Health Survey, 2015). More recent estimates suggest that among Canadian adults, 36.3% are overweight and 26.8% obese (StatCan, 2019). Alarmingly the prevalence of obesity in Canada is projected to increase further within the next two decades (Bancej et al., 2015). Population level interventions are needed to halt this troubling trend.

While individual-based strategies are important for management of excess weight, population-based strategies such as healthy public policy and provision of physical activity supportive built characteristics are also beneficial (Mayne, Auchincloss, & Michael, 2015). While often mixed, there is growing evidence suggesting relationships between neighbourhood characteristics and weight outcomes (Paulo dos Anjos Souza Barbosa et al., 2019). Most evidence from cross-sectional studies suggest that neighbourhood characteristics are associated with obesity in the general population (Müller-Riemenschneider et al., 2013; Oliver et al., 2015; Persson et al., 2018; Theodora Pouliou & Elliott, 2010). Much of the previous evidence suggests that neighbourhood characteristics such as *land use (business destination density), street connectivity (street intersection density),* and *population density* could be important for reducing obesity (Oliver et al., 2015; Paulo dos Anjos Souza Barbosa et al., 2019; T. Pouliou, Elliott, Paez, & Newbold, 2014). However, few studies have assessed whether associations between the neighbourhood environment and weight are more pronounced for certain sociodemographic subgroups (Carlson et al., 2016; Frank, Kerr, Sallis, Miles, & Chapman, 2008; Li & Ghosh, 2018; Persson et al., 2018). For instance, the effects of neighbourhood characteristics on weight outcomes sometimes appear stronger in men than in women (Frank et al., 2008; Li & Ghosh, 2018) or women than in men (Persson et al., 2018).

In response to calls for more policy and practice relevant built environment measures in health-related research (Giles-Corti et al., 2015), researchers have begun to explore novel but intuitive metrics of the built environment. For instance, several studies have applied space syntax metrics to better understand how the built environment is associated with various health-related outcomes (e.g., outdoor violence, car use, physical activity, and weight status) (Baran, Rodríguez, & Khattak, 2008; Koohsari et al., 2018; Koohsari et al., 2017; Koohsari, Sugiyama, et al., 2016b; McCormack et al., 2019; Summers & Johnson, 2017). Space syntax maps topology of street layouts with an emphasis on the alignment between open spaces and built-up areas in the local neighbourhood (Koohsari, Owen, Cerin, Giles-Corti, & Sugiyama, 2016a). One measure of space syntax is *street integration*, which is visualized as the number of turns taken by a pedestrian to travel from one street to another street within a network (Bafna, 2003). Higher *street integration* suggest more route choices and connectivity thus favouring pedestrian movement (Bin Jiang, 2009). *Street integration* has also been combined with *population density* to create the '*space syntax walkability*' (Koohsari et al., 2018; Koohsari, Owen, et al., 2016a). Space syntax walkability is positively correlated with components of overall walkability such as *net residential density*, *street intersection density*, and *retail floor area ratio* (Koohsari, Owen, et al., 2016a). *Street integration* is positively correlated with *street intersection density*, *availability of local destinations*, and *Walk Score*® (Koohsari et al., 2017; Koohsari, Sugiyama, et al., 2016b).

Studies have found space syntax measures (*street integration* and *space syntax walkability*) to be positively associated with transportation and leisure walking (Baran et al., 2008; Koohsari, Owen, et al., 2016a; Koohsari et al., 2017), especially neighbourhood-based transportation and leisure walking (McCormack et al., 2019). In a US study, Baran et al. (2008) showed that space syntax measures were positively associated with frequency of leisure walking. In an Australian study, Koohsari et al. (2016a) found that space syntax walkability to be positively associated with frequency of transportation walking. In another Australian study, Koohsari et al. (2017) found *street integration* to be positively associated with participation in any transportation walking and participation in >30 minutes of transportation walking per day. More recently, in a

