BMJ Open

Associations between neighborhood walkability and sedentary time in New Zealand adults

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-016128
Article Type:	Research
Date Submitted by the Author:	01-Feb-2017
Complete List of Authors:	Hinckson, Erica; Auckland University of Technology, Faculty of Health and Environmental Sciences Cerin, Ester; Australian Catholic University Mavoa, Suzanne; University of Melbourne Smith, Melody; University of Auckland Badland, Hannah; RMIT University Witten, Karen; Massey University Kearns, Robin; University of Auckland Schofield, Grant; Auckland University of Technology, Faculty of Health and Environmental Sciences
Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology
Keywords:	PUBLIC HEALTH, EPIDEMIOLOGY, PREVENTIVE MEDICINE, SOCIAL MEDICINE

Associations between neighborhood walkability and sedentary time in New Zealand adults

Hinckson E[1*], Cerin E[2, 3], Mavoa S[4, 5], Smith M[6], Badland H[7], Witten, K[5], Kearns, R[6], Schofield G[1]

[1]Auckland University of Technology, Human Potential Centre, New Zealand

[2] Institute for Health and Ageing, Australian Catholic University, Australia

[3] School of Public Health, The University of Hong Kong, Hong Kong, China

[4] McCaughey VicHealth Community Wellbeing Unit, Melbourne School of Population and Global Health, Faculty of Medicine, Dentistry and Health Science, The University of Melbourne, Australia

[5] SHORE & Whariki Research Centre, Massey University, New Zealand

[6]The University of Auckland, New Zealand

[7]RMIT University, Australia

Short title: Built environment and sedentary time

Please address correspondence to: Erica Hinckson*

Associate Professor

Auckland University of Technology

Faculty of Health and Environmental Sciences

Auckland 92006, New Zealand

Email: erica.hinckson@aut.ac.nz

Ester Cerin: Ester.Cerin@acu.edu.au

Suzanne Mavoa: suzanne.mavoa@unimelb.edu.au

Melody Smith: melody.smith@auckland.ac.nz

Hannah Badland: hannah.badland@rmit.edu.au

Karen Witten: K.Witten@massey.ac.nz

Robin Kearns: Robin Kearns: r.kearns@auckland.ac.nz

Grant Schofield: grant.schofield@aut.ac.nz

Associations between neighbourhood walkability and sedentary time in New Zealand adults

Abstract

Objectives: We estimated associations between objectively-determined neighbourhood 'walkability' attributes and accelerometer-derived sedentary time (ST) by sex, city, or type of day.

Design: A cross-sectional study

Setting: The URBAN study was conducted in 48 neighborhoods across four cities in New Zealand (August 2008-October 2010).

Participants: The response rate was 41% (2029 recruited participants/5007 eligible households approached). In total, 1762 participants (aged 41.4±12.1, M±SD) met the data inclusion criteria and were included in analyses.

Primary and secondary outcome measures: The exposure variables were GIS measures of neighborhood walkability (i.e. street connectivity, residential density, land use mix, retail-floor area ratio) for street network buffers of 500 m and 1000 m around residential addresses. Participants wore an accelerometer for seven days. The outcome measure was average daily minutes of ST.

Results: Data were available from 1762 participants (aged 41.4 ± 12.1 years; 58% female). No significant main effects of GIS-based neighborhood walkability measures were found with ST. Retail-floor area ratio was negatively associated with sedentary time in women, significant only for 500 m residential buffers. An increase of 1 decile in street connectivity was significantly associated with a decrease of over 5 minutes of ST per day in Christchurch residents for both residential buffers.

Conclusion: Neighborhoods with proximal retail and higher street connectivity seem to be associated with less ST. These effects were sex and city specific.

Key words: Built environment, Connectivity, Dwelling density, Mixed land use, Sitting.

Strengths and Limitations of this study

- The strength of this paper is the large sample size from across four cities in New Zealand with sufficient numbers to make inter-city comparisons and the use of objective measures for sedentary time and the built environment.
- Data on retail floor area were not available and so the retail building footprint was used as a proxy.
- The retail land use was derived from zoning data which potentially excludes smaller retail areas.
- The effects of neighbourhood self-selection and neighborhood characteristics that promoted sedentary time were not differentiated.
- The lack of variation between New Zealand cities (low walkability in the global sense) may have also influenced our findings.
- The type of sedentary behavior participants engaged in were not identified.
- Hip-mounted accelerometers can misclassify very light activity and standing as sedentary behaviour.

1.0 Background

Sedentary behavior is a common behavior in adults, characterised by sitting times (median or mean) of 5 to 8 hours per day [1, 2]. Evidence indicates that prolonged periods of inactivity, induced through sitting, have detrimental health effects [3]. A dose–response association has been reported between sitting time and all-cause mortality and cardiovascular disease, [3, 4] as well as higher risk for obesity and Type 2 diabetes [5]. These adverse effects are present even in individuals who meet public health guidelines for moderate-to-vigorous physical activity [6].

Correlates of sedentary behaviour identified thus far in adults include age, attitudes, body mass index, depressive symptoms/quality of life, education, employment status, gender, income, moderate-to-vigorous physical activity and smoking status [7]. A socio-ecological approach to understanding health behaviours suggests that broader factors such as the built environment may play a role [8]. However, while there is a large body of research focusing on behavioural and sociodemographic correlates of sedentary behaviour, research on social and environmental correlates remains scarce.

A recent systematic review on built environment attributes and sedentary behaviour relationships [8] found that very few studies showed significant associations between neighborhood built environment attributes and sedentary behaviors in the expected direction. However, overall, residents living in urban areas with diverse destinations close to their residential address had lower levels of sedentary behavior [8]. It is theorized that environments more conducive to physical activity may encourage less sitting [9]. It is also theorized that the neighborhood environment may have an added direct influence on women than men because in general women are more likely to engage with their residential neighborhood through shopping/running errands and therefore more likely to be affected by the neighborhood design [10].

Studies thus far have used a mixture of self-reported and objectively measured sedentary behaviour and built environment measures. The latest review by Kooshari and colleagues [8] did not differentiate between objective and subjective measures of either the built environment or sedentary behaviour, presumably due to the limited number of studies available in this area. Objective measures are generally more reliable and valid than self-reports [11].

In response, the main aim of this paper was to examine associations between Geographical Information System (GIS)-measured components of the neighborhood built environment within 500 m and 1000 m individual buffer zones of participant's homes and objectively measured sedentary time. We also explored whether these associations varied by sex, city, or type of day (weekday versus weekend).

2.0 Methods

A detailed description of the methods has been reported previously [12]. Briefly, cross-sectional data were collected from designated neighborhoods in four cities in New Zealand; North Shore, Waitakere, Wellington, and Christchurch. The URBAN Study commenced in April 2008 in

North Shore City and was completed in August 2010 in Christchurch. The host institutions of the research granted ethical approval for the study procedures (AUTEC: 07/126, MUHECN: 07/045).

2.1 Neighborhood selection

Twelve neighborhoods were selected from each city, resulting in a total of 48 neighborhoods being sampled. Neighborhoods were selected based on the walkability profile and ethnic population distribution (Māori, indigenous people) within contiguous mesh blocks (geographic census unit of approximately 100 households) of the selected cities. [13] Neighborhood selection resulted in three high walkability/high Māori, three high walkability/low Māori, three low walkability/high Māori and three low walkability/low Māori neighborhoods. The study was relevant nationally by over-sampling for Māori. Māori are the indigenous people of New Zealand, and are the second largest ethnic group (after New Zealand European) in New Zealand. [14] The walkability index was based on measures of street connectivity, dwelling density, land use mix, and retail floor area ratio, and was generated using GIS software, ArcInfo 9.1 (ESRI, Redlands, CA). The construction of these measures replicated existing research [15].

2.2 Procedures

The method of recruitment was by door to door; random start points were created in each neighborhood and every nth house (n ranged from one to four according to neighborhood dwelling density) was approached. Five maximum visits were made to the eligible house. One adult (20-65 years) per household was invited to participate. Once the participant agreed to take part in the study, two subsequent visits were arranged eight days apart. At the first visit, the study was introduced, informed consent was gained, and the accelerometer and compliance log were provided to the participants. At the second visit, the researcher collected the accelerometer and compliance log (participants wore the accelerometer for seven consecutive days) and completed the survey and anthropometric measures.

2.3 Sample size and sample

We intended to recruit 2,000 adults for the URBAN study. We also expected a reduction in our data by 10% for lack of compliance. Therefore, the predicted sample size for full analysis was estimated to 1,800 adults. On the basis of 12 background covariates explaining 25% of the variability of the dependent variable, and intraclass correlation coefficient cluster effects of 0.05, the predicted sample of 1,800 adults, α=0.05 and statistical power of 80%, the clustered multi-linear regression models was set to detect the smallest change in r2 of ≤2.3% and clustered logistic regression models odds ratio of ≤1.27 if the prevalence rate of overweight/obesity was 60%.

From each neighborhood 42 adults were randomly recruited. Participants from selected households were identified using the next birthday method. Exclusion criteria were: falling outside the age ranges, not intending to live in the household over the measurement period, unable to speak the English language, or impaired ability to walk.

2.4 Measures

Sedentary time. Sedentary time was objectively measured with the Actical accelerometer (Mini-Mitter, Sunriver, OR) fitted to an elastic waistband and worn above the right hip. The units have been shown to be reliable and valid [16, 17]. Prior to distribution, the units were tested for functionality and set up to record physical activity in 30-second epochs. Participants were instructed to wear the monitors during waking hours, but remove them when participating in water-based or contact activities. The threshold for sedentary time was set to <100 counts/minute using the Crouter 2R equation for the count threshold [18]. Data from participants with at least 10 hours of wear time for at least 5 days (including 1 weekend day) were included in the analyses. Non-wear time was defined as 60 minutes or more of consecutive zero counts [19, 20].

2.5 Demographic variables. Participants completed a face-to-face survey from which the following demographic characteristics were extracted: age, sex, ethnicity, marital status, academic qualification, total household income, and employment status.

