# Neighbourhood walkability and body mass index among different age groups: a cross-sectional analysis



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**Title:** Neighbourhood walkability and body mass index among different age groups: a cross-sectional analysis

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**ABSTRACT**

**Background**: Studies of neighbourhood walkability and BMI have shown mixed results, possibly due to biases from self-reported outcomes or differential effects across age groups. Our objective was to examine relationships between walkability and objectively-measured BMI in various age groups, in a nationally-representative population.

**Methods**: The study population came from the 2007-2011 Canadian Health Measures Survey, a cross-sectional survey of a nationally-representative Canadian population. In our covariate-adjusted analyses, we included survey respondents aged 6-79 who were not pregnant, did not live in rural areas, were not missing data, and were not thin/underweight. We used objectively-measured height and weight to calculate BMI among adults aged 18-79 and zBMI among children aged 6-17. We categorized respondents into walkability quintiles based on their residential Street Smart Walk Score® values. We performed linear regression to estimate differences between walkability quintiles in BMI and zBMI. We analyzed adults and children overall as well as the following age subgroups: 6-11, 12-17, 18-29, 30-44, 45-64, and 65-79.

**Results**: The covariate-adjusted models included 9,265 respondents in total. After adjustment, differences between walkability quintiles in BMI and zBMI were small and not statistically significant. This was true for children and adults overall, and for all age subgroups.

**Conclusion**: After accounting for confounding factors, we did not find evidence of a relationship between walkability and BMI in any of the age groups analyzed. Future studies should investigate the possibility of a relationship between walkability and diabetes or cardiovascular disease, which may exist independently of a relationship with BMI.

**Strengths and Limitations of this study:**

- This is the first study to examine how the relationship between walkability and BMI differs between different age groups, using objective measures of walkability and BMI
- This study analyzes a large nationally-representative Canadian population sample, which allows for stratification by age and adjustment for numerous socio-demographic variables
- Differences between study participants in variables such as caloric intake, amount of time spent in neighbourhood of residence, and preference for living in a more walkable neighbourhood were not accounted for
- The results are based on analyses of cross-sectional survey data and cannot be used to draw conclusions about a causal relationship between walkability and BMI

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**Contributorship statement:**
All authors contributed to conceptualizing and designing the study, planning analytical methods, and analyzing and interpreting statistical output. Justin Thielman conducted the literature review, statistical analysis, and drafted the manuscript. All authors reviewed the manuscript for intellectual content, made revisions as needed, and approved the final version for publication. All authors agree to be accountable for this work and to ensure that questions relating to the work are investigated and resolved.

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**Competing interests:** The authors have no personal, commercial, political, academic, financial, or other conflicts of interest to declare.

**Patient and public involvement**
Participant data are from a survey previously conducted by Statistics Canada. All participant identifiers had been removed from the data, so it was not possible to involve participants in the design of the study or dissemination of the results.

**Ethics approval:** The Ethics Review Board at Public Health Ontario approved this study after reviewing the protocol.

**Data sharing statement:**
No data are available.

## INTRODUCTION

Body mass index (BMI), a measure of body fat or adiposity, is an important risk factor for many chronic diseases.(1,2) BMIs from 25.0-29.9 kg/m$^2$ are classified as overweight and 30.0 kg/m$^2$ and over are classified as obese.(1,3) People with BMIs of 25.0 kg/m$^2$ and over are at increased risk of common and serious chronic illnesses, such as cardiovascular disease, type II diabetes, and certain cancers.(1,3) The prevalence of overweight and obesity, as measured through elevated BMI, has increased across the globe in recent decades.(3,4) Elevated BMI is common in the Canadian population; over half of adults and over a quarter of children have BMIs of 25 kg/m$^2$ or more.(5,6)

Health interventions that focus on changing individual behaviours have fallen short of reducing the high prevalence of overweight and obesity, which has prompted a focus on the environmental determinants of BMI.(7) In recent years, public health has focused on walkability, a measure of neighbourhood design that includes residential density, proximity to stores and services, and intersection density.(7) The underlying hypothesis is that walkable neighbourhoods encourage walking for transportation and other types of physical activity that contribute to reducing adiposity and lowering BMI.(8)

Despite the enthusiasm around walkability, research into the relationship between walkability and BMI or overweight and obesity has been mixed, with some studies showing a relationship and others showing minimal effects.(9,10) To some extent, this may be the result of differences in analytic methods or in measurement of study variables, such as BMI assessment method. Most studies have relied on self-reported height and weight to estimate BMI, which have been shown to be less accurate than direct measures.(4,11) People tend to overestimate height and underestimate weight, resulting in an artificially low BMI.(4,11) Failure to account for age differences in the relationship between walkability and BMI may also have contributed to the mixed results. Different studies have focused on specific age groups, such as children, youth, working-age adults, and seniors; however, all of these age groups have not been analyzed in a single study of walkability and BMI, where differential effects by age could be examined. Additionally, many earlier studies of walkability focused on only one or two cities, which may not have been representative of a broader population. Therefore, the objective of our study was to examine associations between walkability and objectively-measured BMI and compare associations across a range of age groups, in a nationally-representative population.



## METHODS

### Study design

This study was a cross-sectional survey that used cycle 1 (2007-2009) and cycle 2 (2009-2011) of the Canadian Health Measures Survey (CHMS).(12,13) The CHMS is a national health survey that collects both self-reported and direct measures. It uses a multi-stage sampling design stratified by geographic region, age, and sex. The survey covers 96% of Canadians, but excludes people in institutions, full-time Canadian Armed Forces members, people living on reserves or other Aboriginal settlements, certain remote regions, and the three Canadian territories.

**Setting**

The CHMS involves an in-person questionnaire conducted at participants' households, followed by direct measures taken at mobile clinics within 50 km of their households.(12,13)

**Population**

We combined CHMS cycles 1 and 2 to increase sample size. The combined response rate for people who completed both the household questionnaire and visit to the mobile examination centre was 51.7% in the 2007-2009 CHMS and 55.5% in the 2009-2011 CHMS. The response rate averaged across both cycles was 53.6%. Respondents were weighted to be nationally representative. Both cycles used the same data collection methods and included respondents with similar characteristics.(12,13) Cycle 1 included people aged 6-79, while cycle 2 included those aged 3-79; for comparability, we excluded 3-5 year olds from cycle 2 before combining the two cycles. When calculating walkability, we used points within census-defined geographic areas as proxies for residential locations; however, these geographic areas were very large in rural areas and therefore poor proxies for residential locations, so we excluded respondents living in rural areas. Non-rural dwelling was defined as continuous built-up areas of 1000 people or more, with at least 400 people/km$^2$.(14) We also excluded females who were pregnant or missing data on pregnancy because elevated BMI due to pregnancy is not necessarily an indicator of overweight or obesity. We excluded children under 18 who were missing birth dates, as these were needed to calculate BMI-for-age z-scores, and excluded any respondents missing directly measured height or weight, as these were needed to calculate BMIs and BMI z-scores. After these exclusions, our population sample included people aged 6-79, living in non-rural areas, not pregnant, and not missing data on pregnancy, height, weight, or birth date if under 18 (Figure 1). This is the population described in Table 1 and analyzed in the unadjusted analyses. Our adjusted analyses also excluded people missing any of the covariates in the models, as well as people classified as thin or underweight (BMI z-score >2 standard deviations below the mean for children, BMI < 18.5 kg/m$^2$ for adults). This was done because BMIs low enough to be classified thin or underweight are associated with unique health problems, such as chronic respiratory diseases,(15) that are not hypothesized to be related to walkability.

**Walkability data**

Our walkability indicator was the Street Smart Walk Score® metric (henceforth referred to as Walk Score®).(16) It is a validated metric that ranges from 0 (low walkability) to 100 (high walkability).(17,18) It is based on the number, variety, and proximity of different neighbourhood amenities such as restaurants/bars, parks, and schools, as well as street connectivity. The website https://www.redfin.ca/how-walk-score-works contains more information on the Walk Score® methodology. In 2014, we obtained Walk Score® values for latitude/longitude coordinates within the census dissemination areas in which CHMS respondents lived. Dissemination areas are designed to cover areas with 400-700 people.(19) In non-rural areas, this is small enough to approximate the locations of respondents' residences. We matched dissemination areas and their corresponding Walk Score® values to respondents by their postal codes using Statistics Canada's Postal Code Conversion File.(20)

**Body Mass Index (BMI)**

The CHMS measured participants' weights using a digital scale and their heights using a stadiometer. For respondents aged 18-79, we calculated BMI as weight in kilograms divided by squared height in metres. For respondents aged 6-17 we used a tool from the World Health Organization (WHO) that calculates BMI-for-age z-score.(21)

**Statistical analysis**

We divided respondents into quintiles based on their survey-weighted Walk Score® values. We also log transformed adult BMI to correct for its unequal variability at different Walk Score® values, as recommended by a Box-Cox transformation of BMI. We examined the degree of correlation between respondents in the same dissemination areas using the intraclass correlation coefficient. We built both unadjusted and covariate-adjusted linear regression models. Previous studies have shown that age interacts with walkability,(10,22) so we performed subgroup analyses within the following age strata: 6-11, 12-17, 18-29, 30-44, 45-64, 65-79. These groupings reflected our hypothesis that walkability may have varying effects on the following life stages: child, youth, young adult, early-middle-aged adult, late-middle-aged adult, and older retired/semiretired adult. For age groups 6-11 and 12-17, we modeled BMI z-score, adjusting for age, sex, cultural/racial origin, immigration within the past 10 years, household income, fruit/vegetable consumption, and survey cycle. For age groups 18-29, 30-44, 45-64, and 65-79, we modeled log(BMI), adjusting for all variables listed above, plus marital status, smoking, and leisure physical activity. We identified these variables as the most important confounders based on earlier research.(2,23–28). In all analyses, we used the bootstrap survey weights that were provided with the CHMS data to account for the complex survey design. We performed all analyses using SAS version 9.4.

