Published in final edited form as:
Int J Obes (Lond). 2010 August ; 34(8): 1275–1283. doi:10.1038/ijo.2010.36.

Changes in BMI over 6 years: the role of demographic and neighborhood characteristics

TR Berry[1], **JC Spence**[1], **C Blanchard**[2], **N Cutumisu**[1], **J Edwards**[3], and **C Nykiforuk**[4]

[1]Faculty of Physical Education and Recreation, University of Alberta, Alberta, Alberta, Canada

[2]Department of Medicine, Centre for Clinical Research Dalhousie University, Halifax, Nova Scotia, Canada

[3]Population and Public Health Portfolio, Alberta Health Services, Alberta, Alberta, Canada

[4]Centre for Health Promotion Studies, School of Public Health Sciences, University of Alberta, Alberta, Alberta, Canada

Abstract

Objective—To undertake a 6-year longitudinal investigation of the relationship between the built environment (perceived and objectively measured) and change in body mass index (BMI). Specifically, this research examined whether change in BMI was predicted by objectively measured neighborhood walkability and socioeconomic status (SES), and perceived neighborhood characteristics (for example, crime, traffic and interesting things to look at) in addition to other factors such as age, gender, education, physical activity, fruit and vegetable consumption and smoking.

Design—Longitudinal study

Subjects—500 adults who provided complete data in 2002 and 2008 and who did not move over the course of the study (47.8% female; age in 2002: 18–90 years).

Measurements—Telephone surveys in 2002 and 2008 measuring perceptions of their neighborhood environment and demographic factors. Objective measures of neighborhood characteristics were calculated using census data and geographical information systems in 2006.

Results—Age, neighborhood SES and perceived traffic were significantly related to increased BMI over the 6 years. Younger participants and those in lower SES neighborhoods were more likely to have increased BMI. Agreement with the statement that traffic made it difficult to walk also predicted increased BMI.

Conclusion—This study adds to the literature to show that BMI increased in low SES neighborhoods. Although more research is needed to fully understand how neighborhood SES contributes to obesity, it is without question that individuals in socially disadvantaged neighborhoods face more barriers to health than their wealthier counterparts. This study also calls

Correspondence: Dr TR Berry, Faculty of Physical Education and Recreation, University of Alberta, E4-88 Van Vliet Centre, Edmonton, Alberta, T6G 2H9, Canada. Tanya.berry@ualberta.ca.

Conflict of interest
The authors declare no conflict of interest.

into question the relationship between walkability and changes in BMI and emphasizes the necessity of longitudinal data rather than relying on cross-sectional research.

Keywords

built environment; walkability; BMI change; longitudinal

Obesity is a contributing factor to multiple chronic diseases including cardiovascular disease, hypertension, osteoarthritis and diabetes.[1] Similarly, change in body mass index (BMI) over time is related to increased risk of disease. For example, gaining more than two BMI points over 8 years increased risk of having a major cardiovascular event in men younger than 60 years[2] and BMI gains over 14 years increased cardiovascular disease risk factors.[3] Men who were overweight with high risk of cardiovascular disease (CVD) at midlife who lost weight when older were at the highest risk of mortality.[4] Given such evidence, prospective studies into the etiology of increased BMI are warranted.

One factor hypothesized to influence obesity is the walkability of a neighborhood; that is, how pleasant and easy it is to walk in a neighborhood. Such environmental measures can be objectively measured or can be assessed by asking neighborhood residents their perceptions of their neighborhoods and both have been shown to be related to health outcomes. Features of perceived walkability include residential density, proximity and perceived access to stores and facilities, street connectivity, facilities for walking and cycling, aesthetics and safety from traffic and crime.[5] Similarly, features within the built environment can be used to quantify objective walkability into indices that are found to be associated with walking[6,7] and with obesity.[8–11] The most popular index of objective walkability consists of an assessment of density, diversity, design and area in retail use.[6]

As objective walkability of a neighborhood is associated with physical activity,[11,12] it is reasonable to expect that walkability may be associated with obesity risk and associated diseases. Indeed, there is cross-sectional evidence that children and adults who live in higher density, mixed-use neighborhoods (that is, include both residential and commercial properties) have lower rates of obesity than do people who live in lower density, residential only neighborhoods.[11,13] Frank *et al.*[14] reported that an improvement in the objective walkability of a neighborhood of only 5% was associated with 32% more time spent in active transportation and a 0.23 point reduction in BMI. However, others have found no relationship between the objectively measured built environment and obesity for those participants who had lived in the same house for more than 2 years.[15] In one of the few longitudinal studies published to date, only women and not men living in areas of a city with high street connectivity (one indicator of walkability) were less likely to be overweight or obese.[16] Another study showed that although cross-sectional data supported relationships between less urban sprawl and increased walking and lower rates of obesity, longitudinal data did not support a relationship between moving to less sprawling communities and lower BMI. According to the argument of Lee *et al.*[17] this suggests that cross-sectional data supporting relationships between walkable neighbourhoods and activity rates or obesity reflect self-selection to neighbourhoods rather than features within neighbourhoods influencing physical activity. Perceptions of the neighborhood environment including poor sidewalks, crime and physical disorder are also associated with higher levels of obesity.[18–21] According to Burdette and Hill,[19] much of this association may be explained by psychological distress.