2.6 Walkability measures. We extracted measures of neighborhood built environment from a GIS database that used ArcGIS 9.3 software (Environmental Systems Research Institute, California). The methods have been described in detail elsewhere [12, 21]. Briefly the walkability variables were:

- Street connectivity, estimated by calculating intersection density, the number of intersections per square kilometer within 20 meters of a mesh-block boundary.
- Dwelling density, number of dwellings, estimated by dividing the number of dwellings by the residential land area for each meshblock.
- Mixed land use, use of land including commercial, residential, industrial, open space and other, was calculated using an entropy index, [15] where 0 indicates homogeneity of land use and 1 heterogeneity.
- Retail floor area ratio, which, in the absence of floor area data, was estimated as the area of the retail building footprint divided by the area of the retail land parcel. A higher ratio facilitates pedestrian access as it has smaller setbacks and less surface parking [22].

Walkability measures were calculated for administrative units and also for 500 m and 1000 m road network buffers calculated around participant's residential addresses.

2.7 Data analytic plan

Data were analyzed in July 2014. Descriptive statistics (means, standard deviations and percentages) were computed for the whole sample and by city for all variables. Generalized additive mixed models (GAMMs) [23] were used to estimate associations between walkability and sedentary time. GAMMs can account for dependency in residuals (multiple measures taken on the same participants sampled from selected administrative units), and estimate complex, dose-response relationships of unknown form [23]. Three-level random intercept GAMMs with Gaussian variance and identity link functions, appropriate for approximately normally distributed residuals (diagnostic tests were conducted to determine the appropriateness of the variance and link functions), were used to estimate the above associations. These models accounted for three levels of variability in the outcome – namely, variability at the administrative units selected for participant recruitment, at the person level (i.e., between-participant differences), and at the within-person level (within-participant differences between weekday and weekend day estimates of sedentary time).

Separate main-effect GAMMs estimated the dose-response relationships of walkability components for the 500 m and 1 km road network buffers, respectively, with accelerometry-based sedentary time, adjusting for city, socio-demographic covariates (sex, age, marital status, educational attainment, ethnicity, and employment status), neighborhood deprivation (NZ Deprivation Index), average minutes of accelerometer wear time, number of valid days of wear, and type of day (weekday versus weekend day). It was possible to simultaneously enter all GIS variables in the GAMMs as they were not collinear (mean absolute correlation = 0.26; range of absolute correlations =0.07 - 0.48). Curvilinear relationships of environmental attributes with outcomes were estimated using non-parametric smooth terms in GAMMs, which were modeled using thin-plate splines [23]. Smooth terms failing to provide sufficient evidence of a curvilinear relationship (based on Akaike Information Criterion (AIC)) were replaced by simpler linear terms. Separate GAMMs were run to estimate two-way and three-way walkability component by sex, city and type of day interaction effects. The significance of interaction effects was evaluated by comparing AIC values of models with and without a specific interaction term. An interaction effect was deemed significant if it yielded a >2-unit smaller AIC than the main effect model [24]. Significant interaction effects were probed by computing the sex-, city-, and/or type of day-specific associations (as appropriate) of GIS-based components of walkability with accelerometry-based sedentary time via linear functions.

There were 12.5% cases with missing or invalid accelerometer data (252 out of 2014), and these were excluded in the analyses. Participants with valid accelerometer data were older (p<.001), more likely to live in high SES neighbourhoods (p=.010) and be employed (p<.001). All regression models were adjusted for these variables. There were less than 1.3% of remaining participants with missing data on any other variables. Given the low percentage of missing data, these values were imputed with the most common values for the sample (mean values or modes, as appropriate). All analyses were conducted in R [25] using the packages 'car' [26] and 'mgcv' [23].

3.0 Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the Institution's ethical approval process and the requirement of consent by participants (indigenous and otherwise) but are available from the corresponding author on reasonable request.

4.0 RESULTS

The response rate was 41% (2029 recruited participants/5007 eligible households approached). In total, 1762 participants (aged 41.4±12.1, M±SD) met the data inclusion criteria and were included in analyses. Table 1 reports the descriptive statistics of participants with accelerometer data for each city. This includes sample socio-demographic characteristics, GIS-based walkability components and accelerometry-based variables. Mean age of the total sample was 41.4 years (SD=12.1). Average sitting time was lower on weekends (mean = 409 minutes/day) than weekdays (mean = 480 minutes per day). Participants living in Christchurch had the highest sitting time on weekends, but the lowest on weekdays.

On average, selected neighborhoods in Christchurch had the lowest levels of dwelling density and net retail floor area ratios, whilst Wellington had the highest levels of dwelling density, intersection density and land use mix.

PLEASE INSERT TABLE 1 ABOUT HERE

4.1 Associations between socio-demographic variables, city and type of day with accelerometry-based sedentary time

Men, older participants, and more highly educated participants engaged in significantly more sedentary time than their counterparts (Table 2). For example, compared with participants with less than secondary schooling, those who completed tertiary education accumulated 41.7 more minutes of sedentary time per day. Being employed, living with a partner (as opposed to being single) and not being of Asian or Māori/Polynesian ethnicity was associated with lower levels of sedentary time. On average, participants from Wellington accumulated less sedentary time than those from other study sites. Weekend days were on average associated with approximately 18 fewer minutes of sedentary time than weekdays (Table 2).

PLEASE INSERT TABLE 2 ABOUT HERE

4.2 Associations of walkability components with accelerometry-based sedentary time

No significant main effects of GIS-based walkability components with accelerometry-based sedentary time were found (Table 3). However, significant interaction effects were found between street connectivity by city, and net retail floor area ratio by sex. Street connectivity was significantly negatively associated with sedentary time in Christchurch only. Among participants from Christchurch, an increase of 1 decile in street connectivity was associated with a decrease of over 5 minutes of sedentary time per day. This effect was observed for both residential buffer sizes. While net retail floor area ratio was not predictive of sedentary time in men, it was negatively associated with sedentary time in women across all cities. However, this effect was stronger (and significant only) for 500 m residential buffers across the four cities (Table 3).

PLEASE INSERT TABLE 3 ABOUT HERE

5.0 Discussion

There were no significant main effects of GIS-based walkability on sedentary time, however significant interaction effects were found between street connectivity in one city-Christchurch and net retail floor area ratio in women. This and the study by Van Dyck [19] and colleagues are the only studies that have examined associations between objectively measured built environment and sedentary time in adults.

Our a priori assumption was that built environments more conducive to physical activity may encourage less time spent in sedentary behavior. Our findings do not necessarily support this, as there were no significant main effects of GIS-based walkability on sedentary time. Perhaps sedentary behavior is influenced by neighborhood cultural or social phenomena or built environment factors not measured in the study such as public transport (which is highest in Wellington). Also, since sedentary behavior is not the reverse of physical activity, [27] the presence of walkable features may not influence the transition from sitting to walking. Another explanation may be that since sedentary time seems to be associated with home-based activities (e.g. television watching, computer use) [28] perhaps built environment associations around smaller buffers (close proximity to the home) may have been more appropriate. Certainly, in our study, there was only one significant interaction effect observed within a 1000 m buffer and only two interaction effects within the 500 m buffer. Nonetheless, smaller buffers may be problematic in countries in which neighborhoods are of comparatively low walkability such as New Zealand

[29]. On the other hand, a measure of regional accessibility may need to be included to account for environments of residents that commonly access (work and non-work) beyond the neighborhood. Regional accessibility is defined as being determined by large regional shopping centers and employment clusters, usually farther away, offering a variety of services [30]. It is possible that multi-purpose trips are done in this way, conceivably reducing the possibility of local accessibility irrespective of the neighborhood environment. Ubiquity of car ownership, as is the case for New Zealand, is also important. Ivory and colleagues [10] saw a strong relationship between built environment characteristics and car access, where almost half of those with restricted car access lived in the most connected street network areas, compared with approximately a third who had full car access. Lastly, it is plausible that different GIS measures may need to be considered for the development of sedentary behavior index in the future but extensive conceptualization and research must take place first.

In the interaction effects model, two relationships showed significance: street connectivity in Christchurch (within both 500m and 1000 m neighborhood buffer) and retail floor area ratio in women (within 500m neighborhood buffer only). For participants from Christchurch, an increase of 1 decile in street connectivity was associated with a decrease of over 5 minutes of sedentary time per day. The result makes sense due to the city's relatively flat topography and city design in comparison to Auckland and Wellington. Christchurch was one of four cities in the world (prior to the 2010 Christchurch earthquake) that was designed in a rectangular grid fashion with a central city square, surrounded by four city squares and a parklands area [31]. Literature has shown that street connectivity is positively associated with overall walking [32] and walking for transport [32, 33]. In terms of the second interaction effect, a significant association was observed between sedentary time and higher floor area retail ratio within the 500 m, but not the 1000 m neighbourhood buffer. Across all cities, the presence of retail outlets within a 500 m neighborhood buffer was predictive of less sedentary time in women but not men. Aside from the sex difference, we theorized that neighbourhoods more conducive to physical activity, in this case presence of retail (any type) in close proximity, may encourage reduction of sedentary time. Mixing residential neighborhoods with retail and other uses is not a new concept and remained the design of traditional European cities and towns for several centuries. Traditional neighborhoods morphed around the individual's needs to walk short distances to a destination. In terms of the sex difference, a similar sex association has been shown with self-reported sedentary behaviour in women and neighbourhood walkability, [34] women residing in low-walkable neighbourhoods reported increased levels of television viewing compared with those who lived in higher-walkable neighbourhoods [34]. While other studies have not investigated sex differences, Kooshari and colleagues [35] reported that in high walkable Australian neighbourhoods, in particular those with high retail area ratio, residents spent less time sitting in cars, while in Belgian adults, Van Dyck and associates, [19] found that daily sedentary time was higher for residents living in a high walkable environment. Nonetheless, according to our results, one may infer that women who reside in neighbourhoods with better access to retail spend less time in sedentary pursuits because they walk to a destination of interest frequently. These associations need to be investigated further to understand the reasons behind these.