**Ethics approval**

The Ethics Review Board of Public Health Ontario granted ethics approval after reviewing our study protocol. Statistics Canada's Research Data Centre granted access to the CHMS after reviewing our application and study protocol.

**Patient and public involvement**

Participant data are from a survey previously conducted by Statistics Canada. All participant identifiers had been removed from the data, so it was not possible to involve participants in the design of the study or dissemination of the results.

**RESULTS**

**Population**

There were 9,425 people aged 6-79, living in non-rural areas, not pregnant, and not missing data on pregnancy, height, weight, or birth date if under 18 in our sample. Table 1 shows the sociodemographic characteristics of the overall sample, as well as within each Walk Score® quintile. The population analyzed in our multivariable analysis, which also excluded people who were thin/underweight or missing covariates, was 9,265, including 3,098 children aged 6-17 and 6,167 adults aged 18-79 (Figure 1).

The intraclass correlation coefficient for respondents with the same dissemination area was 0.05, indicating low correlation; we, therefore, did not account for clustering by dissemination area in the analyses.

Table 1: Characteristics of Canada-wide study population, overall and by Walk Score® quintiles, N=9425

| Variable | Total | Lowest Walk Score® Q1: 0-23 | Walk Score® Q2: 24-40 | Walk Score® Q3: 41-58 | Walk Score® Q4: 59-79 | Highest Walk Score® Q5: 80-100 |
|---|---|---|---|---|---|---|
| **Age category (%)** | | | | | | |
| 6 - 11 | 7.3 | 9.9 | 8.4 | 7.6 | 6.3 | 4.8 |
| 12 - 17 | 8.5 | 8.8 | 11.0 | 9.3 | 7.7 | 6.2 |
| 18 - 29 | 19.2 | 16.8 | 19.4 | 16.7 | 21.0 | 22.1 |
| 30 - 44 | 23.8 | 23.8 | 20.9 | 24.4 | 20.5 | 29.1 |
| 45 - 64 | 30.9 | 32.1 | 31.4 | 31.2 | 31.2 | 28.9 |
| 65 - 79 | 10.2 | 8.7 | 9.0 | 10.8 | 13.3 | 8.9 |
| **Sex (%)** | | | | | | |
| Male | 50.3 | 48.8 | 48.0 | 49.2 | 51.6 | 53.7 |
| Female | 49.7 | 51.2 | 52.0 | 50.8 | 48.4 | 46.3 |
| **Cultural/racial origin (%)** | | | | | | |
| White | 75.7 | 86.3 | 81.3 | 73.5 | 68.9 | 69.2 |
| Black | 3.0 | 1.4 | 2.2 | 3.9 | 4.5 | 2.9 |
| Asian | 7.3 | 2.2 | 5.2 | 5.6 | 9.4 | 13.7 |
| South Asian | 4.8 | 2.5 | 4.7 | 5.9 | 8.2 | 2.5 |
| Other/N.A.[a] | 9.2 | 7.6 | 6.6 | 11.0 | 8.9 | 11.6 |
| **Immigrated to Canada in previous 10 years (%)** | | | | | | |
| Yes | 9.9 | 5.0 | 5.0 | 10.7 | 11.7 | 16.7 |
| No | 90.1 | 95.0 | 95.0 | 89.3 | 88.3 | 83.3 |
| **Marital status (%)** | | | | | | |
| Partnered | 52.7 | 57.0 | 54.8 | 53.2 | 51.8 | 47.3 |
| Not partnered | 47.3 | 43.0 | 45.2 | 46.8 | 48.2 | 52.7 |
| **Smoking status (age 12+ only) (%)** | | | | | | |
| Daily/non-daily smoker | 19.6 | 18.2 | 17.9 | 19.9 | 20.6 | 21.1 |
| Former/never smoker | 80.4 | 81.8 | 82.1 | 80.1 | 79.4 | 78.9 |
| **Household income[b, c]** $1,000 increments | 69000 (60000) | 80000 (60000) | 79000 (60000) | 69000 (55000) | 59000 (55000) | 55000 (60000) |
| **Number of times per day fruits or vegetables eaten[c]** | 3.1 (2.4) | 3.2 (2.4) | 3.1 (2.3) | 3.2 (2.4) | 3.1 (2.1) | 3.3 (2.4) |
| **Energy expenditure on leisure physical activity[c] (age 12+ only)** kcal/kg/day | 1.4 (2.4) | 1.4 (2.4) | 1.4 (2.3) | 1.3 (2.4) | 1.3 (2.3) | 1.6 (2.3) |
| **BMI (age 18+)** | 26.2 (6.5) | 26.9 (6.0) | 26.5 (6.9) | 26.5 (6.7) | 26.2 (6.6) | 24.9 (6.5) |
| **BMI z-score (age 6-17)** | 0.4 (1.7) | 0.5 (1.5) | 0.3 (1.9) | 0.3 (1.6) | 0.3 (1.6) | 0.3 (1.6) |

Q = Quintile. [a] "Other" includes people who reported Latin American, Southeast Asian, Arab, West Asian, Other, or Multiple; "N.A." includes people not asked about cultural/racial origin, which includes anyone who self-identified as Aboriginal. [b]Incomes rounded to nearest $1000.00. [c]Cell numbers are medians (interquartile ranges). All other cell numbers are percentages that have been weighted using Canadian Health Measures Survey sample weights, unless otherwise specified.

## BMI z-score

In the unadjusted analysis, 6-11 year olds in the third Walk Score® quintile had significantly lower BMI z-scores than those in the lowest Walk Score® quintile, on average. However, this association was no longer significant after adjusting for age, sex, cultural/racial origin, immigration, household income, and fruit/vegetable consumption (Table 2). There were no other significant associations between any Walk Score® quintiles among children under age 18, both before and after adjusting for covariates.

Table 2: Unadjusted and adjusted differences from lowest Street Smart Walk Score® quintile in BMI z-score, participants aged 6-17 N=9265

| Age group | Quintile (Street Smart Walk Score® range) | Unadjusted difference [95% CI] | Adjusted[a] difference [95% CI] | N for adjusted analysis |
|---|---|---|---|---|
| 6 to 17 | Q1 (0-23) | REF | REF [b] | 762 |
| | Q2 (24-40) | -0.115 [-0.340, 0.110] | -0.049 [-0.250, 0.153] | 656 |
| | Q3 (41-58) | -0.117 [-0.299, 0.065] | -0.099 [-0.275, 0.078] | 639 |
| | Q4 (59-79) | -0.199 [-0.434, 0.035] | -0.168 [-0.402, 0.066] | 566 |
| | Q5 (80-100) | -0.146 [-0.439, 0.148] | -0.129 [-0.410, 0.153] | 475 |
| 6 to 11 | Q1 (0-23) | REF | REF | 447 |
| | Q2 (24-40) | -0.257 [-0.530, 0.016] | -0.191 [-0.433, 0.051] | 364 |
| | Q3 (41-58) | **-0.250 [-0.474, -0.027]** | -0.174 [-0.390, 0.043] | 350 |
| | Q4 (59-79) | -0.107 [-0.427, 0.212] | -0.096 [-0.371, 0.180] | 326 |
| | Q5 (80-100) | -0.143 [-0.522, 0.236] | -0.086 [-0.381, 0.209] | 272 |
| 12 to 17 | Q1 (0-23) | REF | REF | 315 |
| | Q2 (24-40) | 0.034 [-0.240, 0.309] | 0.112 [-0.156, 0.379] | 292 |
| | Q3 (41-58) | 0.027 [-0.233, 0.287] | 0.030 [-0.245, 0.304] | 289 |
| | Q4 (59-79) | -0.240 [-0.548, 0.069] | -0.158 [-0.487, 0.170] | 240 |
| | Q5 (80-100) | -0.109 [-0.467, 0.250] | -0.112 [-0.499, 0.275] | 203 |

Statistically significant estimates at p<0.05 in bold. CI = confidence interval, Q1 = 1st Walk Score® quintile, Q2 = 2nd Walk Score® quintile, Q3 = 3rd Walk Score® quintile, Q4 = 4th Walk Score® quintile, Q5 = 5th Walk Score® quintile. [a]Estimates adjusted for sex, cultural/racial origin, immigration to Canada in the past 10 years, household income quintile, fruit/vegetable consumption, and survey cycle. [b]Analyses also adjusted for age category. Walk Score® values from 2014. Remaining variables from 2007-2011 Canadian Health Measures Survey.