The relationship between socioeconomic status (SES) and obesity should also be considered as SES is predictive of increased BMI.[22] Living in areas that are at a socioeconomic disadvantage was associated with less overall physical activity.[23] There is also a relationship between neighborhood SES and perceptions of walkability. Giles-Corti and Donovan[24] found that individuals living in low SES neighborhoods were more likely to perceive they had access to sidewalks, but that their neighborhood was busier with traffic, less attractive and less supportive of walking. In other research, low-SES residents reported their neighborhoods were less pleasant, had greater numbers of unattended dogs, higher crime rates and less trustworthy neighbours than did individuals in high-SES neighborhoods.[25] Lopez and Hynes[26] have referred to low rates of physical activity and high rates of obesity in low-income urban areas despite mixed-use environments and high street connectivity (that is, areas that are objectively walkable) as the inner-city paradox. They argue that this conflicting relationship is likely because of a mix of land-use, social and infrastructure issues. For example poverty (social), abandoned buildings (land-use) and lack of adequate street lighting (infrastructure) combine to make walking a challenge for residents. Within this relationship, it is also important to consider demographic factors related to BMI, as cross-sectional research has shown both men and women with less than high school education, married men and sedentary individuals have higher BMI. Harrington *et al.*[27] also reported lower BMI in smokers. These authors report that although such individual level differences account for the majority of the variance, neighborhood SES also predicted BMI and thus both individual and neighborhood variables should be taken into account. Others have also reported that BMI increased with age, and was associated with less education.[28]

Although there are research-linking features of the built environment, both objective and perceived, such as neighborhood walkability and SES and obesity, the body of literature is limited by primarily cross-sectional research designs and studies are needed to examine these relationships longitudinally. Therefore, the objective of this research was to undertake a 6-year longitudinal investigation of the relationship between the built environment (perceived and objectively measured) and obesity (as measured by BMI). Specifically, this research examined if objectively measured neighborhood walkability and SES, and perceived neighborhood characteristics (e.g., crime, traffic and interesting things to look at) in addition to other factors such as age, gender, education, physical activity, fruit and vegetable consumption and smoking predicted change in BMI.

Materials and methods

Data used in this study were collected through population surveys in 2002 and 2008 in the Edmonton region of Alberta. The 2002 data were part of a population health survey conducted by the Population Health and Research Department, Public Health, in the former Capital Health region, Edmonton. The purpose of the survey was to assess and monitor selected population health issues, health determinants, risk factors and priorities in the Capital Health region (which includes the City of Edmonton and outlying regions). The survey target population was individuals aged 18 years or older and living in the former Capital Health region.

There were 4175 participants in the 2002 sample. This sample was restricted to those living within the City of Edmonton limits (n=3174), as the geographical data layers that were used to calculate a walkability index are available for within city limits only. Of these participants, 2362 agreed to be contacted for future studies. In 2008, 822 participants completed the follow-up survey, of whom 599 had not moved since 2002. Complete data were available for 500 participants after list-wise deletion of missing data, thus our final analysis was conducted with these data. Data from the original sample were gathered between 28 October, 2002 and 15 December, 2002. The follow-up survey took place between 10 November, 2008 and 15 January, 2009.

Measures

The survey instrument was designed by members of the Population Health and Research branch, with assistance from researchers from the University of Alberta. For comparability to other Canadian and provincial studies, most survey questions were consistent with the International Physical Activity Questionnaire (IPAQ),[29] Canadian Tobacco Use Monitoring Survey[30] and Canadian Community Health Survey.[31]

Sociodemographic variables—Sociodemographics questions were based on the Canadian Community Health Survey[31] and included age, gender, ethnicity, education, employment, marital status and household annual income. In the 2008 survey, participants were also asked if they had moved since 2002.

Fruit and vegetable consumption—Three questions were based on the fruits and vegetables module of the Canadian Community Health Survey[31] and asked how many times per week participants usually drank fruit juices, ate fruit and ate vegetables. A total weekly intake score was calculated and two groups were created: ate fewer than five servings of fruits and vegetables per day or ate five or more servings per day.

Smoking status—Based upon the Canadian Tobacco Use Monitoring Survey[30] participants were asked if '*At the present time do you smoke cigarettes every day/almost everyday, occasionally, or not at all?*' Those who responded 'every day' or 'occasionally' were classified as smokers, whereas those who responded 'not at all' were classified as non-smokers.

BMI—Self-reported height and weight were used to estimate BMI at both time points. In keeping with other researchers[2] we created the following BMI change groups: greater than 0.5 BMI point decrease (mean BMI change −1.4 (s.d.=1.2) points in men), stable (within ± 0.5 points; mean BMI change 0.03 (s.d.=0.25) in men), between 0.5 and 2.0 point increase (mean BMI change 1.10 (s.d.=0.4) in men) and greater than 2.0 increase (mean BMI change 3.9 (s.d.=2.8) in men). Such changes in BMI have shown to be meaningful in the etiology of diseases[2,32] and therefore it is of interest to examine how built environment variables might contribute to similar BMI changes.