The strength of this paper is the large sample size from across four cities in New Zealand with sufficient numbers to make inter-city comparisons. An additional strength is the use of objective measures for sedentary time and the built environment. Notwithstanding the strengths of the study, there are limitations that need to be acknowledged. One of the main limitations is that the data were derived from a cross-sectional study and causation cannot be assumed. While the retail floor area ratio potentially identifies differences between big-box retail and strips (includes carparking), the spatial data used for this measure were limited in two ways. First, data on retail floor area were not available and so the retail building footprint was used as a proxy. Second, retail land use was derived from zoning data which potentially excludes smaller retail areas. Further, given that our study neighborhoods were located in areas unlikely to be within 1000 m of big box retail, in our study we consider the retail floor area ratio as a proxy for access to retail. We were unable to differentiate between the effects of neighborhood self-selection and neighborhood characteristics that promoted sedentary time. It is possible that an alternative aggregate of GIS measures might have captured city differences better than the measures that we've used; for example, topography was not included in the GIS variables measured. The lack of variation between New Zealand cities (low walkability in the global sense) may have also influenced our findings and possibly the reason for the difference in findings with the Belgian study. Since we used accelerometry to determine sedentary behavior, we were unable to determine the type of sedentary behavior participants engaged in. Finally, hip-mounted accelerometers can misclassify very light activity and standing with sedentary behavior. For this reason hip-mounted accelerometers tend to overestimate sedentary behavior.

6.0 Conclusion

Our results imply that sedentary behaviour (time) was not correlated with the built environment in the New Zealand context. While there were no significant main effects between GIS-based walkability and sedentary time, neighborhoods within a 500 m neighborhood buffer that included retail were associated with less sedentary time in women residents only. In Christchurch, higher street connectivity was associated with less sedentary time. Taken together, it is possible that since sedentary behavior is not the reverse of physical activity, [27] the presence of walkable features may not influence the transition from sitting to walking and other factors (social and cultural) may supersede. This paper provided several alternatives to explain these results.

Declarations

Ethics approval and consent to participate

The host institutions of the research granted ethical approval for the study procedures (AUTEC: 07/126, MUHECN: 07/045).

Consent for publication

All authors have consented to publication of this manuscript.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare there is no conflict of interest.

Funding

This work was funded by the Health Research Council (HRC) of New Zealand [grant numbers: 07/356 and 08/048]. The funding body was not involved in the design, conduct, data collection, management, or publication of the study. The authors also gratefully acknowledge the participants who completed the study, research assistants who collected the data and the territorial authorities for providing the GIS datasets. EC is supported by an Australian Research Council (ARC) Future Fellowship (FT#140100085). HB and SM are in part supported by VicHealth, the National Health and Medical Research Council (NHMRC) Centre of Research Excellence in Healthy Liveable Communities (#1061404), and The Australian Prevention Partnership Centre (#9100001) with funding provided by NHMRC, ACT Health, NSW Health, the Australian National Preventive Health Agency, the Hospitals Contribution Fund of Australia and the HCF Research Foundation.

Authors' contributions

EH has provided the first draft and subsequent drafts, is the corresponding author, and conceptualised the content of manuscript and analysis, CE analyzed the data and provided the results and tables, SM conducted the GIS analysis and contributed to the manuscript, MS contributed to the manuscript, HB managed the study and contributed to the manuscript, KW co-primary investigator and contributed to the manuscript, RK, contributed to the manuscript, GS co-primary investigator and contributed to the manuscript.

REFERENCES

Table 1. Overall and site-specific area and sample characteristics

	Study site				
	All sites	North Shore	Waitakere	Wellington	Christchurch
Overall N	1762	463	466	417	443
Socio-demographics					
Mean age (SD) [Missing: 1.2%]	41.4 (12.1)	41.8 (11.6)	41.5 (11.7)	40.0 (12.5)	42.1 (12.5)
Sex, %men [Missing: 0.0%]	42.1	36.2	39.9	47.2	45.4
Education, % [Missing: 0.3%]					
Less than secondary school	4.5	2.3	4.5	0.5	10.4
Completed secondary school	56.3	58.0	64.2	45.1	56.9
Tertiary education	38.9	38.8	31.3	54.4	32.5
Work status, %working [Missing: 0.0%]	82.9	78.0	84.6	86.8	82.2
Marital status,	65.6	72.0	74.0	59.5	56.0

%couple [Missing: 0.2%]					
Ethnicity, % [Missing: 0.0%]					
Maori/Polynesian	15.8	18.1	21.7	10.1	12.6
Asian	9.8	9.6	14.8	8.2	6.3
NZ European / Pakeha / Other	74.4	72.3	63.5	81.8	81.0
Mean environmental variables (SD) [Missing: 0.0%]					
NZ Deprivation Index	5.1 (2.6)	4.2 (2.2)	5.3 (2.6)	4.7 (2.3)	6.2 (2.8)
Dwelling density – 500m buffers	5.5 (2.9)	5.5 (2.9)	5.6 (3.0)	6.3 (2.7)	4.5 (2.5)
Street connectivity – 500m buffers	5.4 (2.8)	4.4 (2.7)	4.8 (2.8)	6.3 (3.1)	6.4 (2.2)
Land use mix – 500m buffers	5.5 (2.9)	4.7 (2.7)	4.6 (2.6)	7.2 (2.8)	5.6 (2.7)
Net retail floor area ratio – 500m buffers	4.4 (2.9)	4.0 (3.3)	4.8 (4.8)	5.5 (3.6)	3.2 (3.4)
Dwelling density – 1km buffers	5.5 (2.9)	5.1 (2.9)	6.2 (2.8)	7.0 (2.1)	3.7 (2.5)
Street connectivity –	5.4 (2.9)	3.7 (2.2)	4.3 (2.4)	7.5 (2.9)	6.5 (2.1)

1km buffers					
Land use mix – 1km buffers	5.5 (2.8)	4.0 (2.7)	4.2 (2.4)	8.2 (1.8)	5.7 (2.1)
Net retail floor area ratio – 1km buffers	5.3 (3.1)	4.5 (2.3)	6.0 (4.5)	6.6 (2.4)	4.1 (1.8)
Mean accelerometry-based variables (SD) [Missing: 0.0%]					
Daily minutes of wear time - weekdays	789.5 (134.9)	796.4 (122.9)	802.2 (153.3)	812.8 (111.4)	748.2 (136.7)
Daily minutes of wear time - weekend	681.1 (191.7)	697.1 (187.8)	649.9 (207.1)	717.2 (141.9)	668.0 (208.8)
Percent of valid weekdays	89.4 (15.8)	92.0 (13.2)	90.6 (17.0)	85.9 (14.3)	88.7 (17.3)
Percent of valid weekend days	74.5 (33.0)	79.8 (32.0)	69.8 (36.7)	75.8 (22.7)	73.4 (36.5)
Sedentary time – weekdays (min/day)	479.5 (130.8)	483.2 (124.5)	489.7 (137.3)	484.4 (128.7)	460.8 (130.4)
Sedentary time – weekend (min/day)	409.3 (148.6)	410.3 (148.5)	406.1 (160.2)	407.7 (125.1)	413.1 (154.9)

Table 2. Associations of socio-demographic characteristics, type of day and study sites with accelerometry-based sedentary time

Predictor	b	95% CI	p
Socio-demographic			
Sex (reference: female)			
Male	18.1	9.5, 26.8	**<.001**
Education (reference: less than secondary school)			
Completed secondary school	18.7	-2.8, 40.2	.096
Tertiary education	41.7	19.1, 64.3	**<.001**
Working status (reference: not working)			
Working	-12.6	-24.1, -1.1	**.032**
Marital status (reference: single)			
Couple	-23.6	-32.8, -14.4	**<.001**
Ethnicity (reference: Maori/Polynesian			
Asian	-0.1	-18.0, 17.9	.978
European / Pakeha / Other	-14.5	-27.1, -1.8	**.025**
Age (yrs)	0.7	0.3, 1.0	**<.001**
New Zealand Deprivation Index	0.3	-4.6, 5.1	.860
Study site (reference: North Shore)			
Waitakere	8.1	-6.43, 22.5	.287
Wellington	-17.3	-33.0, -1.6	**.039**
Christchurch	3.2	-13.1, 19.4	.548

Type of day (reference: weekday)			
Weekend	-17.9	-23.7, -12.1	**<.001**

Note. All models adjusted for valid days of accelerometer wear and average daily minutes of wear. All models accounted for correlated residuals at the neighborhood and participant levels. b = regression coefficients; 95% CI = 95% confidence intervals.

Table 3. Associations of GIS-based walkability components for 500m and 1km residential buffers with accelerometry-based sedentary time

	500m residential buffers			1km residential buffers		
Predictor	**b**	**95% CI**	**p**	**b**	**95% CI**	**p**
Main effect models						
Dwelling density	-0.39	-2.08, 1.31	.654	-0.57	-2.49, 1.35	.564
Street connectivity	0.14	-1.90, 2.18	.892	-0.34	-2.58, 1.90	.768
Land use mix	1.04	-1.64, 1.15	.265	1.03	-1.08, 3.14	.339
Net retail floor area ratio	-0.24	-1.64, 1.15	.733	-0.02	-1.88, 1.84	.982
Interaction effects						
Street connectivity by study site						
Effect of street connectivity in North Shore	1.02	-2.37, 4.43	.556	0.20	-4.00, 4.41	.927
Effect of street connectivity in Waitakere	1.26	-2.02, 4.55	.452	-0.65	-4.43, 3.12	.733
Effect of street connectivity in Wellington	1.55	-1.78, 4.88	.363	2.12	-1.14, 5.38	.203
Effect of street connectivity in Christchurch	-5.06	-9.25, -0.86	**.019**	-5.18	-9.50, -0.86	**.019**

Net retail floor area ratio (NRFA) by sex						
Effect of NRFA in men	1.49	-0.36, 3.35	.116	1.58	-0.86, 4.01	.205
Effect of NRFA in women	-1.95	-3.60, -0.29	**.022**	-1.48	-3.59, 0.64	.172

Notes. All models adjusted for other walkability components, socio-demographics, New Zealand Deprivation Index, study site, and type of day (weekday versus weekend). All models accounted for correlated residuals at the neighborhood and participant levels. b = regression coefficients; 95% CI = 95% confidence intervals.