Table 3: Unadjusted and covariate-adjusted differences from lowest Street Smart Walk Score® quintile in log(BMI), participants aged 18-79

| Age group | Quintile (Street Smart Walk Score® range) | Unadjusted difference [95% CI] | Adjusted[a] difference [95% CI] | N for adjusted analysis |
|---|---|---|---|---|
| 18 to 79 | Q1 (0-23) | REF | REF [b] | 1265 |
| | Q2 (24-40) | -0.014 [-0.037, 0.010] | -0.002 [-0.025, 0.021] | 1101 |
| | Q3 (41-58) | -0.015 [-0.043, 0.014] | -0.004 [-0.030, 0.022] | 1276 |
| | Q4 (59-79) | -0.025 [-0.055, 0.006] | -0.002 [-0.027, 0.024] | 1311 |
| | Q5 (80-100) | **-0.053 [-0.084, -0.023]** | -0.019 [-0.047, 0.009] | 1214 |
| 18 to 29 | Q1 (0-23) | REF | REF | 196 |
| | Q2 (24-40) | -0.025 [-0.087, 0.037] | -0.027 [-0.093, 0.040] | 197 |
| | Q3 (41-58) | -0.028 [-0.098, 0.043] | -0.033 [-0.101, 0.035] | 232 |
| | Q4 (59-79) | -0.039 [-0.100, 0.023] | -0.025 [-0.083, 0.034] | 275 |
| | Q5 (80-100) | **-0.052 [-0.096, -0.008]** | -0.035 [-0.083, 0.013] | 229 |
| 30 to 44 | Q1 (0-23) | REF | REF | 454 |
| | Q2 (24-40) | 0.013 [-0.045, 0.071] | 0.013 [-0.039, 0.064] | 368 |
| | Q3 (41-58) | -0.004 [-0.061, 0.052] | 0.015 [-0.037, 0.068] | 377 |
| | Q4 (59-79) | -0.015 [-0.071, 0.041] | 0.010 [-0.055, 0.076] | 353 |
| | Q5 (80-100) | -0.052 [-0.110, 0.006] | -0.017 [-0.080, 0.046] | 371 |
| 45 to 64 | Q1 (0-23) | REF | REF | 403 |
| | Q2 (24-40) | -0.017 [-0.047, 0.013] | -0.001 [-0.035, 0.032] | 345 |
| | Q3 (41-58) | -0.020 [-0.069, 0.029] | -0.007 [-0.052, 0.038] | 431 |
| | Q4 (59-79) | -0.017 [-0.060, 0.025] | 0.004 [-0.034, 0.041] | 405 |
| | Q5 (80-100) | -0.041 [-0.088, 0.005] | -0.021 [-0.064, 0.022] | 409 |
| 65 to 79 | Q1 (0-23) | REF | REF | 212 |
| | Q2 (24-40) | -0.021 [-0.066, 0.025] | -0.005 [-0.049, 0.038] | 191 |
| | Q3 (41-58) | -0.011 [-0.047, 0.026] | 0.007 [-0.026, 0.039] | 236 |
| | Q4 (59-79) | -0.029 [-0.066, 0.009] | -0.016 [-0.055, 0.024] | 278 |
| | Q5 (80-100) | -0.040 [-0.086, 0.006] | -0.012 [-0.062, 0.039] | 205 |

Statistically significant estimates at $p<0.05$ in bold. CI = confidence interval, Q1 = 1st Walk Score® quintile, Q2 = 2nd Walk Score® quintile, Q3 = 3rd Walk Score® quintile, Q4 = 4th Walk Score® quintile, Q5 = 5th Walk Score® quintile. [a]Estimates adjusted for sex, cultural/racial origin, immigration to Canada in the past 10 years, household income quintile, fruit/vegetable consumption, leisure physical activity, marital status, smoking status, and survey cycle. [b]Analyses of all respondents also adjusted for age category. Walk Score® values from 2014. Remaining variables from 2007-2011 Canadian Health Measures Survey.

**Log(BMI)**

In the unadjusted analysis of all adults aged 18-79, people in the highest Walk Score® quintile had significantly lower log(BMI) values than those in the lowest quintile. The highest quintile also had lower log(BMI) values among the subgroup of adults aged 18-29. However, both of these associations were no longer significant after adjusting for age, sex, cultural/racial origin, immigration, household income, marital status, smoking, fruit/vegetable consumption, and leisure physical activity. For all other comparisons among adults, there were no statistically significant associations between any Walk Score® quintile and log(BMI), both before and after covariate adjustment (Table 2).

## DISCUSSION

### Summary

After adjusting for relevant covariates, our study did not identify a relationship between neighbourhood walkability and objectively-measured BMI in the overall study population, or in any of the age subgroups. A number of earlier studies that examined the built environment and body mass showed null results as well. A longitudinal study of Australian adults did not find an association between walkability and self-reported weight change.(8) An American longitudinal study saw no significant change in objectively-measured BMI associated with a one standard deviation change in walkability index.(27) Conversely, several previous studies have identified statistically significant relationships. A study of adults aged 30-64 in Southern Ontario, Canada, found that people in the two highest quintiles of walkability had no change in prevalence of self-reported overweight and obesity over 11 years, while people in the lowest three quintiles had increased prevalence of overweight and obesity over this time period.(26) Another study in Ontario found that people in the highest walkability quintile had lower self-reported BMIs than people in the lower quintiles.(29) Findings from other Canadian studies were more mixed. Pouliou and colleagues found an association between walkability and self-reported BMI in Vancouver, but not in Toronto.(30) Glazier and colleagues found that people in the lowest walkability quintile had higher odds of self-reported overweight and obesity combined, but did not have higher odds of obesity alone.(31)

Studies of walkability and BMI have had less consistent findings than studies of walkability and physical activity, which have shown that people in more walkable areas tend to do more walking for transportation and more physical activity.(9,10,32) This may seem counterintuitive, as one might assume that higher physical activity should lower BMI. However, BMI is influenced by many factors of which physical activity is only one.(23) The higher physical activity associated with higher walkability may not be enough to reduce BMI by a measurable amount, given the multitude of other determinants of BMI.(33) For instance, diet may influence BMI to a greater extent than physical activity.(34) According to the Walking Calorie Burn Calculator by Shapesense, a 180 pound person who walks one kilometer in 15 minutes burns only 71 calories.(35)

### Strengths and Limitations

Our study has numerous strengths, including its use of objective measures of walkability and BMI, its large Canada-wide study population, and its inclusion of many sociodemographic characteristics. There are few studies of walkability that have used objective measures of BMI in a nationally-representative population. There are also several limitations that should be considered when interpreting our findings. There may be residual confounding from unmeasured covariates, including differences between quintiles in average caloric intake, the food environment, or length of time exposed to residential neighbourhoods.(36) We were also unable to account for differences in exposure to non-residential areas, such as workplace neighbourhoods, which may also impact BMI. Additionally, there was a time lag between the collection of height and weight data from the CHMS in 2007-2011 and calculation of Walk Score® values in 2014. However, major changes in Walk Score® quintiles are unlikely to have occurred during this time gap. Additionally, this was a cross-sectional study and therefore cannot be used to draw conclusions about a causal relationship. Finally, study results may not be generalizable to children younger than six or rural residents.

Despite the mixed results from studies of walkability and BMI, the potential health benefits of increasing walkability should continue to be investigated. Physical activity appears to improve health regardless of whether it results in weight loss**.**(37,38) While elevated BMI is correlated with several chronic diseases,(3,15) it has limitations as a risk factor for poor health. Other measures of adiposity, such as waist circumference, may be better indicators of metabolic risk than BMI.(39) One study found that women in more walkable areas had lower odds of abdominal obesity measured by waist circumference, but no significant difference in overall obesity measured by BMI.(40) A longitudinal study found that changes in walkability were associated with certain cardiometabolic risk factors, but not with BMI.(27) Future studies of walkability should directly examine the chronic diseases associated with insufficient physical activity, such as type 2 diabetes and cardiovascular disease. Given the established link between physical activity and type 2 diabetes and cardiovascular disease,(37,38) highly walkable areas may reduce risk of these diseases by increasing physical activity levels.

**Conclusions**

Our study did not identify any significant associations between neighbourhood walkability and BMI, overall or in any age group, after adjustment for a variety of confounders. This may reflect a relatively limited influence of moderately increased physical activity on BMI in the absence of a difference in other factors, such as diet. However, previous research has linked walkability with physical activity, which may have health benefits independent of BMI**.**(37,38) Future studies should investigate the relationship between walkability and diabetes or cardiovascular disease. If well-designed studies identify associations with these common chronic diseases, this will strengthen the evidence for improving overall health by increasing walkability.