Physical activity—Using the short-form of the IPAQ,[29] participants were asked to recall how many minutes of walking, moderate and vigorous activity, sitting and sleeping they did over the last 7 days. Total metabolic equivalent (MET) minutes were calculated according to criteria set forth by the IPAQ research committee[33] and used to categorize participants as low, moderately or highly active. The IPAQ has been shown to have adequate reliability and validity.[34]

Perceived environment—Ten questions from the IPAQ-built environment module[35] assessed individual perceptions of participants' neighborhood including main type of housing, shops within easy walking distance, transit stops within a 15 min walk, sidewalks on most streets, cycling trails, recreation facilities such as parks, crime making it unsafe to walk at night, traffic that makes it difficult to walk, others in neighborhood being active and interesting things to look at while walking. All questions were rated on a 5-point scale anchored by 1 (strongly disagree) and 5 (strongly agree) with the exception of the main type of housing question. Options for that question include (1) detached single-family residences; (2) townhouses, row houses, apartments or condominiums of 2–3 stories; (3) mix of single-family residences and townhouses, row houses, apartments or condos; (4) apartments or condos of 4–12 stories; and (5) apartments or condos of more than 12 stories.

Neighborhood SES—Data from the 2006 Canadian census[36] were used to create the neighborhood SES variable. Participants did not give their addresses, but their postal codes were recorded. These postal codes were geocoded (assigned spatial reference) in ArcGIS 9.2[37] using the Postal Code Conversion Files produced by Statistics Canada in 2003[38] and 2008.[39] The procedure described by Demissie *et al.*[40] was employed to calculate the socioeconomic indices for dissemination areas, as well as the socioeconomic indices for neighborhoods. Dissemination areas are geographic units consisting of one or more adjacent blocks encompassing a population of 400–700 persons.[41] The neighborhoods of Edmonton are administrative geographic units designated by the City of Edmonton.

A dissemination area SES index was created for each dissemination area extracted from the 2006 census, where the centroids of respondents' postal codes were located in 2006. The SES index for each dissemination area was calculated using 2006 census data by taking the sum of the *z*-scores of net educational level (the proportion of people with low education subtracted from the proportion of people with and high education aged 15 years and over) and median income of all census families, and then subtracting the proportion of unemployed (unemployed people aged 15 years and over, as a percentage of people aged 15 years and over who were in the labour force). Dissemination areas where respondents resided in 2006 were separately extracted and then classified into high, medium or low SES based upon a tertile split.

Neighborhood walkability—Data from the 2006 census,[36] as well as from a taxation database summarized at the neighborhood level by the City of Edmonton constituted the basis for the creation of the neighborhood walkability variables. Neighborhoods were spatially represented in ArcGIS 9.2[37] using the neighborhood boundary files developed by City of Edmonton. A neighborhood walkability index for 2001 was available for 219 neighborhoods out of 340 and a neighbourhood walkability index for 2006 was available for

237 neighborhoods out of 340. Neighborhood walkability indices were calculated using the 'three-dimensional' method,[42] involving an assessment of diversity, density and design. The walkability index was calculated based on the Frank *et al.*[6] formula. Density represents the density of dwellings per area in residential use. Diversity represents the degree of land-use mix using the floor areas in the following five uses: residential, retail, office, education/institutional (including religious establishments) and entertainment (see[6,7,14] for a detailed description of the diversity index). Design represents the density of true intersections in each neighborhood.[38] We did not include the *z*-score for the retail floor area ratio as Frank *et al.*[6] did, because we could only access data pertaining to the total building area in retail use summarized at the neighborhood level, without parcel-level information Therefore, the following formula was used to determine the three-dimensional walkability index: $z_W = z_{D1} + z_{D2} + 2 * z_{D3}$, where z_W represents the *z*-scores for walkability, z_{D1} represents the *z*-scores for density, z_{D2} represents the *z*-scores for diversity and z_{D3} represents the *z*-scores for design. The *z*-scores for walkability were then classified using quantiles (five classes equal interval) into very high, high, medium, low and very low walkability neighborhood groups.

Data analysis

To determine sample representativeness, demographic data from the 2002 survey were compared between those who agreed to be followed up and those who did not. Of those participants who agreed in 2002, comparisons were made between those who did or did not complete the 2008 survey. Of the 822 participants who completed the 2008 survey, those participants who moved were compared with those who did not because the final analysis only included those participants who provided complete data at both time points and who did not move between 2002 and 2008 (n=500). This sample, compared with Albertans in general, is more highly educated (about 50% of Albertans have a high school degree or less), more likely to be married (about 47% of Albertans are married or in a common-law partnership) and older (approximately 10.4% of Albertans are over the age of 65).[43–46] Participants in our sample also tended to earn more than Albertans in general (mean income of Albertans is $48 017 per year). However, because of missing data, income was not included in the final analysis.

Before conducting the main analysis, crosstabs were used to test whether any cells were empty or very small. Three of the perceived environment variables were problematic. The 'type of housing' question showed very few participants indicated they lived in areas primarily comprised of apartment buildings of any height. Themajority of participants either agreed or strongly agreed with the questions that asked about 'transit stops within 15 min walking distance' (n=530) and 'sidewalks' (n=535). Therefore, these three questions were not included in the analysis. Of the remaining perceived environment variables, we further tested whether they related to BMI change category through a series of analysis of variances. The only variable significantly related to BMI-change was traffic (F (3, 555)=2.65, P=0.05) and therefore was the only one included in the final regression model. Household income was not included in the model because 17.4% of respondents did not provide this information. Ethnicity was not included either because an open-ended question generated 35 different responses (for example, Canadian, Aboriginal, English and Lebanese) with 30.7%

of the sample self-identifying as Canadian. However, this response could include Canadians of multiple racial backgrounds and thus was not an informative variable. We assessed the regression model for fit and excluded variables with poor fit before running the final model.