1. Bauman A, Ainsworth BE, Sallis JF, et al. The descriptive epidemiology of sitting: a 20-country comparison using the International Physical Activity Questionnaire (IPAQ). Am. J. Prev. Med. 2011;**41**(2):228-35 doi: http://dx.doi.org/10.1016/j.amepre.2011.05.003[published Online First: Epub Date]|.
2. Hagströmer M, Troiano RP, Sjöström M, et al. Levels and patterns of objectively assessed physical activity—a comparison between Sweden and the United States. Am. J. Epidemiol. 2010 doi: http://dx.doi.org/10.1093/aje/kwq069[published Online First: Epub Date]|.
3. Katzmarzyk PT, Church TS, Craig CL, et al. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med. Sci. Sports Exerc. 2009;**41**(5):998 doi: http://dx.doi.org/10.1249/MSS.0b013e3181930355[published Online First: Epub Date]|.
4. Thorp AA, Owen N, Neuhaus M, et al. Sedentary behaviors and subsequent health outcomes in adults: a systematic review of longitudinal studies, 1996–2011. Am. J. Prev. Med. 2011;**41**(2):207-15 doi: http://dx.doi.org/0.1016/j.amepre.2011.05.004[published Online First: Epub Date]|.
5. Hu FB, Li TY, Colditz GA, et al. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. JAMA 2003;**289**(14):1785-91 doi: http://dx.doi.org/10.1001/jama.289.14.1785[published Online First: Epub Date]|.

6. Healy GN, Wijndaele K, Dunstan DW, et al. Objectively measured sedentary time, physical activity, and metabolic risk. Diabetes Care 2008;**31**(2):369-71 doi: http://dx.doi.org/10.2337/dc07-1795[published Online First: Epub Date]|.
7. Rhodes RE, Mark RS, Temmel CP. Adult sedentary behavior: a systematic review. Am. J. Prev. Med. 2012;**42**(3):e3-e28 doi: http://dx.doi.org/10.1016/j.amepre.2011.10.020[published Online First: Epub Date]|.
8. Koohsari MJ, Sugiyama T, Sahlqvist S, et al. Neighborhood Environmental Attributes and Adults' Sedentary Behaviors: Review and Research Agenda. Prev. Med. 2015;**77**:141-49 doi: http://dx.doi.org/10.1016/j.ypmed.2015.05.027[published Online First: Epub Date]|.
9. Barnett A, Cerin E, Ching CS, et al. Neighbourhood environment, sitting time and motorised transport in older adults: a cross-sectional study in Hong Kong. BMJ open 2015;**5**(4):e007557 doi: http://dx.doi.org/10.1136/bmjopen-2014-007557[published Online First: Epub Date]|.
10. Ivory VC, Blakely T, Pearce J, et al. Could strength of exposure to the residential neighbourhood modify associations between walkability and physical activity? Soc. Sci. Med. 2015;**147**:232-41 doi: http://dx.doi.org/10.1016/j.socscimed.2015.10.053[published Online First: Epub Date]|.
11. Dyrstad SM, Hansen BH, Holme IM, et al. Comparison of self-reported versus accelerometer-measured physical activity. Med. Sci. Sports Exerc. 2014;**46**(1):99-106 doi: http://dx.doi.org/10.1249/MSS.0b013e3182a0595f[published Online First: Epub Date]|.
12. Badland HM, Schofield GM, Witten K, et al. Understanding the Relationship between Activity and Neighbourhoods(URBAN) Study: research design and methodology. BMC Public Health 2009;**9**(1):224 doi: http://dx.doi.org/10.1186/1471-2458-9-224[published Online First: Epub Date]|.
13. Statistics New Zealand. Census of population and dwellings: Auckland City. What we look like locally. Wellington: Statistics NZ, 2006.
14. Statistics New Zealand. New Zealand in profile: An overview of New Zealand's people, economy, and environment. Wellingotn: Statistics New Zealand, 2009.
15. Leslie E, Coffee N, Frank L, et al. Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. Health Place 2007;**13**(1):111-22 doi: http://dx.doi.org/10.1016/j.healthplace.2005.11.001[published Online First: Epub Date]|.
16. Esliger DW, Tremblay MS. Technical reliability assessment of three accelerometer models in a mechanical setup. Med. Sci. Sports Exerc. 2006;**38**(12):2173-81 doi: http://dx.doi.org/10.1249/01.mss.0000239394.55461.08[published Online First: Epub Date]|.
17. Esliger DW, Probert A, Gorber SC, et al. Validity of the Actical Accelerometer Step-Count Function. Med. Sci. Sports Exerc. 2007;**39**(7):1200-04 doi: http://dx.doi.org/10.1249/mss.0b013e3804ec4e9[published Online First: Epub Date]|.
18. Crouter SE, DellaValle DM, Horton M, et al. Validity of the Actical for estimating free-living physical activity. Eur. J. Appl. Physiol. 2011;**111**(7):1381-89 doi: http://dx.doi.org/10.1007/s00421-010-1758-2[published Online First: Epub Date]|.
19. Van Dyck D, Cardon G, Deforche B, et al. Neighborhood walkability and sedentary time in Belgian adults. Am. J. Prev. Med. 2010;**39**(1):25-32 doi: http://dx.doi.org/10.1016/j.amepre.2010.03.004[published Online First: Epub Date]|.
20. Oliver M, Badland HM, Schofield GM, et al. Identification of accelerometer nonwear time and sedentary behavior. Res. Q. Exerc. Sport 2011;**82**(4):779-83 doi: http://dx.doi.org/10.1080/02701367.2011.10599814[published Online First: Epub Date]|.
21. Mavoa S, Witten K, Pearce J, et al. Measuring Neighbourhood Walkability in New Zealand Cities, 2009.

22. Frank LD, Sallis JF, Saelens BE, et al. The development of a walkability index: application to the Neighborhood Quality of Life Study. Br. J. Sports Med. 2010;**44**(13):924-33 doi: http://dx.doi.org/10.1136/bjsm.2009.058701[published Online First: Epub Date]|.
23. Wood S. *Generalized additive models: an introduction with R.* Boca Raton, Florida: Chapman & Hall, 2006.
24. Burnham K, Anderson D. *Model selection and multimodel inference: a practical information-theoretic approach, 2nd ed* New York, NY: Springer, 2002.
25. R Core Team. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing, 2013.
26. Fox J, Weisberg S. *An R companion to applied regression, 2nd ed*. Thousand Oaks CA: Sage, 2011.
27. Healy GN, Dunstan DW, Salmon JO, et al. Television time and continuous metabolic risk in physically active adults. Med. Sci. Sports Exerc. 2008;**40**(4):639 doi: http://dx.doi.org/10.1249/MSS.0b013e3181607421[published Online First: Epub Date]|.
28. Owen N, Sugiyama T, Eakin EE, et al. Adults' sedentary behavior: determinants and interventions. Am. J. Prev. Med. 2011;**41**(2):189-96 doi: http://dx.doi.org/10.1016/j.amepre.2011.05.013[published Online First: Epub Date]|.
29. Sallis JF, Bowles HR, Bauman A, et al. Neighborhood environments and physical activity among adults in 11 countries. Am. J. Prev. Med. 2009;**36**(6):484-90 doi: http://dx.doi.org/10.1016/j.amepre.2009.01.031[published Online First: Epub Date]|.
30. Handy S. Regional versus local accessibility: Implications for nonwork travel. University of California: University of California Transportation Center, 1993:58-66.
31. Wilson J, Dowson S, Adam J, et al. Contextual Historical Overview of Christchurch City. Christchurch: Christchurch City Council, 2005.
32. Witten K, Blakely T, Bagheri N, et al. Neighborhood built environment and transport and leisure physical activity: findings using objective exposure and outcome measures in New Zealand. Environ. Health Perspect. 2012;**120**(7):971–77 doi: http://dx.doi.org/10.1289/ehp.1104584[published Online First: Epub Date]|.
33. Koohsari MJ, Sugiyama T, Lamb KE, et al. Street connectivity and walking for transport: Role of neighborhood destinations. Prev. Med. 2014;**66**:118-22 doi: http://dx.doi.org/10.1016/j.ypmed.2014.06.019[published Online First: Epub Date]|.
34. Sugiyama T, Salmon J, Dunstan DW, et al. Neighborhood walkability and TV viewing time among Australian adults. Am. J. Prev. Med. 2007;**33**(6):444-49 doi: http://dx.doi.org/10.1016/j.amepre.2007.07.035[published Online First: Epub Date]|.
35. Koohsari MJ, Sugiyama T, Kaczynski AT, et al. Associations of leisure-time sitting in cars with neighborhood walkability. J. Phys. Act. Health 2014;**11**(6):1129-32 doi: http://dx.doi.org/10.1123/jpah.2012-0385[published Online First: Epub Date]|.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-7
Objectives	3	State specific objectives, including any prespecified hypotheses	7
Methods			
Study design	4	Present key elements of study design early in the paper	7-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	8-9
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	9-10
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	9-11
Bias	9	Describe any efforts to address potential sources of bias	11
Study size	10	Explain how the study size was arrived at	9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	11-13
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	11-12
		(*b*) Describe any methods used to examine subgroups and interactions	11-12
		(*c*) Explain how missing data were addressed	13
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
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	13
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	13-14
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	13-15
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	13-15
		(*b*) Report category boundaries when continuous variables were categorized	13-15
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	16-18
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	19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16-20
Generalisability	21	Discuss the generalisability (external validity) of the study results	19
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	21

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

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

What are the associations between neighborhood walkability and sedentary time in New Zealand adults? The URBAN cross-sectional study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-016128.R1
Article Type:	Research
Date Submitted by the Author:	02-Jul-2017
Complete List of Authors:	Hinckson, Erica; Auckland University of Technology, Faculty of Health and Environmental Sciences Cerin, Ester; Australian Catholic University Mavoa, Suzanne; University of Melbourne Smith, Melody; University of Auckland Badland, Hannah; RMIT University Witten, Karen; Massey University Kearns, Robin; University of Auckland Schofield, Grant; Auckland University of Technology, Faculty of Health and Environmental Sciences
Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology
Keywords:	PUBLIC HEALTH, EPIDEMIOLOGY, PREVENTIVE MEDICINE, SOCIAL MEDICINE

What are the associations between neighborhood walkability and sedentary time in New Zealand adults? The URBAN cross-sectional study

Hinckson E[1*], Cerin E[2, 3], Mavoa S[4, 5], Smith M[6], Badland H[7], Witten, K[5], Kearns, R[6], Schofield G[1]

[1]Auckland University of Technology, Human Potential Centre, New Zealand

[2] Institute for Health and Ageing, Australian Catholic University, Australia

[3] School of Public Health, The University of Hong Kong, Hong Kong, China

[4] McCaughey VicHealth Community Wellbeing Unit, Melbourne School of Population and Global Health, Faculty of Medicine, Dentistry and Health Science, The University of Melbourne, Australia

[5] SHORE & Whariki Research Centre, Massey University, New Zealand

[6]The University of Auckland, New Zealand

[7]RMIT University, Australia

Short title: Built environment and sedentary time

Please address correspondence to: Erica Hinckson*

Associate Professor

Auckland University of Technology

Faculty of Health and Environmental Sciences

Auckland 92006, New Zealand

Email: erica.hinckson@aut.ac.nz

Ester Cerin: Ester.Cerin@acu.edu.au

Suzanne Mavoa: suzanne.mavoa@unimelb.edu.au

Melody Smith: melody.smith@auckland.ac.nz

Hannah Badland: hannah.badland@rmit.edu.au

Karen Witten: K.Witten@massey.ac.nz

Robin Kearns: Robin Kearns: r.kearns@auckland.ac.nz

Grant Schofield: grant.schofield@aut.ac.nz

Associations between neighbourhood walkability and sedentary time in New Zealand adults

Abstract

Objectives: We estimated associations between objectively-determined neighbourhood 'walkability' attributes and accelerometer-derived sedentary time (ST) by sex, city, or type of day.