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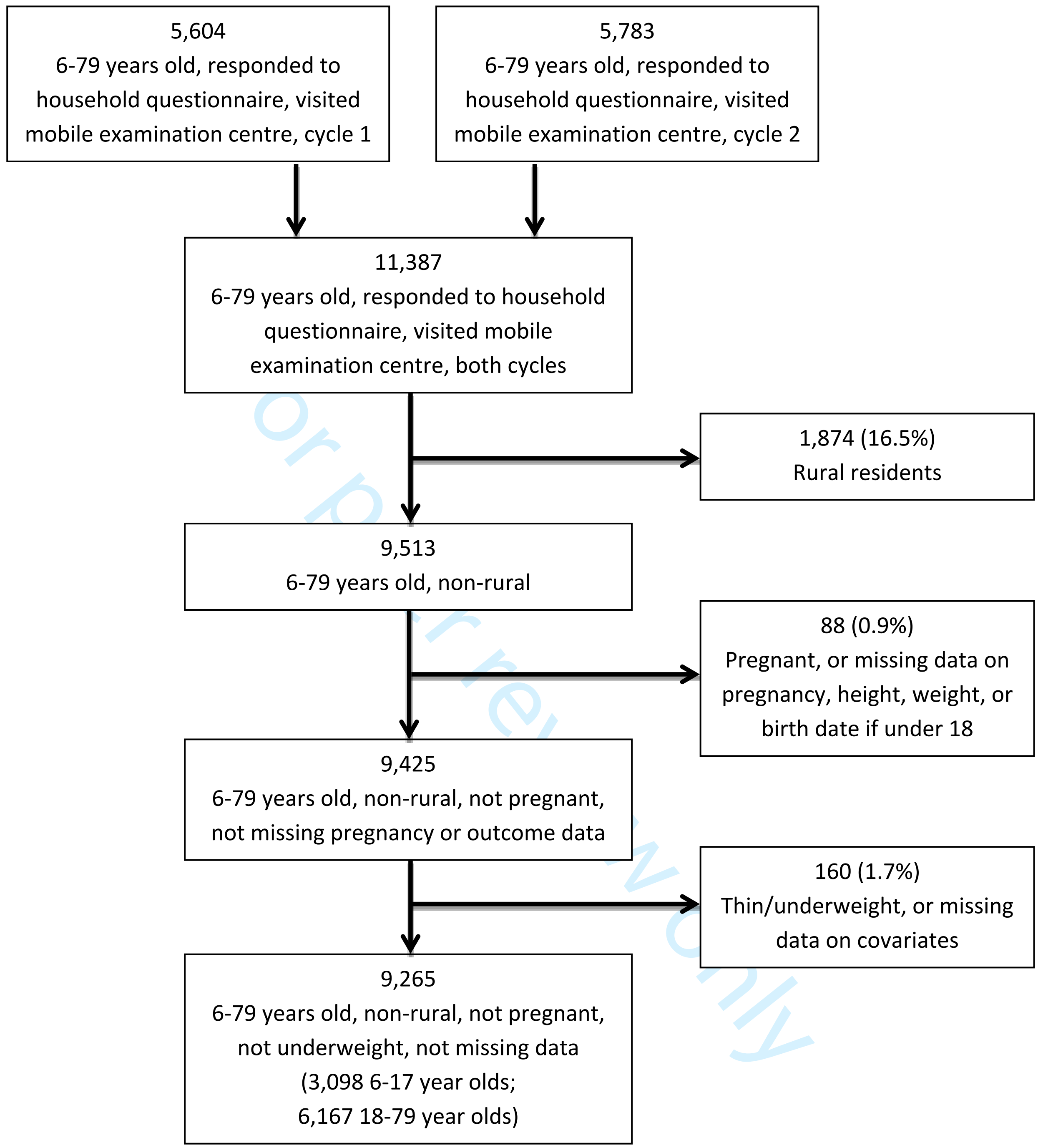


Figure 1: Flow diagram of study participants

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

| | Item No | Recommendation | Page No |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | iii |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | iii |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 1 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 1 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 1 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 1-2 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants | 1-2 |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 2-3 |
| 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 | 2-3 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 3 |
| Study size | 10 | Explain how the study size was arrived at | 2 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 3 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 3 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | 3 |
| | | (*c*) Explain how missing data were addressed | 2 |
| | | (*d*) If applicable, describe analytical methods taking account of sampling strategy | 3 |
| | | (*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 | Figure 1 |
| | | (b) Give reasons for non-participation at each stage | Figure 1 |
| | | (c) Consider use of a flow diagram | Figure 1 |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Table 1 |
| | | (b) Indicate number of participants with missing data for each variable of interest | Can't due to privacy |
| Outcome data | 15* | Report numbers of outcome events or summary measures | Table 1 |

| | | | |
|---|---|---|---|
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | Pg. 3, table 2, table 3 |
| | | (*b*) Report category boundaries when continuous variables were categorized | Table 1, table 2, table 3 |
| | | (*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 | 3-7 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 7 |
| 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 | 7-8 |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 7-8 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 8 |
| **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 | ii |

*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.

BMJ Open

# Is neighbourhood walkability related to body mass index among different age groups? A cross-sectional study of Canadian urban areas

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**Title:** Is neighbourhood walkability related to body mass index among different age groups? A cross-sectional study of Canadian urban areas

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## ABSTRACT

**Background**: Studies of neighbourhood walkability and BMI have shown mixed results, possibly due to biases from self-reported outcomes or differential effects across age groups. Our objective was to examine relationships between walkability and objectively-measured BMI in various age groups, in a nationally-representative population.

**Methods**: The study population came from the 2007-2011 Canadian Health Measures Survey, a cross-sectional survey of a nationally-representative Canadian population. In our covariate-adjusted analyses, we included survey respondents aged 6-79 who were not pregnant, did not live in rural areas, were not missing data, and were not thin/underweight. We used objectively-measured height and weight to calculate BMI among adults aged 18-79 and zBMI among children aged 6-17. We categorized respondents into walkability quintiles based on their residential Street Smart Walk Score® values. We performed linear regression to estimate differences between walkability quintiles in BMI and zBMI. We analyzed adults and children overall; age subgroups 6-11, 12-17, 18-29, 30-44, 45-64, 65-79; and sex subgroups.

**Results**: The covariate-adjusted models included 9,265 respondents overall. After adjustment, differences between walkability quintiles in BMI and zBMI were small and not statistically significant, except for males aged 6-17 in the second-highest walkability quintile who had significantly lower zBMIs than those in the lowest quintile.

**Conclusion**: After accounting for confounding factors, we did not find evidence of a relationship between walkability and BMI in children or adults overall, or in any age subgroup with sexes combined. However, post hoc analysis by sex suggested males aged 6-17 in more walkable areas may have lower zBMIs.

**Strengths and Limitations of this study:**

- This study uses objective measures of walkability and BMI to examine how the relationship between walkability and BMI differs between different age groups
- This study analyzes a large nationally-representative Canadian population sample, which allows for stratification by age and adjustment for numerous socio-demographic variables
- Differences between study participants in variables such as caloric intake, amount of time spent in neighbourhood of residence, and preference for living in a more walkable neighbourhood were not accounted for
- Residents of rural areas and individuals aged younger than six years or older than 79 years are not included in the study, so results may not be generalizable to these populations.

**Acknowledgments:** Access and support for using the Canadian Health Measures Survey was provided by

Statistics Canada's Research Data Centre Program. Street Smart Walk Score® values were provided by Redfin's Walk Score.

**Contributorship statement:**
JT, RC, LCR, MC, and HM contributed to conceptualizing and designing the study, planning analytical methods, and analyzing and interpreting statistical output. JT conducted the literature review, statistical analysis, and drafted the manuscript. JT, RC, LCR, MC, and HM reviewed the manuscript for intellectual content, made revisions as needed, and approved the final version for publication. JT, RC, LCR, MC, and HM agree to be accountable for this work and to ensure that questions relating to the work are investigated and resolved.

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**Disclaimer:** The study sponsor had no role in the study design; collection, analysis, or interpretation of data; report writing or review; approval of the manuscript; or the decision to submit for publication.

**Competing interests:** The authors have no personal, commercial, political, academic, financial, or other conflicts of interest to declare.

**Ethics approval:** The Ethics Review Board at Public Health Ontario approved this study after reviewing the protocol.

**Data sharing statement:**
The Canadian Health Measures Survey data are de-identified participant data, available upon successful application to Statistics Canada's Research Data Centre program:
https://www.statcan.gc.ca/eng/rdc/index

Street Smart Walk Score® values are geocoded walkability data available from Redfin's Walk Score:
https://www.redfin.ca/how-walk-score-works

## INTRODUCTION

Body mass index (BMI), a measure of body fat or adiposity, is an important risk factor for many chronic diseases.(1,2) BMIs from 25.0-29.9 kg/m$^2$ are classified as overweight and 30.0 kg/m$^2$ and over are classified as obese.(1,3) People with BMIs of 25.0 kg/m$^2$ and over are at increased risk of common and serious chronic illnesses, such as cardiovascular disease, type II diabetes, and certain cancers.(1,3) The prevalence of overweight and obesity, as measured through elevated BMI, has increased across the globe in recent decades.(3,4) Elevated BMI is common in the Canadian population; over half of adults and over a quarter of children have BMIs of 25 kg/m$^2$ or more.(5,6)

Health interventions that focus on changing individual behaviours have fallen short of reducing the high prevalence of overweight and obesity, which has prompted a focus on the environmental determinants of BMI.(7) In recent years, public health has focused on walkability, a measure of neighbourhood design that includes residential density, proximity to stores and services, and intersection density.(7) The underlying hypothesis is that walkable neighbourhoods encourage walking for transportation and other types of physical activity that contribute to reducing adiposity and lowering BMI.(8)

Despite the enthusiasm around walkability, research into the relationship between walkability and BMI or overweight and obesity has been mixed, with some studies showing a relationship and others showing minimal effects.(9,10) To some extent, this may be the result of differences in analytic methods or in measurement of study variables, such as BMI assessment method. Most studies have relied on self-reported height and weight to estimate BMI, which have been shown to be less accurate than direct measures.(4,11) People tend to overestimate height and underestimate weight, resulting in an artificially low BMI.(4,11) Failure to account for age differences in the relationship between walkability and BMI may also have contributed to the mixed results. Different studies have focused on specific age groups, such as children, youth, working-age adults, and seniors; however, all of these age groups have not been analyzed in a single study of walkability and BMI, where differential effects by age could be examined. Additionally, many earlier studies of walkability focused on only one or two cities, which may not have been representative of a broader population. Therefore, the objective of our study was to examine associations between walkability and objectively-measured BMI and compare associations across a range of age groups, in a nationally-representative population.

