Built Environment and Frailty: Understanding the influence of neighbourhood on older people's health

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Scholarly activity

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Thesis declaration - Statement of originality

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31/01/2020

Beatriz Arakawa Martins Date

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Abstract

Never in the history of the world have so many humans lived for so long, with over 11% of the world's current population being 60 years old and older. Australia and Japan are the countries in the Western Pacific region with the highest proportion of older people aged 65 years old and over, estimated to reach 18.3% and 31.2% respectively by 2030. This demographic transition represents a significant challenge for health and social care systems. In this context, a study of frailty is of particular interest as we move away from disease-oriented models of care to more patient-oriented integrated care, considering biological and non-biological causes of disease.

Frailty is defined as a state of extreme vulnerability to intrinsic and extrinsic stressors leading to an increased risk of adverse outcomes, such as hospitalisation, institutionalisation and death. The risk of frailty increases with age, with worldwide prevalence varying from 4.0% to 59.1%, depending on which criteria used and clinical context.

The role of place in older adults' health is not a new concept but has only recently been recognised as important for the achievement of healthy ageing. Although there is some research suggesting that the neighbourhood built environment is associated with walking, physical activity and well-being in older adults, very little has been done to investigate the relationships between frailty, objective neighbourhood environment and individual perceptions of the neighbourhood environment. This research sought to understand relationships between these factors in two culturally different cities, Nagoya, Japan and Adelaide, Australia. The interdisciplinary nature of the research required the development of new methods and the conduct of quantitative and mixed-method projects.

Firstly we (1) assessed the level of importance medical students assigned to the topic of frailty after taking a geriatric medical course, along with their self-perceived competence in the area of frailty diagnosis and care. Then, a range of projects were undertaken to investigate the associations between neighbourhood environment and frailty: (2) a feasibility study of the research tools; (3) a mixed-method study investigating older adults' experiences and perceptions of the public space of a hospital; (4) the development of a frailty index for the analysis of (5) the association between frailty and neighbourhood perceptions in older adults from Nagoya and (6), with similar methodology, investigation of the same associations in older adults from Adelaide, with adjustment for the objective environment.

The initial feasibility study (2) identified successful recruiting strategies for frail older adults, as well as issues that needed to be addressed to improve execution and acceptance by older adults. The mixed-method study (3) identified aspects of the built environment that could be directly associated with older adults' intrinsic capacity and elements that were facilitators or barriers to the use of the built space. Several themes were identified as associated with older

adults' experiences as outpatients, such as lighting, noise, temperature, design, seating, wayfinding and access/transportation.

In the Nagoya Longitudinal Study for Healthy Elderly, using the frailty index (4), we identified the prevalence of frail and pre-frail older adults in the sample, and age, polypharmacy, physical activity, walking speed and weight circumference were significantly associated with being frail and pre-frail. Using this frailty index, the cross-sectional analysis of associations between frailty and neighbourhood environment in Nagoya (5) revealed that increased frailty was independently associated with worse perceptions of neighbourhood environment. There were inverse linear associations between the frailty index and perceptions of the neighbourhood environment, and higher frailty was associated with poorer perceptions of land use mix diversity, land use mix access, street connectivity, walking infrastructure, aesthetics, and crime safety.

In Adelaide (6), with the inclusion of an objective record of the environmental characteristics of place, the neighbourhood environment variables retained a significant association with frailty, and specific associations were found between worse land use mix and accessibility and worse crime safety and frailty and pre-frailty. Finally, fifth-year medical students' perceived competence and the level of importance assigned to assessing, diagnosing and managing frailty significantly improved after a geriatric medical course in the University of Adelaide (1). Increasing medical students' awareness of frailty topic and attitudes towards ageing will help shape future health professionals in the better care of older adults in Australia.

Frailty is a common and prevalent condition in older adults from Australia and Japan, and several modifiable risk factors have been identified in relation to frailty, with the neighbourhood environment being one of them. Research from this doctoral thesis contributes to the understanding of the complex relationship between the neighbourhood environment and frailty in older adults, delivering insights that need to be taken into consideration when assessing the impact of community settings on frailty, as well as the impact of frailty on perceptions of the built environment of the community.

Medical students perceived competence on the assessment and management of frailty can be improved through a geriatric medicine course and it is important given population ageing that geriatric medicine teaching programs are included in medical program curricula. Frailty was independently associated with worse neighbourhood environment perceptions in Nagoya and Adelaide. This influence might lead to worse physical and social activities in the neighbourhood which might be a cause of increased frailty risk in the studied groups.

In conclusion, considering the effects of the neighbourhood environment on older adults' health is an important public health and therapeutic strategy to help manage and prevent frailty in the community.

Built environment and frailty: Understanding the influence of neighbourhoods on older people's health

Introduction – Healthy ageing and the environment

1.1 Defining healthy ageing and the origins of environment health

Population ageing is reaching unprecedented levels in developed and developing countries around the world, given the continued combination of low fertility rates and increased life expectancy (WHO, 2015b). Australia and Japan are the countries in the Western Pacific region with the highest proportion of older people, estimated to reach 18.3% and 32.1% of older adults aged 65 years old and over, respectively by 2030 (National Institute of Population and Social Security Research, 2017; Australian Bureau of Statistics, 2018). A critical feature of these marked increases of lived years lies in achieving healthy ageing. In 2015, a World Health Organisation (WHO) report on ageing and health defined healthy ageing as 'the maintenance of functional ability that enables well-being in older age' (WHO, 2015b, p. 28). In order to maintain functional ability as you age, two interacting factors must be considered: intrinsic capacity (all your mental and physical capacities) and the environment in which a person lives. WHO further proposes that environments help promote capacity enhancing behaviours, improving intrinsic capacity, and reducing barriers for individuals already experiencing reductions in capacity.