Design: A cross-sectional study

Setting: The URBAN study was conducted in 48 neighborhoods across four cities in New Zealand (August 2008-October 2010).

Participants: The response rate was 41% (2029 recruited participants/5007 eligible households approached). In total, 1762 participants (aged 41.4±12.1, M±SD) met the data inclusion criteria and were included in analyses.

Primary and secondary outcome measures: The exposure variables were GIS measures of neighborhood walkability (i.e. street connectivity, residential density, land use mix, retail footprint area ratio) for street network buffers of 500 m and 1000 m around residential addresses. Participants wore an accelerometer for seven days. The outcome measure was average daily minutes of ST.

Results: Data were available from 1762 participants (aged 41.4 ± 12.1 years; 58% female). No significant main effects of GIS-based neighborhood walkability measures were found with ST. Retail footprint area ratio was negatively associated with sedentary time in women, significant only for 500 m residential buffers. An increase of 1 decile in street connectivity was significantly associated with a decrease of over 5 minutes of ST per day in Christchurch residents for both residential buffers.

Conclusion: Neighborhoods with proximal retail and higher street connectivity seem to be associated with less ST. These effects were sex and city specific.

Key words: Built environment, Connectivity, Net dwelling density, Mixed land use, Sitting.

Strengths and Limitations of this study

- The strength of this paper is the large sample size from across four cities in New Zealand with sufficient numbers to make inter-city comparisons and the use of objective measures for sedentary time and the built environment.
- Data on retail floor area were not available and so the retail building footprint was used as a proxy.
- The retail land use was derived from zoning data which potentially excludes smaller retail areas.
- The effects of neighbourhood self-selection and neighborhood characteristics that promoted sedentary time were not differentiated.
- The lack of variation between New Zealand cities (low walkability in the global sense) may have also influenced our findings.

1.0 Background

Sedentary behavior is a common behavior in adults, characterised by sitting times (median or mean) of 5 to 8 hours per day [1, 2]. Evidence indicates that prolonged periods of inactivity, induced through sitting, have detrimental health effects [3]. A dose–response association has been reported between sitting time and all-cause mortality and cardiovascular disease, [3, 4] as well as higher risk for obesity and Type 2 diabetes [5]. These adverse effects are present even in individuals who meet public health guidelines for moderate-to-vigorous physical activity [6].

Correlates of sedentary behaviour identified thus far in adults include age, attitudes, body mass index, depressive symptoms/quality of life, education, employment status, gender, income, moderate-to-vigorous physical activity and smoking status [7]. A socio-ecological approach to understanding health behaviours suggests that broader factors such as the built environment may play a role [8]. However, while there is a large body of research focusing on behavioural and sociodemographic correlates of sedentary behaviour, research on social and environmental correlates remains scarce.

A recent systematic review on built environment attributes and sedentary behaviour relationships [8] found that very few studies showed significant associations between neighborhood built environment attributes and sedentary behaviors in the expected direction. However, overall, residents living in urban areas with diverse destinations close to their residential address had lower levels of sedentary behavior [8]. It is theorized that environments more conducive to physical activity may encourage less sitting [9]. It is also theorized that the neighborhood environment may have an added direct influence on women than men because in general women are more likely to engage with their residential neighborhood through shopping/running errands and therefore more likely to be affected by the neighborhood design [10].

Studies thus far have used a mixture of self-reported and objectively measured sedentary behaviour and built environment measures. The latest review by Kooshari and colleagues [8] did not differentiate between objective and subjective measures of either the built environment or sedentary behaviour, presumably due to the limited number of studies available in this area. Objective measures are generally more reliable and valid than self-reports [11].

In response, the main aim of this paper was to examine associations between Geographical Information System (GIS)-measured components of the neighborhood built environment within 500 m and 1000 m individual buffer zones of participant's homes and objectively measured sedentary time. We also explored whether these associations varied by sex, city, or type of day (weekday versus weekend).

2.0 Methods

Data for the current analysis were supplied by the Understanding the Relationship between Activity and Neighbourhoods (URBAN) Study. A detailed description of the methods has been reported previously [12]. Briefly, cross-sectional data were collected from designated neighborhoods in four cities in New Zealand; North Shore, Waitakere, Wellington, and Christchurch. The URBAN Study commenced in April 2008 in North Shore City and was completed in August 2010 in Christchurch. Although data collection started at different time points across the four locations, they were collected in a balanced manner across 12-14 months in each location to avoid clustering of seasonal effects by city. The host institutions of the research granted ethical approval for the study procedures (AUTEC: 07/126, MUHECN: 07/045).

2.1 Neighborhood selection

Twelve neighborhoods were selected from each city, resulting in a total of 48 neighborhoods being sampled. Neighborhoods were selected based on the walkability profile and ethnic population distribution (Māori, indigenous people) within contiguous mesh blocks (geographic census unit of approximately 100 households, median area: 0.30 km^2, range: 1.03 km^2) of the selected cities. [13] Neighborhood selection resulted in three high walkability/high Māori, three high walkability/low Māori, three low walkability/high Māori and three low walkability/low Māori neighborhoods. The study was relevant nationally by over-sampling for Māori. Māori are the indigenous people of New Zealand, and are the second largest ethnic group (after New Zealand European) in New Zealand. [14] The walkability index was based on measures of street connectivity, net dwelling density, land use mix, and retail footprint area ratio, and was generated using GIS software, ArcInfo 9.1 (ESRI, Redlands, CA). The construction of these measures replicated existing research [15].

2.2 Procedures

The method of recruitment was by door to door; random start points were created in each neighborhood and every n^{th} house (n ranged from one to four according to neighborhood net dwelling density) was approached. Five maximum visits were made to the eligible house. One adult (20-65 years) per household was invited to participate. Once the participant agreed to take part in the study, two subsequent visits were arranged eight days apart. At the first visit, the study was introduced, informed consent was gained, and the accelerometer and compliance log were provided to the participants. A compliance log is a “diary” where participants note the time they have taken off or put on the accelerometer and reason, time they went to bed or woke up in the morning or any other information relevant to the accelerometer. At the second visit, the researcher collected the accelerometer and compliance log (participants wore the accelerometer for seven consecutive days) and completed the survey and anthropometric measures.

From each neighborhood 42 adults were randomly recruited. Participants from selected households were identified using the next birthday method. Exclusion criteria were: falling outside the age ranges, not intending to live in the household over the measurement period, unable to speak the English language, or impaired ability to walk.

2.3 Measures

Sedentary time. Sedentary time was objectively measured with the Actical accelerometer (Mini-Mitter, Sunriver, OR) fitted to an elastic waistband and worn above the right hip. The units have been shown to be reliable and valid [16, 17]. Prior to distribution, the units were tested for functionality and set up to record physical activity in 30-second epochs. Participants were instructed to wear the monitors during waking hours, but remove them when participating in water-based or contact activities. The threshold for sedentary time was set to <100 counts/minute using the Crouter 2R equation for the count threshold [18]. Data from participants with at least 10 hours of wear time for at least 5 days (including 1 weekend day) were included in the analyses. Non-wear time was defined as 60 minutes or more of consecutive zero counts [19, 20]. Daily measures of sedentary time were aggregated by averaging across all days for each participant.

2.4 Demographic variables. Participants completed a face-to-face survey from which the following demographic characteristics were extracted: age, sex, ethnicity, marital status, academic qualification, total household income, and employment status.

2.5 Walkability measures. We extracted measures of neighborhood built environment from a GIS database that used ArcGIS 9.3 software (Environmental Systems Research Institute, California). The methods have been described in detail elsewhere [12, 21]. Briefly the walkability variables were:

- Street connectivity, estimated by calculating intersection density, the number of intersections per square kilometer ~~within 20 meters of a mesh-block boundary~~. Intersections were extracted from road centreline data provided by Territorial Local Authorities.
- Net dwelling density, number of dwellings, estimated by dividing the number of dwellings by the residential land area for each meshblock. Dwelling data was sourced from the 2006 New Zealand census.
- Mixed land use, use of land including commercial, residential, industrial, open space and other, was calculated using an entropy index, [15] where 0 indicates homogeneity of land use and 1 heterogeneity. Zoning data sourced from Territorial Local Authorities was used as a proxy for land use.

$$\text{LUM} = -\frac{\sum_k (p_k \ln p_k)}{\ln N}$$

where k is the land use category, p is the proportion of land area in a specific land use, and N is the number of land uses.

- Retail footprint area ratio, which, due to the lack of floor area data, was estimated as the area of the retail building footprint divided by the area of the retail land parcel. Participants with no retail land use in their buffer were assigned a retail footprint area ratio of zero. A higher ratio facilitates pedestrian access as it has smaller setbacks and less surface parking [22].

Walkability measures were calculated for administrative units and also for 500 m and 1000 m road network buffers calculated around participant's residential addresses. Road network buffers were created using the ArcGIS Service Area function. Road centreline data was sourced from Territorial Local Authorities and prior to calculation of the buffers, roads not accessible to pedestrians (e.g., motorways and on- and off-ramps) were removed.