## METHODS

### Study design

This study was a cross-sectional survey that used cycle 1 (2007-2009) and cycle 2 (2009-2011) of the Canadian Health Measures Survey (CHMS).(12,13) The CHMS is a national health survey that collects both self-reported and direct measures. It uses a multi-stage sampling design stratified by geographic region, age, and sex. The survey covers 96% of Canadians, but excludes people in institutions, full-time Canadian Armed Forces members, people living on reserves or other Aboriginal settlements, certain remote regions, and the three Canadian territories.

**Setting**

The CHMS involves an in-person questionnaire conducted at participants' households, followed by direct measures taken at mobile clinics within 50 km of their households.(12,13)

**Population**

We combined CHMS cycles 1 and 2 to increase sample size. The combined response rate for people who completed both the household questionnaire and visit to the mobile examination centre was 51.7% in the 2007-2009 CHMS and 55.5% in the 2009-2011 CHMS. The response rate averaged across both cycles was 53.6%. Respondents were weighted to be nationally representative. Both cycles used the same data collection methods and included respondents with similar characteristics.(12,13) Cycle 1 included people aged 6-79, while cycle 2 included those aged 3-79; for comparability, we excluded 3-5 year olds from cycle 2 before combining the two cycles. When calculating walkability, we used points within census-defined geographic areas as proxies for residential locations; however, these geographic areas were very large in rural areas and therefore poor proxies for residential locations, so we excluded respondents living in rural areas. Non-rural dwelling was defined as continuous built-up areas of 1000 people or more, with at least 400 people/km$^2$.(14) We also excluded females who were pregnant or missing data on pregnancy because elevated BMI due to pregnancy is not necessarily an indicator of overweight or obesity. We excluded children under 18 who were missing birth dates, as these were needed to calculate BMI-for-age z-scores, and excluded any respondents missing directly measured height or weight, as these were needed to calculate BMIs and BMI z-scores. After these exclusions, our population sample included people aged 6-79, living in non-rural areas, not pregnant, and not missing data on pregnancy, height, weight, or birth date if under 18 (Figure 1). This is the population described in Table 1 and analyzed in the unadjusted analyses. Our adjusted analyses also excluded people missing any of the covariates in the models, as well as people classified as thin or underweight (BMI z-score >2 standard deviations below the mean for children, BMI < 18.5 kg/m$^2$ for adults). This was done because BMIs low enough to be classified thin or underweight are associated with unique health problems, such as chronic respiratory diseases,(15) that are not hypothesized to be related to walkability.

**Walkability data**

Our walkability indicator was the Street Smart Walk Score® metric (henceforth referred to as Walk Score®).(16) It is a validated metric that ranges from 0 (low walkability) to 100 (high walkability).(17,18) It is based on the number, variety, and proximity of different neighbourhood amenities such as restaurants/bars, parks, and schools, as well as street connectivity. The website https://www.redfin.ca/how-walk-score-works contains more information on the Walk Score® methodology. In 2014, we obtained Walk Score® values for latitude/longitude coordinates within the census dissemination areas in which CHMS respondents lived. Dissemination areas are designed to cover areas with 400-700 people.(19) In non-rural areas, this is small enough to approximate the locations of respondents' residences. We matched dissemination areas and their corresponding Walk Score® values to respondents by their postal codes using Statistics Canada's Postal Code Conversion File.(20)

### Body Mass Index (BMI)

The CHMS measured participants' weights using a digital scale and their heights using a stadiometer. For respondents aged 18-79, we calculated BMI as weight in kilograms divided by squared height in metres. For respondents aged 6-17 we used a tool from the World Health Organization (WHO) that calculates BMI-for-age z-score.(21)

### Statistical analysis

We divided respondents into quintiles based on their survey-weighted Walk Score® values. We also log transformed adult BMI to correct for its unequal variability at different Walk Score® values, as recommended by a Box-Cox transformation of BMI. We examined the degree of correlation between respondents in the same dissemination areas using the intraclass correlation coefficient. We built both unadjusted and covariate-adjusted linear regression models. Previous studies have shown that age interacts with walkability,(10,22) so we performed subgroup analyses within the following age strata: 6-11, 12-17, 18-29, 30-44, 45-64, 65-79. These groupings reflected our hypothesis that walkability may have varying effects on the following life stages: child, youth, young adult, early-middle-aged adult, late-middle-aged adult, and older retired/semiretired adult. We also performed post hoc subgroup analyses of males and females separately, as sex has also been shown to interact with walkability (23). For age groups 6-11 and 12-17, we modeled BMI z-score, adjusting for age, sex, cultural/racial origin, immigration within the past 10 years, household income, fruit/vegetable consumption, and survey cycle. For age groups 18-29, 30-44, 45-64, and 65-79, we modeled log(BMI), adjusting for all variables listed above, plus marital status, smoking, and leisure physical activity. We identified these variables as the most important confounders based on earlier research.(2,23–28). After modeling log(BMI), we reverse transformed the mean predicted log(BMI) values and their confidence intervals to obtain the average predicted BMI in each Walk Score® quintile. In all analyses, we used the bootstrap survey weights that were provided with the CHMS data to account for the complex survey design. We performed all analyses using SAS version 9.4.

### Ethics approval

The Ethics Review Board of Public Health Ontario granted ethics approval after reviewing our study protocol. Statistics Canada's Research Data Centre granted access to the CHMS after reviewing our application and study protocol.

### Patient and public involvement

Participant data are from a survey previously conducted by Statistics Canada. All participant identifiers had been removed from the data, so it was not possible to involve participants in the design of the study or dissemination of the results.

## RESULTS

### Population

There were 9,425 people aged 6-79, living in non-rural areas, not pregnant, and not missing data on pregnancy, height, weight, or birth date if under 18 in our sample. Table 1 shows the sociodemographic characteristics of the overall sample, as well as within each Walk Score® quintile. The population analyzed in our multivariable analysis, which also excluded people who were thin/underweight or missing covariates, was 9,265, including 3,098 children aged 6-17 and 6,167 adults aged 18-79 (Figure 1). The intraclass correlation coefficient for respondents with the same dissemination area was 0.05, indicating low correlation; we, therefore, did not account for clustering by dissemination area in the analyses.

Table 1: Characteristics of Canada-wide study population, overall and by Walk Score® quintiles, N=9425