Canadian study, McCormack et al. (2019) found *street integration* and *space syntax walkability* to be positively associated with participation in neighbourhood-based transportation and leisure walking, and weekly minutes of neighbourhood-based transportation walking. Given the fact that the built environment is associated with physical activity and physical activity is associated with weight outcomes (Fan et al., 2013; Farkas, Wagner, Nettel-Aguirre, Friedenreich, & McCormack, 2019), it might be expected that space syntax measures will be associated with weight outcomes. In an Australian longitudinal study, Koohsari et al. (2018) showed that *street integration* was associated with a lower weight gain among adults. In a UK longitudinal study, Sarkar et al. (2013) found built environment features such as land use mix index; density of retail services, churches, recreational and leisure facilities; street network accessibility; and neighbourhood slope variability to be associated with lower body mass index (BMI). However, Koohsari et al. (2018) did not determine the impact of space syntax on weight gain separately for men and women. Sarkar et al. (2013) studied the impact of built features on BMI among men only. This gender-specific evidence is important for designing interventions that are intended to impact weight equally for men and women.

The majority of studies investigating relationships between neighbourhood characteristics and weight outcomes have not taken into consideration number of years of residence in the current neighbourhood (neighbourhood tenure) (Carlson et al., 2016; Frank et al., 2008; Li & Ghosh, 2018; Müller-Riemenschneider et al., 2013; Theodora Pouliou & Elliott, 2010). If neighbourhood tenure is not controlled within regression models then this could lead to biased estimates of the associations between neighbourhood characteristics and weight outcomes (Miltenburg & van der Meer, 2016). To overcome the previous limitation of lack of control for neighbourhood tenure, our study estimated the associations between objectively-determined neighbourhood characteristics and space syntax measures and self-reported BMI. Moreover, we examined these associations for men and women. Understanding how neighbourhood characteristics influence weight status is important for establishing urban design policies in urban settings in Canada and elsewhere.

Methods:

Study and sample design: The methods for this study have been described elsewhere (McCormack et al., 2012). Briefly, during two-time periods (August to October 2007 and January to April 2008) random digit dialing of Calgary residential landline numbers was utilized to recruit adults (≥18 years of age) for a telephone interview. Response rates for telephone interviews during 2007 was 33.6% (n=2,199) and for 2008 was 36.7% (n=2,223), respectively. A subset of participants (1,817) who completed the telephone interview also completed a follow-up postal questionnaire. Between the telephone survey and postal questionnaire, information on sociodemographic and health-related characteristics, health behaviour, and weight status (BMI) was collected. During telephone interviews, participants also reported their 6-digit residential postal code.

Neighbourhood built characteristics: Geographic Information System Pro 2.4 (ESRI) was used to estimate neighbourhood characteristics within a 1600 m line-based network (sausage) buffer around each participant's geocoded postal code (called 'walkshed' area). Using municipal spatial databases (2008) and civic census data (2006), we estimated *population density (per km^2)*, *intersection density (per km^2)*, *sidewalk length (meters/km^2)* and *business destination density (per km^2)* for each walkshed. To calculate *street integration*, Axwomen (B. Jiang, 2012) and DepthMap (Turner, 2004) software were used. Street integration scores were calculated for all street segments within each walkshed with use of street centreline data (2008). For each walkshed, a mean street integration score was calculated by summating scores for all street segments and dividing this total score by number of street segments.

In alignment with previous studies (Carlson et al., 2016; Koohsari, Owen, et al., 2016a; Müller-Riemenschneider et al., 2013), estimates for *business destination density*, *street intersection density, sidewalk length, population density,* and *street integration* were standardized (z-scores) prior to analysis. We created space syntax walkability (SSW) for each participant using the formula (Koohsari, Owen, et al., 2016a): $SSW = Z\ [(Z_{\text{population density}}) + 2*(Z_{\text{street integration}})]$.

