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Objective and subjective measures of the neighbourhood environment: Associations with frailty levels

Beatriz Arakawa Martins [a,b,*], Danielle Taylor [a,b], Helen Barrie [b,d], Jarrod Lange [e], Kareeann Sok Fun Kho [a,b,c], Renuka Visvanathan [a,b,c]

[a] *Adelaide Geriatrics Training and Research with Aged Care (G-TRAC Centre), Discipline of Medicine, Adelaide Medical School, University of Adelaide, South Australia, Australia*
[b] *National Health and Medical Research Council Centre of Research Excellence on Frailty and Healthy Ageing, University of Adelaide, South Australia, Australia*
[c] *Aged & Extended Care Services, The Queen Elizabeth Hospital, Central Adelaide Local Health Network, Adelaide, South Australia, Australia*
[d] *The Australian Alliance for Social Enterprise, UniSA Business, University of South Australia Adelaide, South Australia, Australia*
[e] *Hugo Centre for Population and Housing, School of Social Sciences, University of Adelaide, South Australia, Australia*

A R T I C L E I N F O

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A B S T R A C T

Objectives: The aim of this study was to investigate whether perceptions of the neighbourhood environment (NE) and objective measures of the NE were associated with frailty in older adults.
Methods: A cross-sectional study in Adelaide, Australia, recruited a sample of 115 community-dwelling adults aged ≥60 years. Respondents' perceptions of their NEs were assessed using the Neighbourhood Environment Walkability Scale (NEWS). An objective assessment of these NEWS survey questions was conducted using seven variables: residential density, land use mix diversity, street connectivity, accessibility, seasonal persistent green cover, road crash density and crime rate. Frailty was evaluated using the FRAIL (fatigue, resistance, ambulation, illnesses and loss of weight) scale. Multivariable linear regression analyses were employed to assess the associations between NEWS and frailty, and to assess the associations between objective neighbourhood variables and frailty.
Results: Frail and pre-frail older adults were more likely to live in areas with lower residential density, lower density of road crashes, and higher accessibility than robust participants. Additionally, a poorer perception of the overall environment, worse land-use mix and accessibility and worse crime safety were associated with frailty and pre-frailty after adjustment of covariates and objective GIS variables.
Discussion: Neighbourhood characteristics, both objective and perceived, are associated with frailty levels in older adults, and that strategies to tackle frailty must consider the impact of the neighbourhood environment.

1. Introduction

Growing evidence points to the important role played by the physical neighbourhood environment (NE) in physical and mental health (Beard et al., 2009). Studies have shown a relationship between NE and mortality, chronic diseases, mental health and health behaviours (such as physical activity) (Yen, Michael, & Perdue, 2009).These effects are especially relevant to older adults, because this population group tend to spend more time at home and in their local communities than younger adults (Garin et al., 2014).

Studies arising from environmental gerontology research propose that older adults with functional decline, frailty and/or reduced social networks may be more vulnerable to neighbourhood stressors (Yu, Cheung, Lau, & Woo, 2017). The importance of the NE in achieving healthy ageing has been emphasised by the WHO's *World Report on Ageing and Health* (WHO, 2015). They propose that barriers affecting individuals with reduced functional capacities be removed in order to promote healthy behaviours.

Frailty has been recognised as a multidimensional syndrome, characterised by vulnerability, not only to intrinsic factors, but also to factors in the environment, increasing the risk of adverse outcomes, such as disability and death (Morley et al., 2013). It is a dynamic condition,

* Corresponding author at: The Basil Hetzel Institute for Translational Health Research and University of Adelaide, The Queen Elizabeth Hospital, 28 Woodville Road, Woodville South, SA, 5011, Australia.
E-mail address: beatriz.martins@adelaide.edu.au (B. Arakawa Martins).

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distinguishable from the normal ageing process, with some individuals moving between mild to more severe frailty states and vice versa (Hoogendijk et al., 2019). Strategies for the management of frailty focused on physical activity programs, with or without nutritional supplementation, have produced promising results (Cesari, Nobili, & Vitale, 2016). Furthermore, neighbourhood characteristics, such as low crime rates, the presence of amenities and destinations for recreational activities, as well as the general walkability of neighbourhoods, are associated with increased levels of physical activity in healthy older adults (Haselwandter et al., 2015).