The main analysis consisted of an ordinal regression. The model included BMI change groups regressed onto sociodemographic variables (age group (18–34 years, 35–49 years, 50–64 years and >65 years), gender, job status (employed or other), marital status (married/common-law or other) and education level (less than or completed high school and greater than a high school education)), smoking status (smoker or non-smoker), activity level (low, moderate or high), and fruit and vegetable intake (greater than or equal to 5 servings per day or less than 5 servings per day), the two objective neighborhood variables of walkability (quintiles) and SES rank (tertiles), and the lone perceived environment variable. Apart from BMI change and the two objective neighborhood measures, all variables were from 2002.

Results

Table 1 shows that of the participants who completed the follow-up survey, the sample used in the analyses (that is, participants who completed both surveys and did not move between 2002 and 2008) was, on average, wealthier and more likely to be married than those participants who did move. Respondents were also less likely to have completed high school. Because we used a prospective model and included variables from 2002, it is possible that predictors changed over time. We therefore examined change in these variables and found that marital status did not change for 94% of the participants, job status did not change for 82.8% and education status remained stable for 91.2%. Smoking status did not change for 93% of participants. It is also worth noting that only 5% quit completely as BMI is greater in former smokers than non-smokers.[28] In terms of fruits and vegetable consumption, 71% stayed in the same category and 55.4% changed their activity status.

Body mass index increased at an average of 0.40 (s.d.=2.85) points across the entire sample. BMI decreased more than 0.5 points for 157 participants, which translated to an average BMI decrease of 2.21 (s.d.=2.54) for men and 2.41 (s.d.=1.74) for women. The BMI of 104 participants remained stable (mean increase of 0.006 (s.d.=0.19) for men and mean decrease of 0.002 (s.d.=0.24) for women). The BMI of 146 participants increased between 0.5 and 2 points (mean increase of 1.17 (s.d.=0.43) for men and 1.24 (s.d.=0.45) for women, and 93 participants experienced a BMI increase of more than 2 points (mean increase of 3.88 (s.d.=2.17) for men and 4.41 (s.d.=3.21) for women). These changes in BMI are in keeping with those reported by other researchers.[2] The full ordinal regression model was significant, χ^2 (18)=46.32, P<0.001 and neither tests of goodness of fit were significant (Pearson's χ^2 test (1437)=1449.70, P=0.40, Deviance χ^2 test (1437)=1283.05, P=0.999), allowing us to conclude the model was significantly different from the null model. The amount of variance accounted for was approximately 9.5% (Nagelkerke=0.095). Further, the test of parallel lines was not violated, χ^2 (36)=41.89, P=0.231, indicating the slope coefficients were equivalent across all levels of the dependent variable. As shown in Table 2, age, neighborhood SES, and traffic were significant predictors of BMI change. Neighborhood SES and change in BMI were inversely related; participants in the lowest SES neighborhoods were more likely to experience increases in BMI than participants in the highest SES neighborhoods. Age and change in BMI were also related; younger participants were more likely to have increases in BMI than participants in the oldest age category. Table 3 further explains these findings by illustrating that traffic and change in BMI were positively related such that with each step in agreement with the statement that 'traffic makes it difficult to walk' the likelihood of increased BMI was greater. As also shown in Table 3, more participants in the highest SES neighborhoods compared with the lowest SES neighborhoods decreased BMI by greater than 0.5 points, whereas there were more participants in the lowest SES neighbourhoods who had increases in BMI compared with participants in the highest SES neighborhoods. Similarly, more participants in the younger age groups had increased BMI than participants in the over 65-years age group.

Discussion

We explored the relationship between objectively measured and perceived neighborhood characteristics, and demographic factors, on change in BMI over 6 years among adults living in Edmonton, Canada. Age and neighborhood SES significantly predicted change in BMI. Younger adults and those in lower SES neighborhoods were at greater risk of increased BMI. In addition, the more participants felt that traffic made it unpleasant to walk, the more likely they were to have increased BMI. The lack of relationship between neighborhood walkability and BMI are contrary to the reported cross-sectional relationships.[11,13] This may indicate that there is a self-selection to neighborhoods. That is, those people who choose to live in walkable neighborhoods tend to do so because it reflects their values and therefore crosssectional data shows a relationship. However, it may be there is no change in BMI across time because those who happen to live in a highly walkable neighborhood but are not inclined to walk, will not be influenced by neighborhood features. This reflects recent qualitative research in which developers reported believing that walkable neighborhoods attract walkers rather than the other way round.[47] Other longitudinal data showed no changes in BMI in adults who moved to less sprawling communities.[21] Our findings are also similar to other longitudinal data that showed no relationship between walkability and BMI in adults over the age of 65 years, but did find a relationship between walking behavior and neighborhood walkability.[15] Further research is needed to determine the relationship between neighborhood walkability and BMI.