2.6 Data analytic plan

Data were analyzed in July 2014. Descriptive statistics (means, standard deviations and percentages) were computed for the whole sample and by city for all variables. Generalized additive mixed models (GAMMs) [23] were used to estimate associations between walkability and sedentary time. GAMMs can account for dependency in residuals (multiple measures taken on the same participants sampled from selected administrative units), and estimate complex, dose-response relationships of unknown form [23]. Three-level random intercept GAMMs with Gaussian variance and identity link functions, appropriate for approximately normally distributed residuals (diagnostic tests were conducted to determine the appropriateness of the variance and link functions), were used to estimate associations between walkability and sedentary time. These models accounted for three levels of variability in the outcome – namely, variability at the administrative units selected for participant recruitment, at the person level (i.e., between-participant differences), and at the within-person level (within-participant differences between weekday and weekend day estimates of sedentary time).

First, a GAMM estimated the independent associations of socio-demographic characteristics, type of day and study sites with accelerometry-based sedentary time. Then, separate main-effect GAMMs estimated the dose-response relationships of walkability components for the 500 m and 1 km road network buffers, respectively, with accelerometry-based sedentary time, adjusting for city, socio-demographic covariates (sex, age, marital status, educational attainment, ethnicity, and employment status), neighborhood deprivation (NZ Deprivation Index), average minutes of accelerometer wear time, number of valid days of wear, and type of day (weekday versus weekend day). It was possible to simultaneously enter all GIS variables in the GAMMs as they were not collinear (mean absolute correlation = 0.26; range of absolute correlations =0.07 - 0.48). It was possible to simultaneously enter all GIS variables in the GAMMs as they were not collinear (mean absolute correlation = 0.20; range of absolute correlations = 0.07 – 0.48; mean Variance Inflation Factor, VIF = 1.14; range of VIF = 1.01 – 1.56). Curvilinear relationships of environmental attributes with outcomes were estimated using non-parametric smooth terms in GAMMs, which were modeled using thin-plate splines [23]. Smooth terms failing to provide sufficient evidence of a curvilinear relationship (based on Akaike Information Criterion (AIC)) were replaced by simpler linear terms. Separate GAMMs were run to estimate two-way and three-way walkability component by sex, city and type of day interaction effects. The significance of interaction effects was evaluated by comparing AIC values of models with and without a specific interaction term. An interaction effect was deemed significant if it yielded a >2-unit smaller AIC than the main effect model [24]. Significant interaction effects were probed by computing the sex-, city-, and/or type of day-specific associations (as appropriate) of GIS-based components of walkability with accelerometry-based sedentary time via linear functions.

There were 12.5% cases with missing or invalid accelerometer data (252 out of 2014), and these were excluded in the analyses. Participants with valid accelerometer data were older ($p<.001$), more likely to live in high SES neighbourhoods ($p=.010$) and be employed ($p<.001$). All regression models were adjusted for these variables. There were less than 1.3% of remaining participants with missing data on any other variables. Given the low percentage of missing data, these values were imputed with the most common values for the sample (mean values or modes, as appropriate). All analyses were conducted in R [25] using the packages 'car' [26] and 'mgcv' [23].

3.0 Data availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the Institution's ethical approval process and the requirement of consent by participants (indigenous and otherwise) but are available from the corresponding author on reasonable request.

4.0 RESULTS

The response rate was 41% (2029 recruited participants/5007 eligible households approached). In total, 1762 participants (aged 41.4±12.1, M±SD) met the data inclusion criteria and were included in analyses. Table 1 reports the descriptive statistics of participants with accelerometer data for each city. This includes sample socio-demographic characteristics, GIS-based walkability components and accelerometry-based variables. Mean age of the total sample was 41.4 years (SD=12.1). Average sitting time was lower on weekends (mean = 409 minutes/day) than weekdays (mean = 480 minutes per day). Participants living in Christchurch had the highest sitting time on weekends, but the lowest on weekdays.

On average, selected neighborhoods in Christchurch had the lowest levels of net dwelling density and retail footprint area ratios, whilst Wellington had the highest levels of net dwelling density, intersection density and land use mix.

PLEASE INSERT TABLE 1 ABOUT HERE

4.1 Associations between socio-demographic variables, city and type of day with accelerometry-based sedentary time

Men, older participants, and more highly educated participants engaged in significantly more sedentary time than their counterparts (Table 2). For example, compared with participants with less than secondary schooling, those who completed tertiary education accumulated 41.7 more minutes of sedentary time per day. Being employed, living with a partner (as opposed to being single) and not being of Asian or Māori/Polynesian ethnicity was associated with lower levels of sedentary time. On average, participants from Wellington accumulated less sedentary time than those from other study sites. Weekend days were on average associated with approximately 18 fewer minutes of sedentary time than weekdays (Table 2).

PLEASE INSERT TABLE 2 ABOUT HERE

4.2 Associations of walkability components with accelerometry-based sedentary time

No significant main effects of GIS-based walkability components with accelerometry-based sedentary time were found (Table 3). However, significant interaction effects were found between street connectivity by city, and retail footprint area ratio by sex. Street connectivity was significantly negatively associated with sedentary time in Christchurch only. Among participants from Christchurch, an increase of 1 decile in street connectivity was associated with a decrease of over 5 minutes of sedentary time per day. This effect was observed for both residential buffer sizes. While retail footprint area ratio was not predictive of sedentary time in men, it was negatively associated with sedentary time in women across all cities. However, this effect was stronger (and significant only) for 500 m residential buffers across the four cities (Table 3).

The proportions of sedentary time variance attributable to between-neighbourhood, between-participant (within neighbourhoods) and between-day (within participants) differences were, respectively, 0.02 (p=.002), 0.35 (p<.001) and 0.63 (p<.001). The final GAMMs, including all covariates, environmental variables and interaction terms, explained 95% of the between-neighbourhood, 34% of between-participant and 55% of between-day variance. The proportions of unexplained sitting time variance attributable to differences between neighbourhood, persons and days were approximately <0.01 (p>.250), 0.45 (p<.001) and 0.54 (p<.001).

PLEASE INSERT TABLE 3 ABOUT HERE

5.0 Discussion

There were no significant main effects of GIS-based walkability on sedentary time, however significant interaction effects were found between street connectivity in one city-Christchurch and retail footprint area ratio in women. This and the study by Van Dyck [19] and colleagues are the only studies that have examined associations between objectively measured built environment and sedentary time in adults.

Our a priori assumption was that built environments more conducive to physical activity may encourage less time spent in sedentary behavior. Our findings do not necessarily support this, as there were no significant main effects of GIS-based walkability on sedentary time and only 2% of the variance in sitting time was due to differences between neighborhoods. Perhaps sedentary behavior is influenced by neighborhood cultural or social phenomena or built environment factors not measured in the study such as public transport (Wellington region has the highest use of public transport per capita use in New Zealand). Also, the administrative units used to capture neighborhood-level variability in sedentary time may not represent the optimal geographical scale to detect environmental influences on this specific behavior. Moreover, since sedentary behavior is not the reverse of physical activity, [27] the presence of walkable features may not influence the transition from sitting to walking. Another explanation may be that since sedentary time seems to be associated with home-based activities (e.g. television watching, computer use) [28] perhaps built environment associations around smaller buffers (close proximity to the home) may have been more appropriate. Certainly, in our study, there was only one significant interaction effect observed within a 1000 m buffer and only two interaction effects within the 500 m buffer. Nonetheless, smaller buffers may be problematic in countries in which neighborhoods are of comparatively low walkability such as New Zealand [29]. On the other hand, a measure of regional accessibility may need to be included to account for environments of residents that commonly access (work and non-work) beyond the neighborhood. Regional accessibility is defined as being determined by large regional shopping centers and employment clusters, usually farther away, offering a variety of services [30]. It is possible that multi-purpose trips are done in this way, conceivably reducing the possibility of local accessibility irrespective of the neighborhood environment. Ubiquity of car ownership, as is the case for New Zealand, is also important. Ivory and colleagues [10] saw a strong relationship between built environment characteristics and car access, where almost half of those with restricted car access lived in the most connected street network areas, compared with approximately a third who had full car access. Lastly, it is plausible that different GIS measures may need to be considered for the development of sedentary behavior index in the future but extensive conceptualization and research must take place first.

In the interaction effects model, two relationships showed significance: street connectivity in Christchurch (within both 500m and 1000 m neighborhood buffer) and retail footprint area ratio in women (within 500m neighborhood buffer only). For participants from Christchurch, an increase of 1 decile in street connectivity was associated with a decrease of over 5 minutes of sedentary time per day. The result makes sense due to the city's relatively flat topography and city design in comparison to Auckland and Wellington. Christchurch was one of four cities in the world (prior to the 2010 Christchurch earthquake) that was designed in a rectangular grid fashion with a central city square, surrounded by four city squares and a parklands area [31]. Literature has shown that street connectivity is positively associated with overall walking [32] and walking for transport [32, 33]. In terms of the second interaction effect, a significant association was observed between sedentary time and higher footprint area retail ratio within the 500 m, but not the 1000 m neighbourhood buffer. Across all cities, the floor area retail ratio within a 500 m neighborhood buffer was predictive of less sedentary time in women but not men. Aside from the sex difference, we theorized that neighbourhoods more conducive to physical activity, in this case presence of retail (any type) in close proximity, may encourage reduction of sedentary time. Mixing residential neighborhoods with retail and other uses is not a new concept and remained the design of traditional European cities and towns for several centuries. Traditional neighborhoods morphed around the individual's needs to walk short distances to a destination. In terms of the sex difference, a similar sex association has been shown with self-reported sedentary behaviour in women and neighbourhood walkability, [34] women residing in low-walkable neighbourhoods reported increased levels of television viewing compared with those who lived in higher-walkable neighbourhoods [34]. While other studies have not investigated sex differences, Kooshari and colleagues [35] reported that in high walkable Australian neighbourhoods, in particular those with high retail footprint area ratio, residents spent less time sitting in cars, while in Belgian adults, Van Dyck and associates, [19] found that daily sedentary time was higher for residents living in a high walkable environment. Nonetheless, according to our results, one may infer that women who reside in neighbourhoods with better access to retail spend less time in sedentary pursuits because they walk to a destination of interest frequently. These associations need to be investigated further to understand the reasons behind these.