However, few studies have investigated the relationship between the built environment and frail older adults, who, by definition, are not in robust good health for their age. Living in neighbourhoods with a higher percentage of green space has been associated with an improvement in frailty status in a Hong Kong study (Yu et al., 2018); and aesthetic quality and better walking environments have been associated with frailty in Shanghai (Ye, Gao, & Fu, 2018). However, thus far, frailty studies have focused on one or two environmental characteristics rather than taking a broader approach. Nor have objective measurements and personal perceptions been included in the same study.

The current study aimed to explore the association of frailty levels with perceptions of community-dwelling older South Australians and the objective geographical information system (GIS) measures of the NE. The research sought to determine whether any associations between frailty and perceptions of the NE remained significant after adjustments for objective GIS measures and other co-variates.

2. Methods

2.1. Study population

A convenience sample of community-dwelling older adults (age ≥60 years) was recruited from two associated health studies. All participants in both studies provided informed consent. Ethical approval, including the analysis of the combined data, was obtained from the University of Adelaide Human Research Ethics Committee (H-2017-040). The details of each associated project are outlined below.

2.1.1. Adelaide walkability and frailty study

The Adelaide Walkability and Frailty study enrolled participants from the University for the Third Age (U3A) from the councils of Port Adelaide-Enfield (north west), Charles Sturt (west), Campbelltown (north east), Tea Tree Gully (north east), Adelaide Central Business District (central) and Marion (south), in the metropolitan region of Adelaide. The U3A is a not-for-profit organisation interested in providing learning courses and club activities for older adults. Inclusion criteria were: ≥60 years of age; able to converse in English; and able to leave their home independently at least once in the past four weeks. Participants with advanced cognitive impairment and living outside the Adelaide metropolitan area were excluded.

2.1.2. SMART-MOVE

SMART-MOVE is a randomised, controlled feasibility study investigating the effects of a goal-setting health coaching program in older adults at risk for falls. This study enrolled community-dwelling older adults who presented to the outpatient clinic at The Queen Elizabeth Hospital (TQEH) and to a community-based falls prevention program in Adelaide. The TQEH's catchment area includes the western suburbs of Adelaide.

Inclusion criteria were: positive screening for falls risk; age ≥65 years; the ability to walk independently for up to 10 m, with or without a walking aid; and the ability to converse in English. Exclusion criteria included moderate to severe dementia, being in terminal care, and concurrently participating in another physical activity intervention study. Specific details for this research protocol have been published (Khow et al., 2018).

2.2. Data collection and analysis

2.2.1. Dependent variables

2.2.1.1. Perceptions of neighbourhood built environmental attributes. The subjective measures of the NE were derived from the Neighbourhood Environment Walkability Scale (NEWS). This questionnaire captures differences in the perceptions of populations living in different NE related to walking and cycling (Saelens, Sallis, Black, & Chen, 2003), and has shown high test-retest reliability in several countries. Its reliability has also been supported by confirmatory factor analysis, both in individual questions and subscales (Cerin et al., 2013).

The validated Australian version of NEWS, with the following nine subscales, was used in this study (Cerin, Leslie, Owen, & Bauman, 2008): residential density; land use mix diversity; land use mix access; street connectivity; walking and cycling facilities; traffic safety; traffic load; and crime safety (Supplementary Table 1).

For this study, a composite index was constructed by summing the z-scores of all eight subscales, thus allowing for the summarisation of scales with different score ranges (De Bourdeaudhuij et al., 2015). In all subscales and the composite index, a higher score indicates a better neighbourhood perception.

2.2.1.2. Objective measurements of the neighbourhood environment. Objective measurements of the NE were collected and mapped using *ArcMap* GIS software (version 10.5.1) and using available databases and tools implemented in the Australian Urban Research Infrastructure Network (AURIN) (Sinnott et al., 2015). Each of the GIS-based variables was based on the environmental data contained within a 400 m radial buffer (catchment area) as measured from each participant's residential address.