Outcome variables: Participants self-reported their height and weight in the postal questionnaire. Height and weight were used to estimate BMI. Self-reported height and weight measurements are shown to be reasonably accurate and reliable relative to clinical settings (Lin, DeRoo, Jacobs, & Sandler, 2012). In our analysis, BMI was maintained as a continuous variable as well as binary variable. Consistent with the World Health Organization's classification of obesity (WHO, 2019), we used a BMI cut-off value of 25 kg/m^2 for separating participants into two groups: healthy weight (BMI <25 kg/m^2) versus overweight (including obese) (BMI ≥25 kg/m^2). Our sample size and the low proportion of obese individuals (BMI ≥30 kg/m^2) restricted our analysis to these two BMI-based groups.

Covariates: Our study included the covariates age, gender, highest education level accomplished, gross annual household income, self-rated general health status, and neighbourhood tenure.

Data analysis method: A complete case analysis was the chosen option (n=1,718), as the proportion of missing data was low (5% missing; n=99). Means (standard deviations (SDs)) and frequencies (percentages) were estimated for continuous and categorical variables, respectively. To avoid collinearity, each built environment variable was examined separately in the regression analysis. We used adjusted linear regression models (beta-coefficient; β) to estimate associations between neighbourhood variables and continuous BMI. We used adjusted binary logistic regression models (odds ratio; OR) to estimate associations between neighbourhood variables and binary BMI. For both linear and logistic regression, we estimated 95 percent confidence intervals (CIs). Gender-stratified analysis was undertaken to detect differential effects of neighbourhood characteristics and space syntax measures on weight status among men and women. A p-value <0.05 was considered statistically significant. Statistical analysis was undertaken using Stata Version 15 (Stata Corp LLC, Texas, USA).

Results:

Descriptive statistics of the study participants

The mean (SD) age of the participants was 50.7 (15.2) years. Among the participants, 62% were women, 41% reported good general health status, 46% had completed a university degree, and 30% had earnings of >$120,000/year. Neighbourhood tenure for the participants ranged from 0 to 60 years (mean=12.9 years; SD=11.9 years). The mean (SD) BMI of the participants was 25.8 (4.1) kg/m^2 and 54% of participants were overweight (including obese). Notably, the mean BMI differed among men and women (men=26.6 kg/m^2; women=25.3 kg/m^2; p-value<0.001). The prevalence of overweight was higher in men than in women (men=67%; women=45%; p-value<0.001). *SSW* values for the participants ranged from -2.4 to 3.8 with a mean of 0.0 and a SD of 0.9 (Table 1).

Associations between built environment variables and BMI (pooled analysis)

Among all participants, after adjusting for covariates, *business destination density* was negatively associated with BMI ($\beta_{\textit{business destination density}}$ -0.24; CI -0.42, -0.05) (Table 2). *Business destination density* was also associated with a decrease in the odds of being overweight ($OR_{\text{business destination density}}$ 0.89; CI 0.81, 0.99) (Table 3). *Street integration* was associated with a decrease in the odds of being overweight, but this association only approached statistical significance ($OR_{\text{street integration}}$ 0.91; CI 0.82, 1.01; p-value=0.08) (Table 3). No other significant associations were found (Tables 2 and 3).

Associations between the built environment variables and BMI (men only)

Among men, after adjusting for covariates, *street intersection density* and *sidewalk length* were negatively associated with BMI ($\beta_{\textit{street intersection density}}$ -0.41; CI -0.70, -0.12, and; $\beta_{\text{sidewalk length}}$ -0.31; CI -0.60, -0.02, respectively) (Table 2). *Street intersection density* and *business destination density* were associated with a decrease in odds of being overweight among men ($OR_{\text{street intersection } \textit{density}}$ 0.96; CI 0.92, 0.99; $OR_{\text{business destination density}}$ 0.97; CI 0.94, 0.99) as were *street integration* ($OR_{\textit{street integration}}$ 0.96; CI 0.93, 0.99) and *SSW* ($OR_{\textit{SSW}}$ 0.97; CI 0.94, 0.99) (Table 3).