Our findings support research showing that while neighborhood income was not related to physical activity, residents of lower income neighborhoods had higher BMI and lower neighborhood satisfaction.[48] In other work, the relationship between built environmental features and BMI has been shown to exist in high-income communities, but the relationship did not hold in disadvantaged communities.[49] These authors speculate that this might be because of overriding safety or aesthetic concerns, which reflects our findings already reported. Even though we found no change in BMI by neighborhood walkability, our results do not allow us to conclude that walkable neighborhoods do not have effects on health outcomes as fitness predicts mortality, which is independent of obesity.[50] There are likely multiple contributing factors to the relationship between neighborhood SES and change in BMI. A recent study in Edmonton reported greater odds of adults being obese if there was a higher ratio of fast-food restaurants and convenience stores to grocery stores and produce vendors.[43] Fruit and vegetable intake was not a significant factor in our model, but it is possible the increased obesity in lower SES neighborhoods was related to food accessibility. Our results reflect the idea of the 'inner-city paradox' proposed by Lopez and Hynes;[26] participants in our study who lived in lower-income neighborhoods had greater rates of obesity and also reported generally less-pleasant neighborhoods. Thus, future studies should include objective measures of fitness and exercise behavior when longitudinally measuring the effects of the built environment on health outcomes. Our results also confirm cross-sectional research that showed less likelihood of obesity in adults over the age of 75 years with the highest rates of obesity among Canadians among 50–64-year olds. Although Lee *et al.*[51] found the lowest rates of obesity in Canadians aged 12–34 years, our longitudinal data show what the biggest gains in obesity were in adults aged 18–34 years with gains in BMI also seen in 35–49-year olds, when compared with participants over the age of 65 years. These results are alarming because increases in BMI in middle-aged adults are predictive of heart disease and heart disease risk factors.[2,3] Further, as seen in Table 3, older adults had decreases in BMI, which is also predictive of increased CVD risk.[2]

The longitudinal nature of this study is a definite strength, as is the inclusion of both objective and perceived measures of neighborhoods. However, there are some limitations that should be noted. First, BMI was measured by self-report. Given that people tend to under report their weight in comparison to objective measurements,[52] self-reported BMI usually provides an under representation of overweight and obesity at a population level. However, we have no reason to believe that this bias differentially affected our findings. Another limitation is the measure of physical activity used. Participants were asked to report their activity for 1 week, 6 years apart. Thus, the IPAQ may not have been sensitive enough to capture the influence of physical activity on the modelled relationships and there may be a relationship between neighborhood walkability and activity behavior. A final limitation that should be acknowledged is the change in predictors between 2002 and 2008 for some participants. Although the majority of participants did not change their marital, education, smoking or job status, it is possible that a change in one of these variables could influence BMI. However, because of the small number of participants who did change, and we do not know *when* they changed, the prospective model is still the strongest. If participants quit smoking in 2008 for example, it is not likely that this would have had an influence on BMI in 2008. A larger number of participants did change their activity level, but again because of the limitations of the IPAQ, it is doubtful this measure was sensitive enough to capture true level of activity. An additional limitation is that objective neighborhood SES and walkability indices were calculated from 2006 census data and thus may have changed over time. Future longitudinal research should attempt to measure when significant life changes occur to determine their influences on health outcomes. Also the stability of objectively measured neighborhood walkability and SES should also be considered.

The results of this study support the findings of a systematic review that revealed neighborhood SES was related to obesity.[53] However, the majority of the evidence is cross-sectional. This study therefore adds to the literature to show long-term changes in BMI between various neighborhoods SES and age groups. Thus, there are contributing factors within lower-SES neighborhoods that result in increased likelihood of obesity. Our study also highlights the very complex nature of the relationship. Although more research is needed to fully understand how neighborhood SES contributes to obesity, it is without question that individuals in socially disadvantaged neighborhoods face more barriers to health than their wealthier counterparts. This study also calls into question the relationship between walkability and changes in BMI and adds to a growing body of longitudinal studies that report no relationship between walkable neighborhoods and changes in obesity.

Acknowledgments

This research was supported by grants from the Heart and Stroke Foundation of Canada and the Canadian Institutes of Health Research. Tanya R Berry is supported by a Population Health Investigator Award from the Alberta Heritage Foundation for Medical Research. Chris M Blanchard is supported by the Canada Research Chairs Program. The 2002 Population Health Survey was funded through Population Health and Research in the former Capital Health region of Alberta. We thank Genevieve Selfridge for her help with the manuscript.