This distance was based on previous studies conducted in older populations and observations of average walking distance in this population (Satariano et al., 2010). Seven different area-level measures were chosen to match the existing subscales of NEWS: residential population; land use mix diversity; accessibility to services; street connectivity; persistent green cover; density of road crashes (as a surrogate measure for traffic safety and traffic load); and crime rate. For details of each variable please see Table 1.

Each variable was aggregated to the smallest geographical unit available at each database. The Australian Bureau of Statistics (ABS) considers their smallest geographical unit to be the *mesh block*, determined from a standard set of criteria that broadly reflect land use. Mesh blocks align with town blocks in urban areas, and should be of compact size, but with a dwelling count 30–60 dwellings. The ABS develops statistical areas in order to examine the relationship between small areas of geography and the social, physical and economic realities of the landscape (Statistics, 2016b) [online]. After the mesh block, Statistical Area Level 1 (SA1) is the next largest geographical area used by the ABS when analysing the census data, having an estimated population of between 200 and 800 people (Statistics, 2016b)[online].

2.2.2. Independent variables

2.2.2.1. FRAIL scale. The five item FRAIL scale was used as a frailty measurement as this was available in both the Adelaide Walkability and Frailty study and the SMART-MOVE study. The presence of each of the five components is scored as one point: fatigue; resistance; ambulation; illnesses; and loss of weight (Morley et al., 2012). Upon assessment, participants were categorised as either frail (3–5 points); pre-frail (1–2 points); or robust (0 points).

2.2.2.2. Covariates. Age, gender, education level (tertiary, secondary, primary) and marital status (currently married or partnered, widowed, single or divorced) were used as covariates in the analyses, as were

Table 1
Objective measurements of neighbourhood environment.

Residential density	The average density of the total resident population was calculated using the AURIN Gross Density Tool. Database: ABS 2016 (Statistics, 2016c) Census of population and housing (at mesh block level)
Land use mix diversity	The classification of land use by mesh block was used to create an entropy measure of mix of land uses, measuring the extent to which there is an equal distribution of each land use within each catchment area. Land use mix diversity was calculated using the AURIN Tool Land Use Mix. (ABS 2016) Census of population and housing (at mesh block level)
Accessibility to services (metroARIA)	Participants accessibility to services was obtained from the Metro ARIA (Metropolitan Accessibility/ Remoteness Index of Australia) index (Taylor & Lange, 2016). Metro ARIA combines accessibility measures for five different service themes: education, health, shopping, public transport and financial/postal services by SA1 Level. The final composite index was used and had five accessibility grades from low to high.
Street connectivity	Number of three (or more) way street intersections over the participants' catchment area in square kilometres obtained using the AURIN Tool Connectivity. (Sinnott et al., 2015) PSMA Street Network 2017
Seasonal persistent green cover	Seasonal Persistent Green Cover measures the proportion of vegetation that does not senesce within a year (trees and shrubs), by time series analysis of Landsat satellite imagery with a 30 m resolution. Data are presented as the proportion of time within a year that each pixel in the area remains green (AusCover, 2017). An average mean index was obtained by SA1 level. (TERN Aus Cover 2017) Terrestrial Ecosystem Research Network (TERN) AusCover, 2017
Density of road crashes	The 5-year cumulative number of road accidents with 100 m precision of its location was used to create a density of road crashes index. A kernel density model with bandwidth of 250 m and the magnitude-per-area based on total number of road accidents in each point were chosen to evaluate the density of accidents in a smooth and continuous surface (Hashimoto et al., 2016). This data was aggregated at the SA1 level, and an average density index was obtained per participant. Data SA: South Australian Government Data Directory. *Road Crash Data*
Crime rate	A 5-year cumulative number of offences against the person or property from 2012–2017 was obtained, and divided by population at suburb level. The state suburb geographical unit is an ABS approximation of the local suburbs constructed from the allocation of one or more mesh blocks. Data SA: South Australian Government Data Directory. *Crime Statistics*

levels of physical activity and relative socio-economic advantage and disadvantage.