Associations between the built environment variables and BMI (women only)

Among women, after adjusting for covariates, *business destination density* was negatively associated with BMI (β *business destination density* -0.29; CI -0.55, -0.03) (Table 2). No other significant associations were found between neighbourhood variables and overweight among women (Table 3).

Discussion:

A statement of the principal findings of this study

According to this study, the neighbourhood built environment is associated with self-reported BMI. Importantly, associations between the neighbourhood built environment and BMI differed among men and women. Urban design interventions that target weight change may need to consider the available neighbourhood characteristics and space syntax metrics that may influence weight.

Comparison of study findings with other studies

In support of previous studies (Frank, Andresen, & Schmid, 2004; Theodora Pouliou & Elliott, 2010; Rundle et al., 2007), we found that destinations and land uses, specifically higher *business destination density,* was associated with a lower BMI or lower odds of being overweight. For instance, Pouliou et al. (2010) found that that higher *land use mix* (*residential, commercial, industrial, institutional* and *open space land uses)* was associated with a lower BMI among the Canadian adults. In a study conducted in New York (US), Rundle et al. (2007) found that higher *land use mix* (*commercial* and *residential land uses*) was associated with a lower BMI. In a study conducted in Atlanta (US), Frank et al. (2004) also found higher *land use mix* (*residential, commercial, office*, and *institutional land uses*) to be associated with lower odds of obesity. Fewer studies have found higher land use mix (*commercial* and *industrial land uses*) to be associated with a higher BMI (Rutt & Coleman, 2005) or found no significant associations between land use mix (*residential, commercial/retail, public open space, industrial*, and *other land uses*) and BMI (Oliver et al., 2015). Our findings are complementary to most studies supporting the link between land uses and weight status, but unique in that we included a measure focused on destinations and we also accounted for neighbourhood tenure (an indicator of neighbourhood exposure). While other studies show that the mix of land uses is important, our study demonstrates the count of neighbourhood business destinations is important in terms of weight outcomes. This association may exist because some destinations offer people with opportunities to eat healthy or unhealthily or to participate or not in physical activity in turn which might impact weight.

Street connectivity and *street integration* are special indices of street layout within a street network. *Street connectivity* and *street integration* measure different components of street layout. *Street connectivity* refers to the directness of routes between two locations within a street network (Handy, Paterson, & Butler, 2003). In most instances, *street connectivity* is quantified by measuring the number of street intersections within the local neighbourhood (Koohsari, Oka, Owen, & Sugiyama, 2019). On the other hand, street *integration* refers to the topological distance between two locations within a street network (Bafna, 2003). Simply stating, *street integration* refers to accessibility of a street segment within a street network (Koohsari et al., 2019). Dissimilar from our findings, Oliver et al. (2015) found a negative association between *street intersection density* and BMI among men and women combined. Pouliou et al. (2010) also found a negative association between *street intersection density* and BMI among men and women combined. However, our study found a negative association between *street intersection density* and BMI and odds of overweight (including obese) among men only. Different from the previous Australian longitudinal study (Koohsari et al., 2018), we found higher *street integration* to be associated with lower odds of overweight (including obese) among men. In comparison to previous study findings, our research suggests that some characteristics such as *street intersection density* and *street integration* might impact weight status of men more than the weight status of women. For the general population (not stratified on gender), *street integration* (but not *street intersection density*) is found elsewhere to be associated with higher odds of neighbourhood crime (Summers & Johnson, 2017). Neighbourhoods with higher *street integration* might be perceived by women to be unsafe and therefore they are more likely to participate in behaviours that negatively impact weight (poor diet, sedentary lifestyle, and low physical activity) (Pate, Taverno Ross, Liese, & Dowda, 2015).