References

1. Kopelman P. Health risks associated with overweight and obesity. Obes Rev. 2007; 8(Suppl 1):13–17. [PubMed: 17316295]
2. Bowman TS, Kurth T, Sesso HD, Manson JE, Gaziano JM. Eight-year change in body mass index and subsequent risk of cardiovascular disease in healthy non-smoking men. Prev Med. 2007; 45:436–441. [PubMed: 17727941]
3. Yarnell JWG, Patterson CC, Thomas HF, Sweetnam PM. Comparison of weight in middle age, weight at 18 years, and weight change between, in predicting subsequent 14 year mortality and coronary events: Caerphilly Prospective Study. J Epidemiol Community Health. 2000; 54:344–348. [PubMed: 10814654]
4. Strandberg TE, Strandberg AY, Salomaa VV, Pitkala KH, Tilvis RS, Sirola J, et al. Explaining the obesity paradox: cardiovascular risk, weight change, and mortality during long-term follow-up in men. Eur Heart J. 2009; 30:1720–1727. [PubMed: 19429917]
5. Cerin E, Saelens BF, Sallis JF, Frank L. Neighborhood environment walkability scale: validity and development of a short form. Med Sci Sports Exerc. 2005; 38:1682–1691.
6. Frank LD, Sallis JF, Saelens B, Leary L, Cain K, Conway T, et al. The development of a walkability index: application to the neighbourhood quality of life study. Br J Sports Med. 2009; doi: 10.1136/bjsm.2009.058701
7. Leslie E, Coffee N, Frank L, Owen L, Bauman A, Hugo G. Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. Health Place. 2007; 13:111–122. [PubMed: 16387522]
8. Smith KR, Brown BB, Yamada I, Kowaleski-Jones L, Zick CD, Fan JX. Walkability and body mass index density, design and new diversity measures. Am J Prev Med. 2008; 35:237–244. [PubMed: 18692736]
9. Vandegrift D, Yoked T. Obesity rates, income, and suburban sprawl: an analysis of U.S. states. Health Place. 2004; 10:221–229. [PubMed: 15177197]
10. Lopez R. Urban sprawl and risk for being overweight or obese. Am J Public Health. 2004; 94:1574–1579. [PubMed: 15333317]
11. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. Am J Prev Med. 2004; 27:87–96. [PubMed: 15261894]
12. Gauvin L, Craig RC, Spivock M, Riva M, Foster M, Laforest S, et al. From walkability to active living potential: an ‘ecometric’ validation study. Am J Prev Med. 2005; 28:126–133.
13. Spence JC, Cutumisu N, Edwards J, Evans J. Influence of neighborhood design and access to facilities on overweight among preschool children. Int J Pediatr Obes. 2008; 3:109–116. [PubMed: 18465437]
14. Frank LD, Sallis JF, Conway TL, Chapman JE, Saelens BE, Bachman W. Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. J Am Plann Assoc. 2006; 72:75–87.

15. Berke EM, Koepsell TD, Moudon AV, Hoskins RE, Larson EB. Association of the built environment with physical activity and obesity in older persons. Am J Public Health. 2007; 97:486–492. [PubMed: 17267713]
16. Grafova IB, Freedman VA, Kumar R, Rogowski J. Neighborhoods and obesity in later life. Am J Public Health. 2008; 98:2065–2071. [PubMed: 18799770]
17. Lee IM, Ewing R, Sesso HD. The built environment and physical activity levels: the Harvard alumni health study. Am J Prev Med. 2009; 37:293–298. [PubMed: 19765500]
18. Casey AA, Elliott M, Glanz K, Haire-Joshu D, Lovegreen SL, Saelens BE, et al. Impact of the food environment and physical activity environment on behaviors and weight status in rural U.S. communities. Prev Med. 2008; 47:600–604. [PubMed: 18976684]
19. Burdette AM, Hill TD. An examination of processes linking perceived neighborhood disorder and obesity. Soc Sci Med. 2008; 67:38–46. [PubMed: 18433964]
20. Boehmer TK, Hoehner CM, Deshpande AD, Brennan Ramirez LK, Brownson RC. Perceived and observed neighborhood indicators of obesity among urban adults. Int J Obes. 2007; 31:968–977.
21. Boehmer TK, Hoehner CM, Wyrwich K, Ramirez L, Brownson R. Correspondence between perceived and observed measures of neighborhood environmental supports for physical activity. J Phys Act Health. 2006; 3:22–36.
22. Sundquist J, Johansson S. The influence of socioeconomic status, ethnicity and lifestyle on body mass index in a longitudinal study. Int J Epi. 1998; 27:57–63.
23. Kavanagh AM, Goller JL, King T, Jolley D, Crawford D, Turrell G. Urban area disadvantage and physical activity: a multilevel study in Melbourne, Australia. J Epidemiol Community Health. 2005; 59:934–940. [PubMed: 16234420]
24. Giles-Corti B, Donovan RJ. The relative influence of individual, social and physical environment determinants of physical activity. Soc Sci Med. 2002; 54:1793–1812. [PubMed: 12113436]
25. Wilson DK, Kirtland KA, Ainsworth BE, Addy CL. Socioeconomic status and perceptions of access and safety for physical activity. Ann Behav Med. 2004; 28:20–28. [PubMed: 15249256]
26. Lopez RP, Hynes HP. Obesity, physical activity and the urban environment: public health research needs. Environ Health. 2006; 5:25. [PubMed: 16981988]
27. Harrington DW, Elliott SJ. Weighing the importance of neighbourhood: a multilevel exploration of the determinants of overweight and obesity. Soc Sci Med. 2009; 68:593–600. [PubMed: 19095339]
28. van Lenthe FJ, Droomers M, Schrijvers CTM, Mackenbach JP. Socio-demographic variables and 6 year change in body mass index: longitudinal results from the GLOBE study. Int J Obes. 2000; 24:1077–1084.
29. International Physical Activity Questionnaire. Available : http://www.ipaq.ki.se/downloads.htm
30. Statistics Canada. Canadian Tobacco Use Monitoring Survey. Available: http://www.statcan.gc.ca/survey-enquete/household-menages/tobacco-tabac/ctums-esutc-eng.htm
31. Statistics Canada. Canadian Community Health Survey (CCHS) Cycle 2.2. Nutrition: General Health File and 24-Hour Dietary Recall. 2004. Available: http://www.statcan.ca/english/sdds/instrument/5049_Q1_V1_E.pdf
32. Looker HC, Knowler WC, Hanson RL. Changes in BMI and weight before and after the development of type 2 diabetes. Diabetes Care. 2001; 24:1917–1922. [PubMed: 11679457]
33. IPAQ research committee. Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ). 2005. Available: http://www.ipaq.ki.se/scoring.pdf
34. Craig CL, Marshall AL, Sjöström M, Bauman AE, Booth ML, Ainsworth BE, et al. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003; 35:1381–1395. [PubMed: 12900694]
35. Alexander A, Bergman P, Hagstromer M, Sjostrom M. IPAQ environmental module; reliability testing. J Public Health. 2006; 14:76–80.
36. Statistics Canada. 2006 Census of Population. Profile for Canada, Provinces, Territories, Census Divisions, Census Subdivisions and Dissemination Areas, 2006 Census, 2008. May.2008 Catalogue no. 94-581-XCB2006002.
37. ESRI. ArcGIS. ESRI; Redlands, CA: 2008. (Version 9.2.) [Computer software]