| Variable | Total | Lowest Walk Score® Q1: 0-23 | Walk Score® Q2: 24-40 | Walk Score® Q3: 41-58 | Walk Score® Q4: 59-79 | Highest Walk Score® Q5: 80-100 |
|---|---|---|---|---|---|---|
| **Age category (%)** | | | | | | |
| 6 - 11 | 7.3 | 9.9 | 8.4 | 7.6 | 6.3 | 4.8 |
| 12 - 17 | 8.5 | 8.8 | 11.0 | 9.3 | 7.7 | 6.2 |
| 18 - 29 | 19.2 | 16.8 | 19.4 | 16.7 | 21.0 | 22.1 |
| 30 - 44 | 23.8 | 23.8 | 20.9 | 24.4 | 20.5 | 29.1 |
| 45 - 64 | 30.9 | 32.1 | 31.4 | 31.2 | 31.2 | 28.9 |
| 65 - 79 | 10.2 | 8.7 | 9.0 | 10.8 | 13.3 | 8.9 |
| **Sex (%)** | | | | | | |
| Male | 50.3 | 48.8 | 48.0 | 49.2 | 51.6 | 53.7 |
| Female | 49.7 | 51.2 | 52.0 | 50.8 | 48.4 | 46.3 |
| **Cultural/racial origin (%)** | | | | | | |
| White | 75.7 | 86.3 | 81.3 | 73.5 | 68.9 | 69.2 |
| Black | 3.0 | 1.4 | 2.2 | 3.9 | 4.5 | 2.9 |
| Asian | 7.3 | 2.2 | 5.2 | 5.6 | 9.4 | 13.7 |
| South Asian | 4.8 | 2.5 | 4.7 | 5.9 | 8.2 | 2.5 |
| Other/N.A.[a] | 9.2 | 7.6 | 6.6 | 11.0 | 8.9 | 11.6 |
| **Immigrated to Canada in previous 10 years (%)** | | | | | | |
| Yes | 9.9 | 5.0 | 5.0 | 10.7 | 11.7 | 16.7 |
| No | 90.1 | 95.0 | 95.0 | 89.3 | 88.3 | 83.3 |
| **Marital status (%)** | | | | | | |
| Partnered | 52.7 | 57.0 | 54.8 | 53.2 | 51.8 | 47.3 |
| Not partnered | 47.3 | 43.0 | 45.2 | 46.8 | 48.2 | 52.7 |
| **Smoking status (age 12+ only) (%)** | | | | | | |
| Daily/non-daily smoker | 19.6 | 18.2 | 17.9 | 19.9 | 20.6 | 21.1 |
| Former/never smoker | 80.4 | 81.8 | 82.1 | 80.1 | 79.4 | 78.9 |
| **Household income[b, c]** $1,000 increments | 69000 (60000) | 80000 (60000) | 79000 (60000) | 69000 (55000) | 59000 (55000) | 55000 (60000) |
| **Number of times per day fruits or vegetables eaten[c]** | 3.1 (2.4) | 3.2 (2.4) | 3.1 (2.3) | 3.2 (2.4) | 3.1 (2.1) | 3.3 (2.4) |
| **Energy expenditure on leisure physical activity[c] (age 12+ only)** kcal/kg/day | 1.4 (2.4) | 1.4 (2.4) | 1.4 (2.3) | 1.3 (2.4) | 1.3 (2.3) | 1.6 (2.3) |
| **BMI[c] (age 18+)** | 26.2 (6.5) | 26.9 (6.0) | 26.5 (6.9) | 26.5 (6.7) | 26.2 (6.6) | 24.9 (6.5) |
| **BMI z-score[c] (age 6-17)** | 0.4 (1.7) | 0.5 (1.5) | 0.3 (1.9) | 0.3 (1.6) | 0.3 (1.6) | 0.3 (1.6) |

Q = Quintile. [a] "Other" includes people who reported Latin American, Southeast Asian, Arab, West Asian, Other, or Multiple; "N.A." includes people not asked about cultural/racial origin, which includes anyone who self-identified as Aboriginal. [b]Incomes rounded to nearest $1000.00. [c]Cell numbers are medians (interquartile ranges). All other cell numbers are percentages that have been weighted using Canadian Health Measures Survey sample weights, unless otherwise specified.

**BMI z-score**

Among 6-17 year olds overall, children in each of the higher Walk Score® quintiles had slightly lower average BMI z-scores than those in the lowest Walk Score® quintile; however, none of these differences were statistically significant, both before and after adjusting for covariates (Table 2). In the unadjusted analysis, 6-11 year olds in the third Walk Score® quintile had significantly lower BMI z-scores than those in the lowest Walk Score® quintile, on average; however, this association was no longer significant after adjusting for age, sex, cultural/racial origin, immigration, household income, and fruit/vegetable consumption (Table 2). In the subgroup analysis by sex, males aged 6-17 in higher Walk Score® quintiles had lower average BMI z-scores, a difference not observed among females (Table 3). The difference among males in the fourth quintile was statistically significant and remained significant after adjusting for age, cultural/racial origin, immigration, household income, and fruit/vegetable consumption. There were no other significant associations between any Walk Score® quintiles among children under age 18, both before and after adjusting for covariates.

Table 2: Unadjusted and adjusted differences from lowest Street Smart Walk Score® quintile in BMI z-score, participants aged 6-17, overall and by age group (N=3,098)

| Age group | Quintile (Street Smart Walk Score® range) | Unadjusted difference in BMI z-score [95% CI] | Adjusted[a] difference in BMI z-score [95% CI] | N for adjusted analysis |
|---|---|---|---|---|
| 6 to 17 | Q1 (0-23) | REF | REF [b] | 762 |
| | Q2 (24-40) | -0.115 [-0.340, 0.110] | -0.049 [-0.250, 0.153] [b] | 656 |
| | Q3 (41-58) | -0.117 [-0.299, 0.065] | -0.099 [-0.275, 0.078] [b] | 639 |
| | Q4 (59-79) | -0.199 [-0.434, 0.035] | -0.168 [-0.402, 0.066] [b] | 566 |
| | Q5 (80-100) | -0.146 [-0.439, 0.148] | -0.129 [-0.410, 0.153] [b] | 475 |
| 6 to 11 | Q1 (0-23) | REF | REF | 447 |
| | Q2 (24-40) | -0.257 [-0.530, 0.016] | -0.191 [-0.433, 0.051] | 364 |
| | Q3 (41-58) | **-0.250 [-0.474, -0.027]** | -0.174 [-0.390, 0.043] | 350 |
| | Q4 (59-79) | -0.107 [-0.427, 0.212] | -0.096 [-0.371, 0.180] | 326 |
| | Q5 (80-100) | -0.143 [-0.522, 0.236] | -0.086 [-0.381, 0.209] | 272 |
| 12 to 17 | Q1 (0-23) | REF | REF | 315 |
| | Q2 (24-40) | 0.034 [-0.240, 0.309] | 0.112 [-0.156, 0.379] | 292 |
| | Q3 (41-58) | 0.027 [-0.233, 0.287] | 0.030 [-0.245, 0.304] | 289 |
| | Q4 (59-79) | -0.240 [-0.548, 0.069] | -0.158 [-0.487, 0.170] | 240 |
| | Q5 (80-100) | -0.109 [-0.467, 0.250] | -0.112 [-0.499, 0.275] | 203 |

Statistically significant estimates at p<0.05 in bold. CI = confidence interval, Q1 = 1st Walk Score® quintile, Q2 = 2nd Walk Score® quintile, Q3 = 3rd Walk Score® quintile, Q4 = 4th Walk Score® quintile, Q5 = 5th Walk Score® quintile. [a]Estimates adjusted for sex, cultural/racial origin, immigration to Canada in the past 10 years, household income quintile, fruit/vegetable consumption, and survey cycle. [b]Analyses also adjusted for age category. Walk Score® values from 2014. Remaining variables from 2007-2011 Canadian Health Measures Survey.

Table 3: Unadjusted and adjusted differences from lowest Street Smart Walk Score® quintile in BMI z-score, participants aged 6-17, by sex (N=3,098)

| Sex | Quintile (Street Smart Walk Score® range) | Unadjusted difference in BMI z-score [95% CI] | Adjusted[a] difference in BMI z-score [95% CI] | N for adjusted analysis |
|---|---|---|---|---|
| Male | Q1 (0-23) | REF | REF | 396 |
| | Q2 (24-40) | -0.191 [-0.644, 0.261] | -0.110 [-0.499, 0.279] | 321 |
| | Q3 (41-58) | -0.303 [-0.677, 0.071] | -0.239 [-0.537, 0.058] | 326 |
| | Q4 (59-79) | **-0.460 [-0.812, -0.107]** | **-0.399 [-0.737, -0.060]** | 301 |
| | Q5 (80-100) | -0.373 [-0.859, 0.113] | -0.333 [-0.804, 0.139] | 227 |
| Female | Q1 (0-23) | REF | REF | 366 |
| | Q2 (24-40) | -0.009 [-0.208, 0.190] | 0.050 [-0.220, 0.320] | 335 |
| | Q3 (41-58) | 0.075 [-0.148, 0.298] | 0.090 [-0.119, 0.298] | 313 |
| | Q4 (59-79) | 0.086 [-0.236, 0.408] | 0.161 [-0.129, 0.452] | 265 |
| | Q5 (80-100) | 0.098 [-0.164, 0.360] | 0.188 [-0.018, 0.393] | 248 |

Statistically significant estimates at $p<0.05$ in bold. CI = confidence interval, Q1 = 1st Walk Score® quintile, Q2 = 2nd Walk Score® quintile, Q3 = 3rd Walk Score® quintile, Q4 = 4th Walk Score® quintile, Q5 = 5th Walk Score® quintile. [a]Estimates adjusted for age category, cultural/racial origin, immigration to Canada in the past 10 years, household income quintile, fruit/vegetable consumption, and survey cycle. Walk Score® values from 2014. Remaining variables from 2007-2011 Canadian Health Measures Survey.

**Log(BMI)**

In the unadjusted analysis of all adults aged 18-79, people in the highest Walk Score® quintile had significantly lower log(BMI) values than those in the lowest quintile (Table 4). The highest quintile also had significantly lower log(BMI) values among the subgroup of adults aged 18-29, and among the male and female subgroups (Tables 4 and 5). However, all of these associations were no longer significant after adjusting for age, sex, cultural/racial origin, immigration, household income, marital status, smoking, fruit/vegetable consumption, and leisure physical activity. While average log(BMI)s were slightly lower in the highest Walk Score® quintiles in all other comparisons among adults, the differences were not statistically significant, both before and after covariate adjustment.

