

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

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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 (Understanding the Relationship between Activity and Neighbourhoods) study was conducted in 48 neighbourhoods across four cities in New Zealand (August 2008 to October 2010).

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

Primary and secondary outcome measures The exposure variables were geographical information system (GIS) measures of neighbourhood walkability (ie, 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 7 days. The outcome measure was average daily minutes of ST.

Results Data were available from 1762 participants (aged 41.4±12.1 years; 58% women). No significant main effects of GIS-based neighbourhood 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 min of ST per day in Christchurch residents for both residential buffers.

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

BACKGROUND

Sedentary behaviour is a common behaviour 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

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 intercity 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 neighbourhood 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.

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 socioecological 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 relationships⁸ found that very few studies showed significant associations between neighbourhood built environment attributes and



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sedentary behaviours in the expected direction. However, overall, residents living in urban areas with diverse destinations close to their residential address had lower levels of sedentary behaviour.⁸ It is theorised that environments more conducive to physical activity may encourage less sitting.⁹ It is also theorised that the neighbourhood environment may have an added direct influence on women than men because, in general, women are more likely to engage with their residential neighbourhood through shopping/running errands and therefore more likely to be affected by the neighbourhood 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 colleagues⁸ 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 neighbourhood built environment within 500m and 1000m 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 vs weekend).

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 neighbourhoods 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 (AUTEK: 07/126, MUHECN: 07/045).

Neighbourhood selection

Twelve neighbourhoods were selected from each city, resulting in a total of 48 neighbourhoods being sampled. Neighbourhoods 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 km², range: 1.03 km²) of the selected cities.¹³ Neighbourhood selection resulted in three high walkability/high Māori, three high walkability/low Māori, three low walkability/high Māori and three low walkability/low

Māori neighbourhoods. The study was relevant nationally by oversampling 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 V.9.1 (Environmental Systems Research Institute, Redlands, California, USA). The construction of these measures replicated existing research.¹⁵

Procedures

The method of recruitment was by door to door; random start points were created in each neighbourhood and every *n*th house (*n* ranged from one to four according to neighbourhood 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 8 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 7 consecutive days) and completed the survey and anthropometric measures.

From each neighbourhood, 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.

Measures

Sedentary time

Sedentary time was objectively measured with the Actical accelerometer (Mini-Mitter, Sunriver, Oregon, USA) 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 s 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 min or more of consecutive zero counts.^{19 20} Daily measures of sedentary time were aggregated by averaging across all days for each participant.

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.

Walkability measures

We extracted measures of neighbourhood built environment from a GIS database that used ArcGIS V.9.3 software (Environmental Systems Research Institute). 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 kilometre. 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 mesh block. Dwelling data were 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 were used as a proxy for land use.
- $$LUM = -\sum_k \left(\frac{p_k \ln p_k}{\ln N} \right)$$
- 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 participants' residential addresses. Road network buffers were created using the ArcGIS Service Area function. Road centreline data were sourced from Territorial Local Authorities, and prior to calculation of the buffers, roads not accessible to pedestrians (eg, motorways and on-ramps and off-ramps) were removed.

Data analytic plan

Data were analysed in July 2014. Descriptive statistics (means, SDs and percentages) were computed for the whole sample and by city for all variables. Generalised 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 (ie, 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 sociodemographic 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, sociodemographic covariates (sex, age, marital status, educational attainment, ethnicity and employment status), neighbourhood deprivation (NZ Deprivation Index), average minutes of accelerometer wear time, number of valid days of wear and type of day (weekday vs 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 modelled 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-specific, city-specific 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 ($p<0.001$), more likely to live in high socioeconomic status neighbourhoods ($p=0.010$) and be employed ($p<0.001$). All regression models were adjusted for these variables. There were less than 1.3% of remaining participants with missing data on any other

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
Sociodemographics					
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, % couple (missing: 0.2%)	65.6	72.0	74.0	59.5	56.0
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)—500 m 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)—500 m 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)—500 m 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 building footprint/area of retail land parcel)—500 m buffers	0.44 (0.29)	0.40 (0.33)	0.48 (0.48)	0.55 (0.36)	0.32 (0.34)
Net dwelling density (dwellings/km ²)—1 km 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)—1 km 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)—1 km 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)—1 km 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 wear time—weekend	681.1 (191.7)	697.1 (187.8)	649.9 (207.1)	717.2 (141.9)	668.0 (208.8)
Per cent of valid weekdays	89.4 (15.8)	92.0 (13.2)	90.6 (17.0)	85.9 (14.3)	88.7 (17.3)
Per cent 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 sociodemographic characteristics, type of day and study sites with accelerometry-based sedentary time

Predictor	b	95% CI	p Value
Sociodemographic			
Sex (reference: female)			
Male	18.1	9.5 to 26.8	<0.001
Education (reference: less than secondary school)			
Completed secondary school	18.7	-2.8 to 40.2	0.096
Tertiary education	41.7	19.1 to 64.3	<0.001
Working status (reference: not working)			
Working	-12.6	-24.1 to 1.1	0.032
Marital status (reference: single)			
Couple	-23.6	-32.8 to 14.4	<0.001
Ethnicity (reference: Māori/Polynesian)			
Asian	-0.1	-18.0 to 17.9	0.978
European/Pakeha/other	-14.5	-27.1 to 1.8	0.025
Age (years)	0.7	0.3 to 1.0	<0.001
New Zealand Deprivation Index	0.3	-4.6 to 5.1	0.860
Study site (reference: North Shore)			
Waitakere	8.1	-6.43 to 22.5	0.287
Wellington	-17.3	-33.0 to 1.6	0.039
Christchurch	3.2	-13.1 to 19.4	0.548
Type of day (reference: weekday)			
Weekend	-17.9	-23.7 to 12.1	<0.001

The regression model was adjusted for valid days of accelerometer wear and average daily minutes of wear and accounted for correlated residuals at the neighbourhood and participant levels. b, regression coefficients.