38. Leslie E, Saelens B, Frank L, Owen N, Bauman A, Coffee N, et al. Residents' perceptions of walkability attributes in objectively different neighbourhoods: a pilot study. Health Place. 2005; 11:227–236. [PubMed: 15774329]

39. Statistics Canada. 2001 Census of Population. Profile for Canada, Provinces, Territories, Census Divisions, Census Subdivisions and Dissemination Areas, 2001 Census, 2003. Oct.2003 Catalogue no. 95F-0495-X2001002.

40. Statistics Canada. Postal Code Conversion File (PCCF). Mar.2008 Catalogue no. 92-153-G.

41. Demissie K, Hanley JA, Menzies D, Joseph L, Ernst P. Agreement in measuring socio-economic status: area-based versus individual measures. Chronic Dis Can. 2000; 21:1–7. [PubMed: 10813687]

42. Cervero R, Kockelman K. Travel demand and the 3Ds: density, diversity, and design. Transport Res. 1997; 2D:199–219.

43. Statistics Canada. Population 15 years and over by highest degree, certificate or diploma, by province and territory (2006 Census) (Alberta, British Columbia, Yukon Territory) (table). 2006 Census: Release topics. 2007. [updated 2009 July 29; cited 2009 Nov 23]. Available from: http://www.40.statcan.gc.ca/l01/cst01/educ41c-eng.htm

44. Statistics Canada. 2007 Table 051-0010 Population by marital status and sex, by province and territory (Alberta, British Columbia and Yukon) (table). CANSIM (database). [updated 2007 Nov 29; cited 2009 Nov 23]. Available from: http://www.40.statcan.gc.ca/l01/cst01/famil01c-eng.htm

45. Statistics Canada. 2009 Table 281-0044 statistics Canada catalogue no. 72-002-X. Earnings, average weekly, by province and territory (table). CANSIM (database). [updated 2009 Aug 16; cited 2009 Nov 23]. Available from: http://www.40.statcan.gc.ca/l01/cst01/labr79-eng.htm

46. Statistics Canada. 2009 Table 051-0001. Population by sex and age group, by province and territory (table). CANSIM (database). [updated 2009 Jan 15; cited 2009 Nov 23]. Available from: http://www.40.statcan.gc.ca/l01/cst01/demo31a-eng.htm

47. Clark MI, Berry TR, Spence JC, Nykiforuk C, Carlson M, Blanchard C. Key stakeholder perspectives on the development of walkable neighbourhoods. Health Place. 2010; 16:43–50. [PubMed: 19733495]

48. Sallis JF, Saelens BE, Frank LD, Conway TL, Slymen DJ, Cain KL, et al. Neighborhood built environment and income: examining multiple health outcomes. Soc Sci Med. 2009; 68:1285–1293. [PubMed: 19232809]

49. Lovasi GS, Neckerman KM, Quinn JW, Weiss CC, Rundle A. Effect of individual or neighborhood disadvantage on the association between neighborhood walkability and body mass index. Am J Public Health. 2009; 99:279–284. [PubMed: 19059849]

50. Xuemei S, LaMonte MJ, Laditka JN, Hardin JW, Chase N, Hooker SP, et al. Cardiorespiratory fitness and adiposity as mortality predictors in older adults. J Am Med Assoc. 2007; 298:2507–2516.

51. Lee DS, Chiu M, Manuel DG, Tu K, Wang X, Austin PC, et al. Trends in risk factors for cardiovascular disease in Canada: temporal, socio-demographic and geographic factors. Can Med Assoc J. 2009; 181:E55–E66. [PubMed: 19620271]

52. Gorber SC, Tremblay M, Moher D, Gorber B. A comparison of direct vs self-report measures for assessing height, weight and body mass index: a systematic review. Obes Rev. 2007; 8:307–326. [PubMed: 17578381]

53. Raine, K., Spence, JC., Church, J., Boule, N., Slater, L., Marko, J., et al. State of the Evidence Review on Urban Health and Healthy Weights. Canadian Population Health Initiative, Canadian Institute for Health Information; Ottawa, ON: 2008.