Levels of physical activity were measured through the sports index of Baecke's Physical Activity Questionnaire (Baecke, Burema, & Frijters, 1982). The sports index measures the intensity and frequency of the most frequently practised sport, which includes walking. Objective measurement with an accelerometer was also obtained using *ActivPAL*™ (PAL Technologies Ltd, Glasgow, UK) attached to the dominant upper thigh for one week.

The covariate socio-economic advantage and disadvantage was obtained from the ABS Index of Relative Socio-Economic Advantage and Disadvantage (IRSAD) using data from the 2016 census for the SA1 scale. IRSAD ranks areas from most disadvantaged to most advantaged by assessing income, education, employment, occupation, housing and other miscellaneous items (Statistics, 2016a).

2.3. Statistical analysis

Only those participants with sufficient data to determine frailty status, neighbourhood perceptions and a geocoded address were included in the final analysis. Continuous variables were presented as mean and standard deviation, and categorical variables as frequencies and percentages. Differences in descriptive data between frailty levels were assessed using one-way ANOVA for continuous variables, with post-hoc Tukey analysis for pair comparisons and a Chi-square test for categorical variables. The correlations between objective and subjective neighbourhood variables were assessed using the Pearson correlation.

Univariate linear regressions were used to investigate associations between neighbourhood perceptions (dependent variable), frailty (independent variable) and other covariates (Table 2).

All variables with a p-value <0.250 were included in the multivariable model. Although the number of steps-per-day individually showed significant associations with the NE variables, due to a significant number of missing values ($n = 14$, 12.7 % of all participants), steps-per-day was excluded from the multivariable analysis. All multivariable regression models were assessed for collinearity of individual variables using the variance inflation factor (VIF). Three final models were established: *model 1* adjusting for age, gender and FRAIL scale; *model 2* including model 1 and socio-demographical variables and frailty; *model 3* including model 2 and the respective objective environmental variables. For the dependent variable of the composite NEWS, all objective variables were included in model 3.

3. Results

The full sample for the study consisted of 125 participants (48, 38.4 % from the Adelaide Walkability study, and 77, 61.6 % from SMART-MOVE). Ten participants (8.0 % of the full sample) were later excluded from the analysis. Eight were eliminated because they lacked a full address for geocoding. Another participant was actually residing outside of the study area (rural Adelaide region) and one did not provide frailty information. There were no statistically significant differences in age, gender, marital status, living situation or frail status among the participants included or excluded from the analysis.

Participants' characteristics have been described in Table 2. Out of 115 participants analysed, 48 (41.7 %) were classified as frail, 38 (33 %) as pre-frail and 29 (25.2 %) as robust by FRAIL scale criteria. Frail and pre-frail participants were older than robust participants (p-value $= 0.002$; post-hoc Tukey analysis p value 0.003 and 0.006 for frail vs. robust, and pre-frail vs. robust respectively), had a lower step count (p-value <0.001 for overall analysis and *post hoc* comparisons) and lower levels of physical activity (evaluated by the sports index, p-value <0.001 for overall analysis and *post hoc* comparisons) than robust participants. Additionally, there were significant differences in education level (p value $= 0.001$) and socio-economic disadvantage (measured by the IRSAD coefficient, p value $= 0.005$) between robust, frail and pre-frail participants. There was a higher proportion of robust participants who had achieved tertiary education and lived in areas of socio-economic advantage than pre-frail and frail participants.

3.1. Intra-class correlations between objective and subjective neighbourhood variables

There was a weak positive correlation between perceived and objective residential density (p-value $= 0.02$) and between perceived aesthetics and greenery and persistent green cover (p-value <0.001). A weak negative correlation was obtained between perceived traffic load and density of road crashes (p-value $= 0.03$) and between perceived crime safety and crime rate (p-value < 0.001) (Table 3)

3.2. Univariate associations between neighbourhood environmental perceptions, frailty and covariates

Univariate associations between NE perceptions, frailty and covariates were observed, as recorded in Supplementary Table 2. Only marital status and sports index did not show strong associations with the

Table 2
Baseline characteristics of included participants.