The strength of this paper is the large sample size from across four cities in New Zealand with sufficient numbers to make inter-city comparisons. An additional strength is the use of objective measures for sedentary time and the built environment. Notwithstanding the strengths of the study, there are limitations that need to be acknowledged. One of the main limitations is that the data were derived from a cross-sectional study and causation cannot be assumed. While the retail footprint area ratio potentially identifies differences between big-box retail and strips (includes carparking), the spatial data used for this measure were limited in two ways. First, data on retail floor area ratio were not available and so the retail building footprint was used as a proxy. Second, retail land use was derived from zoning data which potentially excludes smaller retail areas and doesn't necessarily correspond to current use. Further, given that our study neighborhoods were located in areas unlikely to be within 1000 m of big box retail, in our study we consider the retail footprint area ratio as a proxy for access to retail. We were unable to differentiate between the effects of neighborhood self-selection and neighborhood characteristics that promoted sedentary time. It is possible that an alternative aggregate of GIS measures might have captured city differences better than the measures that we've used; for example, topography was not included in the GIS variables measured. The lack of variation between New Zealand cities (low walkability in the global sense) may have also influenced our findings and possibly the reason for the difference in findings with the Belgian study [19]. Since we used accelerometry to determine sedentary behavior, we were unable to determine the type of sedentary behavior participants engaged in. Finally, hip-mounted accelerometers can misclassify very light activity and standing with sedentary behavior. For this reason hip-mounted accelerometers tend to overestimate sedentary behavior.

6.0 Conclusion

Our results imply that sedentary behaviour (time) was not correlated with the built environment in the New Zealand context. While there were no significant main effects between GIS-based walkability and sedentary time, neighborhoods within a 500 m neighborhood buffer that included retail were associated with less sedentary time in women residents only. In Christchurch, higher street connectivity was associated with less sedentary time. Taken together, it is possible that since sedentary behavior is not the reverse of physical activity, [27] the presence of walkable features may not influence the transition from sitting to walking and other factors (social and cultural) may supersede. This paper provided several alternatives to explain these results.

Declarations

Ethics approval and consent to participate

The host institutions of the research granted ethical approval for the study procedures (AUTEC: 07/126, MUHECN: 07/045).

Consent for publication

All authors have consented to publication of this manuscript.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare there is no conflict of interest.

Funding

This work was funded by the Health Research Council (HRC) of New Zealand [grant numbers: 07/356 and 08/048]. The funding body was not involved in the design, conduct, data collection, management, or publication of the study. The authors also gratefully acknowledge the participants who completed the study, research assistants who collected the data and the territorial authorities for providing the GIS datasets. EC is supported by an Australian Research Council (ARC) Future Fellowship (FT#140100085). HB and SM are in part supported by VicHealth, the National Health and Medical Research Council (NHMRC) Centre of Research Excellence in Healthy Liveable Communities (#1061404), and The Australian Prevention Partnership Centre (#9100001) with funding provided by NHMRC, ACT Health, NSW Health, the Australian National Preventive Health Agency, the Hospitals Contribution Fund of Australia and the HCF Research Foundation.

Authors' contributions

EH has provided the first draft and subsequent drafts, is the corresponding author, and conceptualised the content of manuscript and analysis, CE analyzed the data and provided the results and tables, SM conducted the GIS analysis and contributed to the manuscript, MS contributed to the manuscript, HB managed the study and contributed to the manuscript, KW co-primary investigator and contributed to the manuscript, RK, contributed to the manuscript, GS co-primary investigator and contributed to the manuscript.

REFERENCES

Table 1. Overall and site-specific area and sample characteristics

	Study site				
	All sites	North Shore	Waitakere	Wellington	Christchurch
Overall N	1762	463	466	417	443
Socio-demographics					
Mean age (SD) [Missing: 1.2%]	41.4 (12.1)	41.8 (11.6)	41.5 (11.7)	40.0 (12.5)	42.1 (12.5)
Sex, %men [Missing: 0.0%]	42.1	36.2	39.9	47.2	45.4
Education, % [Missing: 0.3%]					
Less than secondary school	4.5	2.3	4.5	0.5	10.4
Completed secondary school	56.3	58.0	64.2	45.1	56.9
Tertiary education	38.9	38.8	31.3	54.4	32.5
Work status, %working [Missing: 0.0%]	82.9	78.0	84.6	86.8	82.2
Marital status,	65.6	72.0	74.0	59.5	56.0

%couple [Missing: 0.2%]					
Ethnicity, % [Missing: 0.0%]					
Maori/Polynesian	15.8	18.1	21.7	10.1	12.6
Asian	9.8	9.6	14.8	8.2	6.3
NZ European / Pakeha / Other	74.4	72.3	63.5	81.8	81.0
Mean environmental variables (SD) [Missing: 0.0%]					
NZ Deprivation Index	5.1 (2.6)	4.2 (2.2)	5.3 (2.6)	4.7 (2.3)	6.2 (2.8)
Net dwelling density (dwellings/km^2) – 500m buffers	5.5 (2.9)	5.5 (2.9)	5.6 (3.0)	6.3 (2.7)	4.5 (2.5)
Street connectivity (intersections/km^2) – 500m buffers	5.4 (2.8)	4.4 (2.7)	4.8 (2.8)	6.3 (3.1)	6.4 (2.2)
Land use mix (entropy score)– 500m buffers	0.55 (0.29)	0.47 (0.27)	0.46 (0.26)	0.72 (0.28)	0.56 (0.27)
Net retail footprint area ratio (area of retail	0.44 (0.29)	0.40 (0.33)	0.48 (0.48)	0.55 (0.36)	0.32 (0.34)

building footprint/ area of retail land parcel) – 500m buffers					
Net dwelling density (dwellings/km^2)– 1km buffers	5.5 (2.9)	5.1 (2.9)	6.2 (2.8)	7.0 (2.1)	3.7 (2.5)
Street connectivity (intersections/km^2)– 1km buffers	5.4 (2.9)	3.7 (2.2)	4.3 (2.4)	7.5 (2.9)	6.5 (2.1)
Land use mix (entropy score) – 1km buffers	0.55 (0.28)	0.40 (0.27)	0.42 (0.24)	0.82 (0.18)	0.57 (0.21)
Net retail footprint area ratio (area of retail building footprint/ area of retail land parcel) – 1km buffers	0.53 (0.31)	0.45 (0.23)	0.60 (0.45)	0.66 (0.24)	0.41 (0.18)
Mean accelerometry-based variables (SD) [Missing: 0.0%]					
Daily minutes of wear time - weekdays	789.5 (134.9)	796.4 (122.9)	802.2 (153.3)	812.8 (111.4)	748.2 (136.7)
Daily minutes of	681.1	697.1	649.9	717.2	668.0 (208.8)

wear time - weekend	(191.7)	(187.8)	(207.1)	(141.9)	
Percent of valid weekdays	89.4 (15.8)	92.0 (13.2)	90.6 (17.0)	85.9 (14.3)	88.7 (17.3)
Percent of valid weekend days	74.5 (33.0)	79.8 (32.0)	69.8 (36.7)	75.8 (22.7)	73.4 (36.5)
Sedentary time – weekdays (min/day)	479.5 (130.8)	483.2 (124.5)	489.7 (137.3)	484.4 (128.7)	460.8 (130.4)
Sedentary time – weekend (min/day)	409.3 (148.6)	410.3 (148.5)	406.1 (160.2)	407.7 (125.1)	413.1 (154.9)

Table 2. Associations of socio-demographic characteristics, type of day and study sites with accelerometry-based sedentary time

Predictor	b	95% CI	p
Socio-demographic			
Sex (reference: female)			
Male	18.1	9.5, 26.8	**<.001**
Education (reference: less than secondary school)			
Completed secondary school	18.7	-2.8, 40.2	.096
Tertiary education	41.7	19.1, 64.3	**<.001**
Working status (reference: not working)			
Working	-12.6	-24.1, -1.1	**.032**
Marital status (reference: single)			
Couple	-23.6	-32.8, -14.4	**<.001**
Ethnicity (reference: Maori/Polynesian			
Asian	-0.1	-18.0, 17.9	.978
European / Pakeha / Other	-14.5	-27.1, -1.8	**.025**
Age (yrs)	0.7	0.3, 1.0	**<.001**
New Zealand Deprivation Index	0.3	-4.6, 5.1	.860
Study site (reference: North Shore)			
Waitakere	8.1	-6.43, 22.5	.287
Wellington	-17.3	-33.0, -1.6	**.039**
Christchurch	3.2	-13.1, 19.4	.548

Type of day (reference: weekday)			
Weekend	-17.9	-23.7, -12.1	**<.001**

Note. The regression model was adjusted for valid days of accelerometer wear and average daily minutes of wear and accounted for correlated residuals at the neighborhood and participant levels. b = regression coefficients; 95% CI = 95% confidence intervals.

Table 3. Associations of GIS-based walkability components for 500m and 1km residential buffers with accelerometry-based sedentary time

	500m residential buffers			1km residential buffers		
Predictor	**b**	**95% CI**	**p**	**b**	**95% CI**	**p**
Main effect models						
Net dwelling density	-0.39	-2.08, 1.31	.654	-0.57	-2.49, 1.35	.564
Street connectivity	0.14	-1.90, 2.18	.892	-0.34	-2.58, 1.90	.768
Land use mix*	1.04	-1.64, 1.15	.265	1.03	-1.08, 3.14	.339
Net retail footprint area ratio*	-0.24	-1.64, 1.15	.733	-0.02	-1.88, 1.84	.982
Interaction effects						
Street connectivity by study site						
Effect of street connectivity in North Shore	1.02	-2.37, 4.43	.556	0.20	-4.00, 4.41	.927
Effect of street connectivity in Waitakere	1.26	-2.02, 4.55	.452	-0.65	-4.43, 3.12	.733
Effect of street connectivity in Wellington	1.55	-1.78, 4.88	.363	2.12	-1.14, 5.38	.203
Effect of street connectivity in Christchurch	-5.06	-9.25, -0.86	**.019**	-5.18	-9.50, -0.86	**.019**

Net retail footprint area ratio (NRFA) by sex						
Effect of NRFA in men	1.49	-0.36, 3.35	.116	1.58	-0.86, 4.01	.205
Effect of NRFA in women	-1.95	-3.60, -0.29	**.022**	-1.48	-3.59, 0.64	.172

Notes. All models adjusted for other walkability components, socio-demographics, New Zealand Deprivation Index, study site, and type of day (weekday versus weekend). All models accounted for correlated residuals at the neighborhood and participant levels. b = regression coefficients; 95% CI = 95% confidence intervals.