Table 1

Number (N) (%) participants from original survey who agreed or did not agree to follow-up, of those who agreed—did or did not complete the follow-up questionnaire, and of those who completed—did or did not move

Demographic	Agreed (2002)	Did not agree (2002)	Completed follow-up (2008)	Did not complete (2008)	Moved	Did not move (complete data)
Total N	2362	812	822	1540	223	500
*Age** *(years)*						
18–24	463 (19.6)	143 (17.6)	72 (8.8)	374 (24.3)	42 (18.8)	22 (4.4)
25–34	502 (21.3)	174 (21.4)	125 (15.2)	365 (23.7)	67 (30.0)	52 (10.4)
35–49	503 (21.3)	157(19.3)	214 (26.0)	315 (20.5)	46 (20.6)	140 (28.0)
50–64	467 (19.8)	162 (20.0)	220 (26.8)	258 (16.8)	32 (14.3)	157 (31.4)
65+	427 (18.1)	176 (21.7)	191 (23.2)	228 (14.8)	35 (15.7)	129 (25.8)
Gender						
Male	1180 (50.0)	381 (46.9)	402 (48.9)	778 (50.5)	106 (47.7)	261 (52.2)
Female	1182 (50.0)	431 (53.1)	420 (51.1)	762 (49.5)	116 (52.3)	239 (47.8)
*Education**						
≤High school	823 (34.9)	292 (36.5)	260 (31.7)	548 (35.6)	57 (25.7)	165 (33.0)
> High school	1532 (65.1)	507 (63.5)	561 (68.3)	992 (64.4)	165 (74.3)	335 (67.0)
*Employment**						
Employed	1128 (47.8)	378 (46.6)	379 (46.1)	755 (49.0)	114 (51.4)	286 (57.2)
Other	1234 (52.2)	434 (53.4)	443 (53.9)	784 (51.0)	108 (48.6)	214 (42.8)
*Marital status***						
Married/common-law*	1238 (57.3)	415 (56.4)	513 (68.7)	741 (48.1)	109 (54.8)	345 (69.0)
Other	921 (42.7)	321 (43.6)	234 (31.3)	798 (51.9)	89 (45.2)	155 (31.0)
*Income**						
<$60 000	1428 (66.7)	516 (73.7)	471 (61.7)	897 (58.2)	145 (70.0)	227 (45.4)
>$60 000	714 (33.3)	184 (26.3)	292 (38.3)	478 (31.0)	62 (30.0)	196 (39.2)

* χ^2 Analysis significant at $P<0.05$ at all time points.

** χ^2 Analysis significant at $P<0.05$ between those who moved or did not.

Table 2

Ordinal regression model predicting change in body mass index (BMI) from sociodemographic, neighborhood and perceived environment variables

Predictors	Estimate	Standard error	Wald	Significance	95% Confidence interval (CI)
Neighborhood socioeconomic status (SES)					
Low	0.698	0.228	9.370	0.002	0.251–1.144
Medium SES	0.138	0.205	0.452	0.501	−0.264–0.540
High SES			Referent category		
Walkability					
Lowest	0.479	0.288	2.768	0.096	−0.085–1.044
Low	0.251	0.262	0.916	0.339	−0.263–0.765
Mid	0.149	0.256	0.337	0.562	−0.353–0.651
High	0.300	0.251	1.426	0.232	−0.192–0.793
Highest			Referent category		
Age group (years)					
18–34	0.945	0.299	9.957	0.002	0.358–1.532
35–49	1.003	0.278	13.015	0.000	0.458–1.548
50–64	0.750	0.248	9.170	0.002	0.265–1.236
≥65			Referent category		
Gender (male)	0.146	0.171	0.730	0.393	−0.189–0.480
Marital status (other than married)	−0.171	0.189	0.824	0.364	−0.542–0.199
Education (high school or less)	0.097	0.186	0.274	0.601	−0.267–0.462
Job status (not employed)	−0.109	0.197	0.304	0.582	−0.495–0.278
Active					
Lowest	0.025	0.227	0.012	0.914	−0.420–0.470
Medium	−0.196	0.188	1.086	0.297	−0.565–0.173
Highest			Referent Category		
Fruits and vegetables (<5 servings per day)	−0.070	0.169	0.174	0.676	−0.401–0.260
Smoking (non-smoker)	0.044	0.232	0.036	0.850	−0.411–0.499
Traffic	0.237	0.076	9.651	0.002	0.088–0.387

Table 3

Number (%) of participants by demographic groups for significant regression variables as related to body mass index (BMI) change

	BMI-change category				
	≥ 0.5 decrease	Stable	0.5–2.0 Increase	≥2.0 Increase	Total
Neighborhood socioeconomic status (SES)					
Lowest SES	36 (25.0)	25 (17.4)	49 (34.0)	34 (23.6)	144
Medium SES	60 (34.7)	31 (17.9)	51 (29.5)	31 (17.9)	173
Highest SES	61 (33.3)	48 (26.2)	46 (25.1)	28 (15.3)	183
Age group (years)					
18–34	19 (25.7)	12 (16.2)	26 (35.1)	17 (23.0)	74
35–49	35 (25.0)	26 (18.6)	44 (31.4)	35 (25.0)	140
50–64	48 (30.6)	36 (22.9)	44 (28.0)	29 (18.5)	157
>65	55 (42.6)	30 (23.3)	32 (24.8)	12 (9.3)	129
Traffic M (s.d.)	1.92 (.96)	2.09 (1.21)	2.19 (1.18)	2.27 (1.13)	