Variable	Total N(%) or Mean (SD) N = 116	Robust n = 29, 25%)	Pre-frail (n = 39, 33.6%)	Frail (n = 48, 41.4%)	P value
Age	75.53(7.49	71.28(5.1)	76.92(7.5)[a]	76.98(1.1)[a]	0.002
Age					
<65 years old	4(3.4)	2(6.9)	1(2.6)	1(2.1)	0.016
65-75 years old	64(55.2)	22(75.9)	20(51.3)	22(45.8)	
>75 years old	48 (41.4)	5(17.2)	18(46.2)	25(52.1)	
Gender					
female	66(56.9)	11(37.9)	17(43.6)	22(45.8)	0.815
male	50 (43.1)	18(62.1)	22(56.4)	26(54.2)	
Education					
primary school	9(7.8)	0(0)	5(13.2)	4(8.3)	0.001
secondary school	60(52.2)	8(27.6)	21(55.3)	31(64.6)	
tertiary +	46(40)	21(72.4)	12(31.6)	13(27.1)	
Marital Status					0.943
married	56(48.7)	15(51.7)	18(47.4)	23(47.9)	
Living with					
alone	55(47.8)	16(55.2)	17(44.7)	22(45.8)	0.646
with partner/family	60(52.2)	13(44.8)	21(55.3)	26(54.2)	
IRSAD[b]					
most disadvantaged	25(21.7)	1(3.4)	7(18.4)	17(35.4)	0.005
intermediate	75(65.2)	21(72.4)	26(68.4)	28(58.3)	
most advantaged	15(13)	7(24.1)	5(13.2)	3(6.3)	
Sports index	2.6(0.8)	3.1(0.7)[a]	2.7(0.7)	2.3(0.7)[a]	<0.001
step count (steps/day)	4751.7 (3435.7)	7758.2 (4165.8)[a]	4460.8 (3281.2)	3737.6 (2445.4)[a]	<0.001

[a] *Post hoc* analysis (Tukey):significant differences between frail vs robust ($p < 0.05$), and pre-frail vs robust ($p < 0.05$).
[b] IRSAD: Index of Relative Advantage and Disadvantage by SA1 (ABS 2016): most disadvantage (lowest quintile), intermediate level (second to fourth quintile), and most advantage (highest quintile).

Table 3
Intra-class correlation between subjective and objective neighbourhood variables.

	NEWS							
Objective	Residential density	Land Use Mix diversity	Access to services	Road connectivity	Aesthetics and greenery	Traffic safety	Traffic load	Crime safety
Population density	ICC 0.002							
Land use mixture		ICC 0.006 P value 0.371						
Accessibility METROARIA			ICC 0.034 P value 0.727					
Street connectivity				ICC 0.000 P value 0.502				
Persistent green cover					ICC 0.000 P value 0.213			
Density road crashes						ICC 0.000 P value 0.500	ICC 0.000 P value 0.500	
Crime rate								ICC 0.012 P value 0.914

Table 4
Multivariable linear regression models (objective built environment characteristics and frailty).

NEWS	Residential density B (95%CI)	Land use mix diversity B (95%CI)	MetroARIA accessibility index B (95%CI)	Street connectivity B (95%CI)	Persistent green cover B (95%CI)	Density of road crashes B (95%CI)	Crime safety B (95%CI)
Model 1							
Frail	2.1(0.0,4.2)	0.0(0.0,0.1)	0.3(0.0,0.6)	0.3(−0.1,0.7)	−0.5(−3.3,2.3)	0.0(−0.1,0.0)	0.1(0.0,0.3)
Pre-frail [a]	0.1(−1.7,2.0)	0.0(0.0,0.1)	0.3(0.0,0.6)	0.2(−0.2,0.6)	−0.4(−3.3,2.5)	0.0(−0.1,0.0)	0.0(−0.1,0.3)
Model 2							
Frail	−3.0(−5.2, −0.8)*	0.0(0.0,0.1)	0.5(0.2,0.8)*	0.2(−0.2,0.6)	1.8(−0.7,4.2)	−0.1(−0.1,0.0)*	0.03 (−0.1,0.2)
Pre-frail [a]	−2.6(−4.8, −0.4)*	0.0(0.0,0.1)	0.4(0.1,0.7)*	0.2(−0.2,0.6)	1.0(−1.5,3.4)	−0.0(−0.1,0.0)*	0.03 (−0.1,0.2)