Table 4: Unadjusted and covariate-adjusted differences from lowest Street Smart Walk Score® quintile in log(BMI), participants aged 18-79, overall and by age group (N=6,167)

| Age group | Quintile (Street Smart Walk Score® range) | Unadjusted difference in log(BMI) [95% CI] | Adjusted[a] difference in log(BMI) [95% CI] | Mean predicted BMI [95% CI] | N for adjusted analysis |
|---|---|---|---|---|---|
| 18 to 79 | Q1 (0-23) | REF | REF [b] | 27.7 [26.8, 28.6] | 1265 |
| | Q2 (24-40) | -0.014 [-0.037, 0.010] | -0.002 [-0.025, 0.021] [b] | 27.5 [26.6, 28.5] | 1101 |
| | Q3 (41-58) | -0.015 [-0.043, 0.014] | -0.004 [-0.030, 0.022] [b] | 27.4 [26.4, 28.4] | 1276 |
| | Q4 (59-79) | -0.025 [-0.055, 0.006] | -0.002 [-0.027, 0.024] [b] | 27.3 [26.2, 28.3] | 1311 |
| | Q5 (80-100) | **-0.053 [-0.084, -0.023]** | -0.019 [-0.047, 0.009] [b] | 26.6 [25.6, 27.6] | 1214 |
| 18 to 29 | Q1 (0-23) | REF | REF | 25.9 [24.3, 27.5] | 196 |
| | Q2 (24-40) | -0.025 [-0.087, 0.037] | -0.027 [-0.093, 0.040] | 25.2 [23.2, 27.3] | 197 |
| | Q3 (41-58) | -0.028 [-0.098, 0.043] | -0.033 [-0.101, 0.035] | 25.1 [23.0, 27.4] | 232 |
| | Q4 (59-79) | -0.039 [-0.100, 0.023] | -0.025 [-0.083, 0.034] | 25.2 [23.2, 27.3] | 275 |
| | Q5 (80-100) | **-0.052 [-0.096, -0.008]** | -0.035 [-0.083, 0.013] | 24.8 [23.1, 26.8] | 229 |
| 30 to 44 | Q1 (0-23) | REF | REF | 27.2 [25.6, 29.0] | 454 |
| | Q2 (24-40) | 0.013 [-0.045, 0.071] | 0.013 [-0.039, 0.064] | 27.7 [26.4, 29.0] | 368 |
| | Q3 (41-58) | -0.004 [-0.061, 0.052] | 0.015 [-0.037, 0.068] | 27.5 [26.2, 29.0] | 377 |
| | Q4 (59-79) | -0.015 [-0.071, 0.041] | 0.010 [-0.055, 0.076] | 27.2 [25.6, 29.0] | 353 |
| | Q5 (80-100) | -0.052 [-0.110, 0.006] | -0.017 [-0.080, 0.046] | 26.3 [24.7, 27.9] | 371 |
| 45 to 64 | Q1 (0-23) | REF | REF | 28.4 [27.2, 29.6] | 403 |
| | Q2 (24-40) | -0.017 [-0.047, 0.013] | -0.001 [-0.035, 0.032] | 28.3 [27.1, 29.7] | 345 |
| | Q3 (41-58) | -0.020 [-0.069, 0.029] | -0.007 [-0.052, 0.038] | 28.0 [26.5, 29.7] | 431 |
| | Q4 (59-79) | -0.017 [-0.060, 0.025] | 0.004 [-0.034, 0.041] | 28.2 [26.7, 29.8] | 405 |
| | Q5 (80-100) | -0.041 [-0.088, 0.005] | -0.021 [-0.064, 0.022] | 27.3 [25.7, 28.9] | 409 |
| 65 to 79 | Q1 (0-23) | REF | REF | 28.6 [27.3, 30.0] | 212 |
| | Q2 (24-40) | -0.021 [-0.066, 0.025] | -0.005 [-0.049, 0.038] | 28.2 [26.8, 29.7] | 191 |
| | Q3 (41-58) | -0.011 [-0.047, 0.026] | 0.007 [-0.026, 0.039] | 28.6 [27.3, 29.9] | 236 |
| | Q4 (59-79) | -0.029 [-0.066, 0.009] | -0.016 [-0.055, 0.024] | 27.9 [26.6, 29.3] | 278 |
| | Q5 (80-100) | -0.040 [-0.086, 0.006] | -0.012 [-0.062, 0.039] | 27.6 [26.1, 29.3] | 205 |

Statistically significant estimates at p<0.05 in bold. CI = confidence interval, Q1 = 1st Walk Score® quintile, Q2 = 2nd Walk Score® quintile, Q3 = 3rd Walk Score® quintile, Q4 = 4th Walk Score® quintile, Q5 = 5th Walk Score® quintile. [a]Estimates adjusted for sex, cultural/racial origin, immigration to Canada in the past 10 years, household income quintile, fruit/vegetable consumption, leisure physical activity, marital status, smoking status, and survey cycle. [b]Analyses of all respondents also adjusted for age category. Walk Score® values from 2014. Remaining variables from 2007-2011 Canadian Health Measures Survey.

Table 5: Unadjusted and adjusted differences from lowest Street Smart Walk Score® quintile in log(BMI), participants aged 18-79, by sex (N=6,167)

| Sex | Quintile (Street Smart Walk Score® range) | Unadjusted difference in log(BMI) [95% CI] | Adjusted[a] difference in log(BMI) [95% CI] | Mean predicted BMI [95% CI] | N for adjusted analysis |
|---|---|---|---|---|---|
| Male | Q1 (0-23) | REF | REF | 28.2 [27.1, 29.3] | 577 |
| | Q2 (24-40) | -0.023 [-0.058, 0.012] | -0.013 [-0.045, 0.020] | 27.6 [26.5, 28.8] | 518 |
| | Q3 (41-58) | -0.012 [-0.046, 0.022] | -0.002 [-0.033, 0.028] | 27.7 [26.6, 28.9] | 600 |
| | Q4 (59-79) | -0.020 [-0.062, 0.023] | 0.001 [-0.033, 0.034] | 27.6 [26.4, 28.8] | 595 |
| | Q5 (80-100) | **-0.050 [-0.092, -0.007]** | -0.019 [-0.062, 0.024] | 27.0 [25.8, 28.2] | 618 |
| Female | Q1 (0-23) | REF | REF | 27.3 [26.1, 28.5] | 688 |
| | Q2 (24-40) | -0.005 [-0.034, 0.025] | 0.006 [-0.018, 0.030] | 27.4 [26.2, 28.7] | 583 |
| | Q3 (41-58) | -0.018 [-0.057, 0.021] | -0.007 [-0.042, 0.027] | 27.1 [25.5, 28.7] | 676 |
| | Q4 (59-79) | -0.031 [-0.064, 0.002] | -0.002 [-0.038, 0.033] | 27.0 [25.6, 28.5] | 716 |
| | Q5 (80-100) | **-0.062 [-0.099, -0.024]** | -0.023 [-0.052, 0.007] | 26.1 [24.8, 27.5] | 596 |

Statistically significant estimates at p<0.05 in bold. CI = confidence interval, Q1 = 1st Walk Score® quintile, Q2 = 2nd Walk Score® quintile, Q3 = 3rd Walk Score® quintile, Q4 = 4th Walk Score® quintile, Q5 = 5th Walk Score® quintile. [a]Estimates adjusted for age category, cultural/racial origin, immigration to Canada in the past 10 years, household income quintile, fruit/vegetable consumption, leisure physical activity, marital status, smoking status, and survey cycle. Walk Score® values from 2014. Remaining variables from 2007-2011 Canadian Health Measures Survey.

## DISCUSSION

### Summary

After adjusting for relevant covariates, our study did not identify a significant relationship between neighbourhood walkability and objectively-measured BMI in the overall study population, or in any of the age subgroups. Although, while not statistically significant, average BMI was slightly lower in the highest walkability quintile among adults overall and in all adult subgroups. Additionally, in our post hoc analysis of sex subgroups, there was evidence that males aged 6-17 living in higher Walk Score® quintiles had lower BMI z-scores than those in the lowest quintile, on average.

A number of earlier studies that examined the built environment and body mass showed null results. A longitudinal study of Australian adults did not find an association between walkability and self-reported weight change.(8) An American longitudinal study saw no significant change in objectively-measured BMI associated with a one standard deviation change in walkability index.(27) Conversely, several previous studies have identified statistically significant relationships. A study of adults aged 30-64 in Southern Ontario, Canada, found that people in the two highest quintiles of walkability had no change in prevalence of self-reported overweight and obesity over 11 years, while people in the lowest three quintiles had increased prevalence of overweight and obesity over this time period.(26) Another study in Ontario found that people in the highest walkability quintile had lower self-reported BMIs than people in the lower quintiles.(29) Ontario is a province of Canada that includes over one third of Canada's population, so the aforementioned positive results are based on populations similar to our study population. Perhaps our discordant results are due to our use of objective measures of BMI, rather than self-report. Self-reported BMI values are prone to biases (4), so it is possible that mitigating these biases resulted in our non-significant results.