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 R²⁵ using the packages ‘car’²⁶ and ‘mgcv’.²³

Data availability

The datasets generated during and/or analysed 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.

RESULTS

The response rate was 41% (2029 recruited participants/5007 eligible households approached). In total, 1762 participants (aged 41.4±12.1, mean±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 sociodemographic 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 min/day) than weekdays (mean=480 min/day). Participants living in Christchurch had the highest sitting time on weekends, but the lowest on weekdays.

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

Associations between sociodemographic 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 were 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**).

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

Predictor	500 m residential buffers			1 km residential buffers		
	b	95% CI	p Value	b	95% CI	p Value
Main effect models						
Net dwelling density	-0.39	-2.08 to 1.31	0.654	-0.57	-2.49 to 1.35	0.564
Street connectivity	0.14	-1.90 to 2.18	0.892	-0.34	-2.58 to 1.90	0.768
Land-use mix*	1.04	-1.64 to 1.15	0.265	1.03	-1.08 to 3.14	0.339
Net retail footprint area ratio*	-0.24	-1.64 to 1.15	0.733	-0.02	-1.88 to 1.84	0.982
Interaction effects						
Street connectivity by study site						
Effect of street connectivity in North Shore	1.02	-2.37 to 4.43	0.556	0.20	-4.00 to 4.41	0.927
Effect of street connectivity in Waitakere	1.26	-2.02 to 4.55	0.452	-0.65	-4.43 to 3.12	0.733
Effect of street connectivity in Wellington	1.55	-1.78 to 4.88	0.363	2.12	-1.14 to 5.38	0.203
Effect of street connectivity in Christchurch	-5.06	-9.25 to 0.86	0.019	-5.18	-9.50 to 0.86	0.019
Net retail footprint area (NRFA) ratio by sex						
Effect of NRFA in men	1.49	-0.36 to 3.35	0.116	1.58	-0.86 to 4.01	0.205
Effect of NRFA in women	-1.95	-3.60 to 0.29	0.022	-1.48	-3.59 to 0.64	0.172

All models adjusted for other walkability components, sociodemographics, New Zealand Deprivation Index, study site and type of day (weekday vs weekend). All models accounted for correlated residuals at the neighbourhood and participant levels. b, regression coefficients. *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 minutes/day of sedentary time associated with a 0.10 increase in these environmental predictors rather than the difference in outcomes between the theoretical minimum (ie, 0) and maximum (ie, 1) values of the predictors.

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 min 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 0.02 ($p=0.002$), 0.35 ($p<0.001$) and 0.63 ($p<0.001$), respectively. 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 ($p>0.250$), 0.45 ($p<0.001$) and 0.54 ($p<0.001$), respectively.

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 Dyck¹⁹ 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 behaviour. 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 neighbourhoods. Perhaps, sedentary behaviour is influenced by neighbourhood 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 neighbourhood-level variability in sedentary time may not represent the optimal geographical scale to detect environmental influences on this specific behaviour. Moreover, since sedentary behaviour 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 (eg, 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 1000m buffer and only two interaction effects within the 500m buffer. Nonetheless, smaller buffers may be problematic in countries in which neighbourhoods 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 neighbourhood. Regional accessibility is defined as being determined by large regional shopping centres and employment clusters, usually farther away, offering a variety of services.³⁰ It is possible that multipurpose trips are done in this way, conceivably reducing the possibility of local accessibility irrespective of the neighbourhood environment. Ubiquity of car ownership, as is the case for New Zealand, is also important. Ivory and colleagues¹⁰ 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 one-third who had full car access. Lastly, it is plausible that different GIS measures may need to be considered for the development of sedentary behaviour index in the future, but extensive conceptualisation and research must take place first.

In the interaction effects model, two relationships showed significance: street connectivity in Christchurch (within both 500m and 1000m neighbourhood buffer) and retail footprint area ratio in women (within 500m neighbourhood buffer only). For participants from Christchurch, an increase of 1 decile in street connectivity was associated with a decrease of over 5min 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 walking³² 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 500m, but not the 1000m neighbourhood buffer. Across all cities, the floor area retail ratio within a 500m neighbourhood buffer was predictive of less sedentary time in women but not men. Aside from the sex difference, we theorised 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 neighbourhoods with retail and other uses is not a new concept and

remained the design of traditional European cities and towns for several centuries. Traditional neighbourhoods 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 walkability³⁴: 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 colleagues³⁵ 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 associates¹⁹ 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 intercity 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 car parking), 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 does not necessarily correspond to current use. Further, given that our study neighbourhoods were located in areas unlikely to be within 1000m 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 neighbourhood self-selection and neighbourhood 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 have 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 behaviour, we were unable to determine the type of sedentary behaviour participants engaged in. Finally, hip-mounted accelerometers can misclassify very light activity and standing with sedentary behaviour. For

this reason, hip-mounted accelerometers tend to overestimate sedentary behaviour.

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, neighbourhoods within a 500m neighbourhood 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 behaviour 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.

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