Note. a FRAIL scale, Model 1: adjusted for age and gender, Model 2: Model 1+ educational level, marital status, IRSAD index, living alone, * p value< 0.05.

majority of the NE perception variables and were excluded from the multivariable analysis.

3.3. Multivariable associations between objective neighbourhood environment and frailty

The associations between objective NE and frailty were investigated in multivariable models (Table 4). After adjustment for age, gender and other socio-economic variables, results indicated that pre-frail and frail participants were more likely to live in areas of lower residential density (β = 3.0, 95 % CI [-5.2, -0.8], p value = 0.007 and β = 2.6, 95 % CI [-4.8, -0.4], p value = 0.022 for frail and pre-frail participants respectively) and recording a lower density of road crashes (β -0.1 95 % CI [-0.1, 0.0], p value = 0.004 and β -0.1 95 % CI [-0.1, 0.0], p value 0.018 for frail and pre-frail participants respectively) than robust participants. On the other hand, pre-frail and frail participants were also located in areas with greater accessibility to services (MetroARIA Index) (β 0.5, 95 % CI [0.2, 0.8], p value = 0.002, and β 0.4, 95 % CI [0.1, 0.7], p value = 0.007, for frail and pre-frail participants respectively) than robust participants.

3.4. Multivariable associations between neighbourhood environment perceptions and frailty

In the multivariable model where associations between the perceptions of the NE were investigated, it was found that frail and pre-frail participants had a worse perception of their NE than robust participants (composite NEWS, β -3.1, 95 %CI [-5.1,-1.2], p-value 0.002 and specifically β -2.7, 95 % CI [-4.8,-0.8] p value = 0.013, for frailty and pre-frailty respectively) (Table 5, model 2). When individual subscales were analysed, land use mix diversity (β -0.5 [-0.8,-0.1], p value = 0.01 and β -0.4 [-0.8,0.0], p value = 0.03 for frailty and pre-frailty respectively), land use mix access (β-0.3 [-0.5,-0.1], p-value <0.001 and β -0.2 [-0.4,-0.1], p value = 0.013, for frailty and pre-frailty respectively) and crime safety (β-0.2 [-0.4,0.0] p-value = 0.037 and β 0.3 [-0.4,-0.1] p value = 0.008, for frailty and pre-frailty respectively) were significantly associated with frailty after adjustment to socio-demographic variables. After adjustment for the respective objective NE variable (model 3), this relationship remained statistically significant for the composite index, land use mix access, land use mix diversity and crime safety.

4. Discussion

Several key findings emerged from this exploratory study. Firstly, frail and pre-frail older adults in Adelaide are more likely to live in areas with lower residential density and lower density of road crashes, but with increased accessibility to services. Similarly to our findings, frail older adults from the Netherlands were also found to live closer to areas with more facilities and functional features than non-frail participants (Etman et al., 2014). This findings could be a result of frail persons moving to areas of increased accessibility to services but unfortunately, in our studies we had not asked participants about how long they had lived in their homes which is something for consideration with future studies of this type. The combination of lower residential density and lower density of road crashes often occur concomitantly in suburb neighbourhoods (Hashimoto et al., 2016), and low residential density has been shown consistent associations with lower levels of physical activity and walking in older adults (Barnett et al., 2016; Nyunt et al., 2015).