* The original values of land use mix and net retail footprint area ratio were multiplied by 10 to obtain point estimates of the regression coefficients that would correspond to the difference in min/day of sedentary time associated with a 0.10 increase in these environmental predictors rather than the difference in outcomes between the theoretical minimum (i.e. 0) and maximum (i.e., 1) values of the predictors.

References

1. Bauman A, Ainsworth BE, Sallis JF, et al. The descriptive epidemiology of sitting: a 20-country comparison using the International Physical Activity Questionnaire (IPAQ). Am. J. Prev. Med. 2011;**41**(2):228-35 doi: http://dx.doi.org/10.1016/j.amepre.2011.05.003[published Online First: Epub Date]|.

2. Hagströmer M, Troiano RP, Sjöström M, et al. Levels and patterns of objectively assessed physical activity—a comparison between Sweden and the United States. Am. J. Epidemiol. 2010 doi: http://dx.doi.org/10.1093/aje/kwq069[published Online First: Epub Date]|.

3. Katzmarzyk PT, Church TS, Craig CL, et al. Sitting time and mortality from all causes, cardiovascular disease, and cancer. Med. Sci. Sports Exerc. 2009;**41**(5):998 doi: http://dx.doi.org/10.1249/MSS.0b013e3181930355[published Online First: Epub Date]|.

4. Thorp AA, Owen N, Neuhaus M, et al. Sedentary behaviors and subsequent health outcomes in adults: a systematic review of longitudinal studies, 1996–2011. Am. J. Prev. Med. 2011;**41**(2):207-15 doi: http://dx.doi.org/0.1016/j.amepre.2011.05.004[published Online First: Epub Date]|.

5. Hu FB, Li TY, Colditz GA, et al. Television watching and other sedentary behaviors in relation to risk of obesity and type 2 diabetes mellitus in women. JAMA 2003;**289**(14):1785-91 doi: http://dx.doi.org/10.1001/jama.289.14.1785[published Online First: Epub Date]|.

6. Healy GN, Wijndaele K, Dunstan DW, et al. Objectively measured sedentary time, physical activity, and metabolic risk. Diabetes Care 2008;**31**(2):369-71 doi: http://dx.doi.org/10.2337/dc07-1795[published Online First: Epub Date]|.

7. Rhodes RE, Mark RS, Temmel CP. Adult sedentary behavior: a systematic review. Am. J. Prev. Med. 2012;**42**(3):e3-e28 doi: http://dx.doi.org/10.1016/j.amepre.2011.10.020[published Online First: Epub Date]|.

8. Koohsari MJ, Sugiyama T, Sahlqvist S, et al. Neighborhood Environmental Attributes and Adults' Sedentary Behaviors: Review and Research Agenda. Prev. Med. 2015;**77**:141-49 doi: http://dx.doi.org/10.1016/j.ypmed.2015.05.027[published Online First: Epub Date]|.

9. Barnett A, Cerin E, Ching CS, et al. Neighbourhood environment, sitting time and motorised transport in older adults: a cross-sectional study in Hong Kong. BMJ open 2015;**5**(4):e007557 doi: http://dx.doi.org/10.1136/bmjopen-2014-007557[published Online First: Epub Date]|.

10. Ivory VC, Blakely T, Pearce J, et al. Could strength of exposure to the residential neighbourhood modify associations between walkability and physical activity? Soc. Sci. Med. 2015;**147**:232-41 doi: http://dx.doi.org/10.1016/j.socscimed.2015.10.053[published Online First: Epub Date]|.

11. Dyrstad SM, Hansen BH, Holme IM, et al. Comparison of self-reported versus accelerometer-measured physical activity. Med. Sci. Sports Exerc. 2014;**46**(1):99-106 doi: http://dx.doi.org/10.1249/MSS.0b013e3182a0595f[published Online First: Epub Date]|.

12. Badland HM, Schofield GM, Witten K, et al. Understanding the Relationship between Activity and Neighbourhoods(URBAN) Study: research design and methodology. BMC Public Health 2009;**9**(1):224 doi: http://dx.doi.org/10.1186/1471-2458-9-224[published Online First: Epub Date]|.

13. Statistics New Zealand. Census of population and dwellings: Auckland City. What we look like locally. Wellington: Statistics NZ, 2006.

14. Statistics New Zealand. New Zealand in profile: An overview of New Zealand's people, economy, and environment. Wellingotn: Statistics New Zealand, 2009.

15. Leslie E, Coffee N, Frank L, et al. Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. Health Place 2007;**13**(1):111-22 doi: http://dx.doi.org/10.1016/j.healthplace.2005.11.001[published Online First: Epub Date]|.

16. Esliger DW, Tremblay MS. Technical reliability assessment of three accelerometer models in a mechanical setup. Med. Sci. Sports Exerc. 2006;**38**(12):2173-81 doi: http://dx.doi.org/10.1249/01.mss.0000239394.55461.08[published Online First: Epub Date]|.

17. Esliger DW, Probert A, Gorber SC, et al. Validity of the Actical Accelerometer Step-Count Function. Med. Sci. Sports Exerc. 2007;**39**(7):1200-04 doi: http://dx.doi.org/10.1249/mss.0b013e3804ec4e9[published Online First: Epub Date]|.

18. Crouter SE, DellaValle DM, Horton M, et al. Validity of the Actical for estimating free-living physical activity. Eur. J. Appl. Physiol. 2011;**111**(7):1381-89 doi: http://dx.doi.org/10.1007/s00421-010-1758-2[published Online First: Epub Date]|.

19. Van Dyck D, Cardon G, Deforche B, et al. Neighborhood walkability and sedentary time in Belgian adults. Am. J. Prev. Med. 2010;**39**(1):25-32 doi: http://dx.doi.org/10.1016/j.amepre.2010.03.004[published Online First: Epub Date]|.

20. Oliver M, Badland HM, Schofield GM, et al. Identification of accelerometer nonwear time and sedentary behavior. Res. Q. Exerc. Sport 2011;**82**(4):779-83 doi: http://dx.doi.org/10.1080/02701367.2011.10599814[published Online First: Epub Date]|.

21. Mavoa S, Witten K, Pearce J, et al. Measuring Neighbourhood Walkability in New Zealand Cities, 2009.

22. Frank LD, Sallis JF, Saelens BE, et al. The development of a walkability index: application to the Neighborhood Quality of Life Study. Br. J. Sports Med. 2010;**44**(13):924-33 doi: http://dx.doi.org/10.1136/bjsm.2009.058701[published Online First: Epub Date]|.

23. Wood S. *Generalized additive models: an introduction with R.* Boca Raton, Florida: Chapman & Hall, 2006.

24. Burnham K, Anderson D. *Model selection and multimodel inference: a practical information-theoretic approach, 2nd ed* New York, NY: Springer, 2002.

25. R Core Team. *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing, 2013.

26. Fox J, Weisberg S. *An R companion to applied regression, 2nd ed*. Thousand Oaks CA: Sage, 2011.

27. Healy GN, Dunstan DW, Salmon JO, et al. Television time and continuous metabolic risk in physically active adults. Med. Sci. Sports Exerc. 2008;**40**(4):639 doi: http://dx.doi.org/10.1249/MSS.0b013e3181607421[published Online First: Epub Date]|.

28. Owen N, Sugiyama T, Eakin EE, et al. Adults' sedentary behavior: determinants and interventions. Am. J. Prev. Med. 2011;**41**(2):189-96 doi: http://dx.doi.org/10.1016/j.amepre.2011.05.013[published Online First: Epub Date]|.

29. Sallis JF, Bowles HR, Bauman A, et al. Neighborhood environments and physical activity among adults in 11 countries. Am. J. Prev. Med. 2009;**36**(6):484-90 doi: http://dx.doi.org/10.1016/j.amepre.2009.01.031[published Online First: Epub Date]|.

30. Handy S. Regional versus local accessibility: Implications for nonwork travel. University of California: University of California Transportation Center, 1993:58-66.

31. Wilson J, Dowson S, Adam J, et al. Contextual Historical Overview of Christchurch City. Christchurch: Christchurch City Council, 2005.

32. Witten K, Blakely T, Bagheri N, et al. Neighborhood built environment and transport and leisure physical activity: findings using objective exposure and outcome measures in New Zealand. Environ. Health Perspect. 2012;**120**(7):971–77 doi: http://dx.doi.org/10.1289/ehp.1104584[published Online First: Epub Date]|.

33. Koohsari MJ, Sugiyama T, Lamb KE, et al. Street connectivity and walking for transport: Role of neighborhood destinations. Prev. Med. 2014;**66**:118-22 doi: http://dx.doi.org/10.1016/j.ypmed.2014.06.019[published Online First: Epub Date]|.

34. Sugiyama T, Salmon J, Dunstan DW, et al. Neighborhood walkability and TV viewing time among Australian adults. Am. J. Prev. Med. 2007;**33**(6):444-49 doi: http://dx.doi.org/10.1016/j.amepre.2007.07.035[published Online First: Epub Date]|.

35. Koohsari MJ, Sugiyama T, Kaczynski AT, et al. Associations of leisure-time sitting in cars with neighborhood walkability. J. Phys. Act. Health 2014;**11**(6):1129-32 doi: http://dx.doi.org/10.1123/jpah.2012-0385[published Online First: Epub Date]|.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-7
Objectives	3	State specific objectives, including any prespecified hypotheses	7
Methods			
Study design	4	Present key elements of study design early in the paper	7-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	8-9
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	9-10
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	9-11
Bias	9	Describe any efforts to address potential sources of bias	11
Study size	10	Explain how the study size was arrived at	9
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	11-13
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	11-12
		(*b*) Describe any methods used to examine subgroups and interactions	11-12
		(*c*) Explain how missing data were addressed	13
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	
		(*e*) Describe any sensitivity analyses	
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	13
		(b) Give reasons for non-participation at each stage	
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	13-14
		(b) Indicate number of participants with missing data for each variable of interest	
Outcome data	15*	Report numbers of outcome events or summary measures	13-15
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	13-15
		(*b*) Report category boundaries when continuous variables were categorized	13-15
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	16-18
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	19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	16-20
Generalisability	21	Discuss the generalisability (external validity) of the study results	19
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	21

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

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.