Some investigators have examined walkability indices in relation to weight outcomes (Carlson et al., 2016; Müller-Riemenschneider et al., 2013). These walkability indices typically include the aggregation of individual built characteristics including: *land use (especially business destination density), street connectivity (especially street intersection density),* and *population density*. In general, study findings suggest negative associations between walkability indices and weight outcomes (Carlson et al., 2016; Müller-Riemenschneider et al., 2013). Our study included a walkability index that combined two built environment variables (*street integration* and *population density*) and was based on space syntax theory. Different from previous studies (Carlson et al., 2016; Müller-Riemenschneider et al., 2013), we included neighbourhood tenure as one of the covariates to account for exposure to the environment. We found that among men, but not women, higher space syntax walkability was associated with a lower odd of being overweight.

Contributing to previous studies (Frank et al., 2008; Li & Ghosh, 2018; Sarkar et al., 2013), we found an effect modification by gender in associations between neighbourhood characteristics and BMI. Previous research show that *residential density, street connectivity,* and *land-use mix* were associated with lower odds of obesity among men. Furthermore, in women, *street connectivity* was also found to be associated with higher odds of being overweight, and *residential density* with higher odds of being obese (Frank et al., 2008). Sarkar et al. (2013) found land use mix index; density of retail, churches, recreational and leisure facilities; street network accessibility; and neighbourhood slope variability to be inversely associated with BMI among men. Li et al. (2018) found that Walk Score® was inversely associated with BMI among middle-aged and old-aged men. Similar to Frank et al. (2008), we found that *street intersection density* and *business destination density* were associated with a lower likelihood of overweight among men. Not consistent with study of Frank et al. (2008), we found that *street intersection density* was negatively associated with BMI among men. Different from Sarkar et al. (2013), we found *business destination density* to be associated with lower BMI among women. Note that previous studies showing gender-specific associations had not adjusted for neighbourhood tenure (Frank et al., 2008; Li & Ghosh, 2018; Sarkar et al., 2013).

Strengths and limitations of this study

The inclusion of objectively-measured neighbourhood characteristics, novel indicators of the built environment determined using space syntax metrics, and adjustment for neighbourhood tenure among other covariates were strengths of this study. This study also has limitations. The cross-sectional study design does not allow us to infer a temporal causal relationship between the built environment and BMI. It is possible, that people's BMI are a reflection of behavioural preferences and these preferences are reflected in choice of neighbourhood based on its built features (i.e., self-selection). While self-reported BMI is reliable, social desirability bias may be present given the perceived stigma associated with height and weight among men and women (Burke & Carman, 2017). However, previous research shows that the estimated health risks are similar for self-reported or objectively measured weight outcomes (Stommel & Schoenborn, 2009). The ethnic composition of our sample consisted principally of 91% Whites and 9% non-Whites is also a limitation given ethnic differences in weight status exist (Kenney, Wang, & Iannotti, 2014). As the groups for ethnicity (non-Whites) were not specific, we did not include ethnicity as a covariate. The original study from which these data were collected investigated relations between the built environment and physical activity (McCormack et al., 2012), thus other built characteristics not available in these data but associated with weight (e.g., food destinations (Stevenson, Brazeau, Dasgupta, & Ross, 2019)) were not included. Our study included mostly established or "built-out" Calgary neighbourhoods that existed in 2007 and 2008. We acknowledge that the built environment in Calgary has changed in the past decade and while some of this change is due to gentrification, much of this change has been the result of new neighbourhood developments. Some built environment characteristics in "built-out" neighbourhoods are enduring and less likely to radically change over time (e.g., street intersections and layout, land use zoning, and sidewalks) while others are impermanent (e.g., destination types and population densities). While the age of these data threatens the external validity of our study, the findings demonstrate the link between the built environment and weight outcomes that still exist today (Paulo dos Anjos Souza Barbosa et al., 2019).