Secondly, frailty and pre-frailty are significantly associated with negative perceptions of the neighbourhood, especially low diversity of land use, lower accessibility to services and perceived lower safety from crime. These associations remained significant even after adjusting for the objective measurement of the environment. In our multivariable analysis, an overall worse perception of the NE was associated with being frail and pre-frail, after adjustment for the objective assessment of the NE and socio-demographical variables. Our research group previously reported in the Nagoya Longitudinal Study of Healthy Elderly that a higher frailty index scores were associated with poor perceptions of the NE and specifically land use mix diversity, land use access, street connectivity, walking infrastructure, aesthetics, and crime safety (Arakawa Martins et al., 2020). This study adds to the current literature showing that after adjustment for the objective assessment of the NE, an association between the higher frailty and the worse perceptions of the NE remained significant.

The way that people use and interact in their built environment is dependent on their perceptions of the space. The differences observed in the data between the environmental perceptions of frail and non-frail older adults may result in different ways of interacting with their environments. Both social interactions and physical activities in NE spaces are potentially constricted when individuals have negative perceptions of their life-spaces (Xue, Fried, Glass, Laffan, & Chaves, 2008). Constrained life-spaces result in a reduction of physiological capacities and a worsening frail status. Further strategies towards frailty prevention and management must focus on breaking this downward cycle by planning, supporting and promoting environments that foster good perceptions of environmental security and accessibility, thereby increasing participation of older adults in activities in their NE (Shach-Pinsly, 2019; Ward

Table 5
Multivariable linear regression models with dependent variables: composite NEWS, residential density, land use mix diversity, land use mix access, street connectivity, aesthetics, traffic safety, crime safety.

NEWS	Composite NEWS B (95%CI)	Residential density B (95%CI)	Land use mix diversity B (95%CI)	Land use mix access B (95%CI)	Street connectivity B (95%CI)	Aesthetics and greenery B (95%CI)	Traffic safety B (95%CI)	Traffic load B (95%CI)	Crime safety B (95%CI)
Model 1	Model 1								
Frail	−5.0(−7.3, −2.9)*	−5.0 (−18.7,8.8)	−0.6(−0.9, −0.4)*	−0.4(−0.6, −0.2)*	−0.1(−0.3,0.1)	−0.5(−0.8, −0.2)*	0.0(−0.3, −0.1)	−0.3 (−0.6,0.0)	−0.4(−0.6, −0.2)*
Pre-frail [a]	−3.9(−6.1, −1.6)*	4.2 (−10.2,18.5)	−0.5(−0.8, −0.1)*	−0.3(−0.4, −0.1)*	−0.1(−0.3,0.1)	−0.3(−0.6,0.1)*	0.0 (−0.2,0.1)	−0.2 (−0.5,0.0)*	−0.4(−0.6, −0.2)*
Model 2	Model 2								
Frail	−3.1(−5.1, −1.2)*	−7.8 (−21.3,5.7)	−0.5(−0.8, −0.1)*	−0.3(−0.5, −0.2)**	−0.1(−0.2,0.1)	−0.2(−0.4,0.1)	0.0 (−0.2,0.2)	−0.2 (−0.5,0.1)	−0.2 (−0.4,0.0)*
Pre-frail [a]	−2.8(−4.8, −0.8)*	−1.5 (−15.2,12.2)	−0.4(−0.8,0.0) *	−0.2(−0.4, −0.1)*	−0.1(−0.3,0.1)	−0.1(−0.3,0.1)	0.0 (−0.2,0.2)	−0.1 (−0.4,0.2)	−0.3(−0.4, −0.1)*
Model 3	Model 3								
Frail	−2.7(−4.6, −0.7)*	−6.3 (−20.0,7.3)	−0.5(−0.8, −0.1)*	−0.3(−0.5, −0.1)*	−0.1(−0.2,0.1)	−0.2(−0.5,0.0)	0.0 (−0.2,0.2)	−0.2 (−0.5,0.1)	−0.2(−0.4, −0.1)*
Pre-frail [a]	−2.6(−4.6, −0.6)*	−1.6 (−15.3,12.2)	−0.4(−0.8, −0.1)*	−0.2 (−0.4,0.0)*	−0.1(−0.3,0.1)	−0.1(−0.4,0.2)	0.0 (−0.2,0.2)	−0.1 (−0.4,0.2)	−0.3(−0.4, −0.1)*

Note. a FRAIL scale, Model 1: adjusted for age and gender, Model 2: Model 1+ educational level, IRSAD index, living alone, Model 3: Model 2+ objective assessment of the environment, * p value< 0.05.