Findings from other Canadian studies were more mixed. Pouliou and colleagues found an association between walkability and self-reported BMI in Vancouver, but not in Toronto.(30) Glazier and colleagues found that people in the lowest walkability quintile had higher odds of self-reported overweight and obesity combined, but did not have higher odds of obesity alone.(31) A longitudinal study by Wasfi and colleagues found that men who moved to more walkable areas had decreased BMI trajectories, while men who moved to less walkable areas had increased BMI trajectories; however, no relationship between walkability and BMI was found among women (23). After adjusting for confounders, our study did not show a significant relationship between walkability and BMI among adult males or females; however, we did find evidence of a lower average BMI z-score among male children in higher Walk Score® quintiles, which did not show up among female children. Firm conclusions cannot be drawn from this finding, as it was the result of a post hoc subgroup analysis. However, future research should further explore how the relationship between walkability and BMI z-score may differ between males and females.

Studies of walkability and BMI have had less consistent findings than studies of walkability and physical activity, which have shown that people in more walkable areas tend to do more walking for transportation and more physical activity.(9,10,32) This may seem counterintuitive, as one might assume that higher physical activity should lower BMI. However, BMI is influenced by many factors of which physical activity is only one.(24) The higher physical activity associated with higher walkability may not be enough to reduce BMI by a measurable amount, given the multitude of other determinants of BMI.(33) For instance, diet may influence BMI to a greater extent than physical activity.(34) According to the Walking Calorie Burn Calculator by Shapesense, a 180 pound person who walks one kilometer in 15 minutes burns only 71 calories.(35)

**Strengths and Limitations**

Our study has numerous strengths, including its use of objective measures of walkability and BMI, its large Canada-wide study population, and its inclusion of many sociodemographic characteristics. There are few studies of walkability that have used objective measures of BMI in a nationally-representative population. There are also several limitations that should be considered when interpreting our findings. There may be residual confounding from unmeasured covariates, including differences between quintiles in average caloric intake, the food environment, or length of time exposed to residential neighbourhoods.(36) We were also unable to account for differences in exposure to non-residential areas, such as workplace neighbourhoods, which may also impact BMI. Additionally, there was a time lag between the collection of height and weight data from the CHMS in 2007-2011 and calculation of Walk Score® values in 2014. However, major changes in Walk Score® quintiles are unlikely to have occurred during this time gap, so we do not expect the time difference to impact the results. Likewise, we do not expect the age of the study data, the oldest of which is from 2007, to impact study findings.

The relationship between walkability and health outcomes, such as BMI, is unlikely to have changed since 2007. Additionally, this was a cross-sectional study and therefore cannot be used to draw conclusions about a causal relationship. Finally, study results may not be generalizable to children younger than six or rural residents.

Despite the mixed results from studies of walkability and BMI, the potential health benefits of increasing walkability should continue to be investigated. Physical activity appears to improve health regardless of whether it results in weight loss**.**(37,38) While elevated BMI is correlated with overall mortality and with several chronic diseases,(3,15) it has limitations as a risk factor for poor health. The association between BMI and mortality is stronger among some populations than others. For instance, it is stronger among younger adults than among older adults (1). Other measures of adiposity, such as waist circumference, may be better indicators of metabolic risk than BMI.(39) One study found that women in more walkable areas had lower odds of abdominal obesity measured by waist circumference, but no significant difference in overall obesity measured by BMI.(40) A longitudinal study found that changes in walkability were associated with certain cardiometabolic risk factors, but not with BMI.(27) Future studies of walkability should directly examine the chronic diseases associated with insufficient physical activity, such as type 2 diabetes and cardiovascular disease. Given the established link between physical activity and type 2 diabetes and cardiovascular disease,(37,38) highly walkable areas may reduce risk of these diseases by increasing physical activity levels.

**Conclusions**

Our study did not identify significant associations between neighbourhood walkability and BMI, overall or in any age group, after adjustment for a variety of confounders. Although, in our post hoc analysis of sex subgroups, there appeared to be a significant association between walkability and BMI z-score among males aged 6-17. Future studies are needed to explore whether a relationship exists among boys, but not girls. Our mostly non-significant findings may reflect a relatively limited influence of moderately increased physical activity on BMI in the absence of a difference in other factors, such as diet. However, previous research has linked walkability with physical activity, which may have health benefits independent of BMI**.**(37,38) Future studies should investigate the relationship between walkability and diabetes or cardiovascular disease. If well-designed studies identify associations with these common chronic diseases, this will strengthen the evidence for improving overall health by increasing walkability.

Figure 1: Flow diagram of study participants

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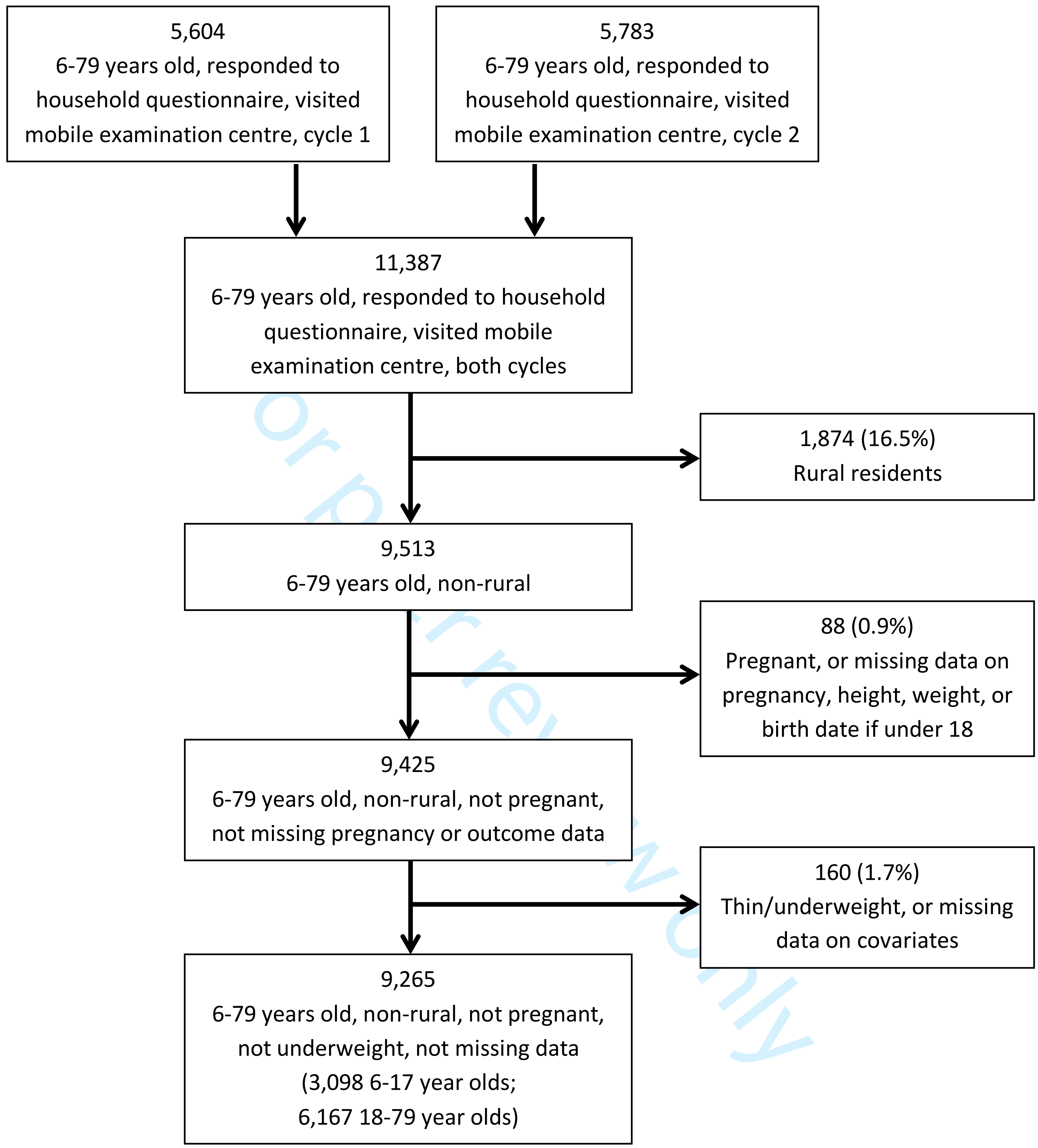


Figure 1: Flow diagram of study participants

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

| | Item No | Recommendation | Page No |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | iii |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | iii |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 1 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 1 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 1 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 1-2 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants | 1-2 |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 2-3 |
| 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 | 2-3 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 3 |
| Study size | 10 | Explain how the study size was arrived at | 2 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 3 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 3 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | 3 |
| | | (*c*) Explain how missing data were addressed | 2 |
| | | (*d*) If applicable, describe analytical methods taking account of sampling strategy | 3 |
| | | (*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 | Figure 1 |
| | | (b) Give reasons for non-participation at each stage | Figure 1 |
| | | (c) Consider use of a flow diagram | Figure 1 |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | Table 1 |
| | | (b) Indicate number of participants with missing data for each variable of interest | Can't due to privacy |
| Outcome data | 15* | Report numbers of outcome events or summary measures | Table 1 |

| | | | |
|---|---|---|---|
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | Pg. 3, table 2, table 3 |
| | | (*b*) Report category boundaries when continuous variables were categorized | Table 1, table 2, table 3 |
| | | (*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 | 3-7 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 7 |
| 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 | 7-8 |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 7-8 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 8 |
| **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 | ii |

*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.