Conclusions and opportunities for future researchers

Neighbourhood characteristics including those estimated via novel space syntax metrics are related to BMI determined weight status in men and women. Our novel research findings were the negative associations of space syntax measures (*street integration* and *space syntax walkability)* with odds of overweight among men. By undertaking longitudinal analysis with more recent data, researchers might be able to better establish the causal link between the built environment and weight outcomes. Notably, more research is needed to investigate potential gender differences in associations between the built environment and BMI, especially as modifications to the built environment often assume that everyone is affected equally. Future studies should consider including space syntax variables, along with traditional measures of the neighbourhood built environment when investigating associations with weight status.

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Table 1: Sociodemographic, health-related, and neighbourhood characteristics of the participants

	Sociodemographic and health-related characteristics			
	Pooled Sample (n=1,718) mean (SD) or %	**Men** (n=657) mean (SD) or %	**Women** (n=1,061) mean (SD) or %	**Test Statistic** (p-value) [#]
Age (years)	50.7 (15.2)	51.6 (15.2)	50.2 (15.1)	1.8 (0.07)
Neighbourhood tenure (years)	12.9 (11.9)	12.5 (11.9)	13.0 (11.9)	-0.8 (0.4)
BMI (kg/m^2)	25.8 (4.1)	26.6 (3.7)	25.3 (4.2)	6.7 (0.000)[*]
Gender				
Men	38.2	100.0	-	-
Women	61.8	-	100.0	
Self-reported general health status				
Poor or fair	14.3	14.8	13.9	
Good	40.7	42.5	39.7	2.4 (0.5)
Very good	34.5	33.2	35.3	
Excellent	10.5	9.5	11.1	
Highest education level				
High school or less	29.4	25.4	31.9	11.6 (0.003)[*]
College or technical college	25.1	24.2	25.6	
University	45.5	50.4	42.5	

Gross household income per year (dollars)				
<60,000	29.3	27.1	30.6	
60,000 to 119,999	32.7	36.5	30.4	12.1 (0.007)*
≥120,000	29.9	30.3	29.6	
Refused or did not know	8.1	6.1	9.4	
BMI (binary)				
Healthy weight (<25 kg/m^2)	46.3	32.6	54.8	81.0 (0.000)*
Overweight and obesity (≥25 kg/m^2)	53.7	67.4	45.2	

Neighbourhood characteristics

	Pooled Sample (n=1,718) mean (SD)	**Men** (n=657) mean (SD)	**Women** (n=1,061) mean (SD)	**Test Statistic** (p-value)#
Population density[a] (Population per km^2 of walkshed)	3082.7 (1633.9)	3155.1 (1763.3)	3037.8 (1547.6)	1.4 (0.2)
Street intersection density[a] (Count of street intersections per km^2 of walkshed)	478.2 (185.8)	490.8 (187.3)	470.4 (184.6)	2.2 (0.03)*
Street integration[a] (Street integration score	191.2 (64.3)	195.9 (65.6)	188.3 (63.4)	2.4 (0.02)*

within walkshed)				
Sidewalk length[a] (Length of sidewalk in meters per km^2 of walkshed)	16193.5 (3677.5)	16287.4 (3730.4)	16135.3 (3644.9)	0.8 (0.4)
Business destination density[a] (Count of all businesses per km^2 of walkshed)	101.3 (218.8)	116.9 (250.1)	91.7 (196.4)	2.2 (0.03)*
SSW[b] (A composite index)	0.0 (0.9)	0.1 (1.1)	-0.04 (0.9)	2.3 (0.02)*

Abbreviations: BMI=body mass index; SD=standard deviation; SSW=space syntax walkability
a=neighbourhood characteristics estimated within a 1600 m line-based network buffer around each participant's geocoded postal code (walkshed area)
b=SSW estimated by using the following formula: SSW=Z $[(Z_{population\ density} + 2*Z_{street\ integration})]$
# =test statistic estimated by using chi-square test or t-test
*=p-value is significant