Thompson, Curl, Aspinall, Alves, & Zuin, 2014).

Physical activity was found to be a moderating factor between the physical environment and frailty in a longitudinal study investigating the role of green spaces on frailty transition in China (Yu et al., 2018), and might explain the mechanisms through which the physical environment affects frailty. Perceived low walkability in a NE (Saelens et al., 2003) is consistently associated with low physical activity levels in older adults (Kerr et al., 2016), an important predictor of frailty development (Yuki et al., 2019). Frail participants in our study were more likely to live in areas of lower residential density, and in environments with a perceived lower diversity of land use and lower accessibility to services This three elements form the concept of "low neighbourhood walkability" as proposed by Saelens (Saelens et al., 2003).

Individualised physical activity programs are first line therapy for the management of frailty and strongly recommended in the international clinical guidelines for the management of frailty as a way of improving physical strength, function and mobility in older frail adults (Dent et al., 2017, 2019).

The poor agreement found between some objective and subjective environmental variables in this study is consistent with that reported in previous published literature (Lin & Moudon, 2010; McGinn, Evenson, Herring, Huston, & Rodriguez, 2007), and may indicate that each objective or subjective variable assesses slightly different environmental dimensions of the built environment. For example, in our study, the objectively-assessed density of road crashes was correlated with individual perceptions of load of traffic but not with perceptions of traffic safety.

Although it has been argued that objective measures of the environment yield stronger associations with health outcomes than subjective measures (Lin & Moudon, 2010), it must be noted that subjective environmental perceptions may have stronger associations with changes in behaviour than objectively collected data. The impact of subjectivity becomes evident in evaluations of *perceptions* of crime safety compared to *actual* crime rates and physical activity behaviours (van Bakergem, Sommer, Heerman, Hipp, & Barkin, 2017).

Our study has several strengths. It is the first study to investigate the frailty of older adults in the context of both objective neighbourhood characteristics and subjective individual attitudes, and has explored a broad range of built environment variables that might be linked with frailty. Nonetheless, we also recognise that the research has faced some limitations.

Due to a convenience sample, participants' neighbourhood locations were not representative of all Adelaide metropolitan areas, and there may have been an overrepresentation from some neighbourhoods. Additionally, the cross-sectional design did not allow any assumptions of causality between variables, and we were unable to adjust for variables that affect the choices individuals make about where to live. Although this is one of the first studies to use a broad range of GIS variables to assess the built environment, these may not reflect all features of the environment related to frailty, such as the presence and location of sidewalks.

In conclusion, in a population of community-dwelling older adults, being pre-frail and frail was associated with several NE characteristics. Older adults' perceptions of the NE might be critical to creating healthy behaviours and social participation, thus influencing frailty status. Planning and building environments that are more accessible, offer more diversity and are clearly safe for older adults could help prevent the development of frailty in the community.

Impact statement

We confirm that this work is novel.

There has been little research on the effects of neighbourhood environment on frailty in older adults, which impacts on their social and physical activity levels, a major strategy for reducing frailty. Older adults perceptions of neighbourhood environment are associated with frailty levels in older adults from Adelaide, Australia.

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CRediT authorship contribution statement

Beatriz Arakawa Martins: Conceptualization, Methodology, Investigation, Formal analysis, Writing - original draft, Writing - review & editing. **Danielle Taylor:** Methodology, Investigation, Writing - review & editing. **Helen Barrie:** Conceptualization, Methodology, Writing - review & editing. **Jarrod Lange:** Methodology, Writing - review & editing. **Kareeann Sok Fun Kho:** Investigation, Writing - review & editing. **Renuka Visvanathan:** Supervision, Writing - review & editing.

Declaration of Competing Interest

The authors report no declarations of interest.

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