Table 2. Multivariable linear regression analysis for the associations of neighbourhood characteristics and space syntax measures with BMI (pooled and gender-specific analysis)

Neighbourhood characteristics	BMI (continuous)		
	Pooled Sample (n=1,718)	**Men** (n=657)	**Women** (n=1,061)
	β (95CI)[cd]	**β (95CI)**[cd]	**β (95CI)**[cd]
Population density[a]	0.08 (-0.11, 0.26)	-0.09 (-0.36, 0.18)	0.21 (-0.04, 0.45)
Street intersection density[a]	-0.13 (-0.31, 0.05)	-0.41 (-0.70, -0.12)*	0.04 (-0.19, 0.27)
Street integration[a]	-0.12 (-0.30, 0.06)	-0.23 (-0.51, 0.06)	-0.05 (-0.28, 0.18)
Sidewalk length[a]	-0.10 (-0.28, 0.09)	-0.31 (-0.60, -0.02)*	0.04 (-0.20, 0.27)
Business destination density[a]	-0.24 (-0.42, -0.05)*	-0.18 (-0.44, 0.07)	-0.29 (-0.55, -0.03)*
SSW[b]	-0.06 (-0.25, 0.12)	-0.20 (-0.47, 0.08)	0.04 (-0.20, 0.27)

Abbreviations: BMI=body mass index; β=beta-coefficient; CI=confidence interval; SSW=space syntax walkability
a=neighbourhood characteristics standardized prior to regression analysis (i.e., converted to z scores)
b=SSW estimated by using the following formula: $SSW=Z\ [(Z_{population\ density} + 2*Z_{street\ integration})]$
c=to prevent collinearity, one neighbourhood characteristic included in one regression model at a time
d=regression models adjusted for age, gender, self-rated health status, highest education level, gross household income, and neighbourhood tenure
*$p < 0.05$

Table 3. Multivariable logistic regression analysis for the associations of neighbourhood characteristics and space syntax measures with overweight and obesity (pooled and gender-specific analysis)

Neighbourhood characteristics	BMI (overweight and obese vs. healthy weight [reference])		
	Pooled Sample (n=922 vs. n=796)	**Men** (n=443 vs. n=214)	**Women** (n=479 vs. n=582)
	OR (95CI)[cd]	**OR (95CI)**[cd]	**OR (95CI)**[cd]
Population density[a]	0.99 (0.90, 1.10)	0.98 (0.95, 1.01)	1.02 (0.99, 1.05)
Street intersection density[a]	0.93 (0.84, 1.03)	0.96 (0.92, 0.99)*	1.00 (0.97, 1.03)
Street integration[a]	0.91 (0.82, 1.01)	0.96 (0.93, 0.99)*	0.99 (0.96, 1.02)
Sidewalk length[a]	0.92 (0.83, 1.03)	0.97 (0.94, 1.00)	0.99 (0.96, 1.02)
Business destination density[a]	0.89 (0.81, 0.99)*	0.97 (0.94, 0.99)*	0.99 (0.95, 1.02)
SSW[b]	0.93 (0.84, 1.03)	0.97 (0.94, 0.99)*	0.99 (0.97, 1.03)

Abbreviations: BMI=body mass index; OR=odds ratio; CI=confidence interval; SSW=space syntax walkability
a=neighbourhood characteristics standardized prior to regression analysis (i.e., converted to z scores)
b=SSW estimated by using the following formula: $SSW=Z [(Z_{\text{population density}} + 2*Z_{\text{street integration}})]$
c=to prevent collinearity, one neighbourhood characteristic included in one regression model at a time
d=regression models adjusted for age, gender, self-rated health status, highest education level, gross household income, and neighbourhood tenure
*$p < 0.05$