The study of the influence of the environment on health can be dated back to ancient Greece, but in modern times it was urbanisation in seventeenth century England that triggered the study of healthy versus unhealthy environments, prompted by evidence that rural environments recorded lower mortality rates than city environments (Macintyre & Ellasway, 2003). The nineteenth century saw the emergence of the sanitary movement and germ theory as central topics in public health, and started the efforts to ecologically map mortality in relation to specific diseases, housing conditions, industry and occupations (Sarkar, Webster, & Gallacher, 2014).

The works of Dr John Snow in London's Soho district, linking water supply to cases of cholera (J. Snow, 1849), was an important scientific breakthrough at the time, when the prevailing belief was that 'poisonous miasmas' were the cause of diseases, and not disease transmission through microscopic living organisms (Sarkar et al., 2014). Although germ theory had not yet been established in medicine, Dr Snow proposed that cholera was being transmitted through organisms present in the water system. Using a dot map, he linked the fatalities due to cholera in the 1855 outbreak to one another by tracking the locations of each occurrence, which showed they were clustered around a water pump located in Broad Street, creating the 'cholera field' (S. J. Snow, 2008) (Figure 1.1).

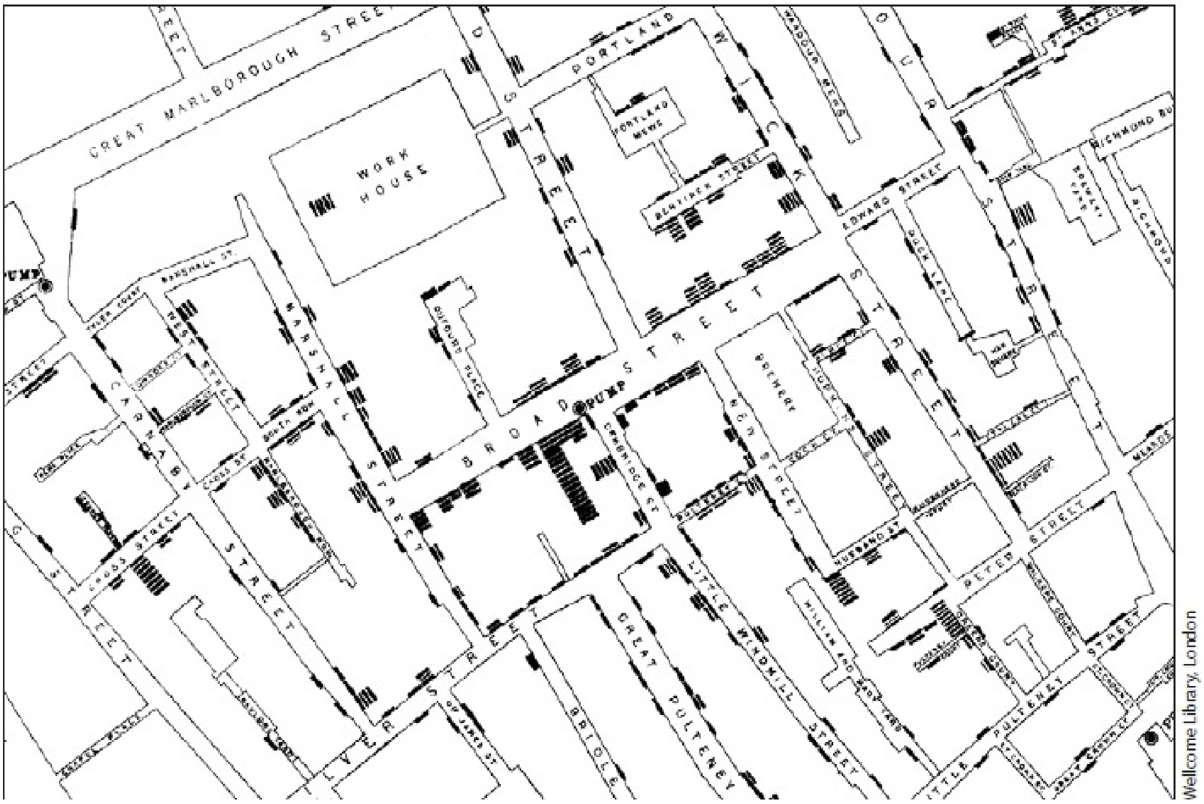

Figure 1.1 **Street map of cholera deaths in Soho in 1853 from John Snow's *On the mode of communication of cholera* [Adapted from the Snow, S. J. (2008). John Snow: the making of a hero? *Lancet, 372*(9632), 22-23, page 22, with permission from Elsevier. (S. J. Snow, 2008)]**

Modern investigations on environmental health have shifted the focus from infectious diseases to the modern epidemic of chronic diseases, investigating how issues such as cardiovascular disease, obesity, physical activity or sedentarism are not determined just by individual characteristics, but by environmental influences.

1.2 Theoretical background

1.2.1 Neighbourhood characteristics and life-space

The prevailing theory in the majority of environmental health research related to older adults is the *ecological model of ageing* (EMA) proposed by Lawton (Lawton & Nahemow, 1973) in 1973. This theory understands ageing as a process of continual adaptation of the individual to the environment and their alteration of the environment as the process of human adaptation. This environment-fit model depends on the complex interplay between the demands of the environment (*environmental press*) and the individual ability to cope with this environment (*individual competence*). In this theory, it is believed that individuals with high competence are able to adapt to a wide range of environmental challenges, while individuals with lower competence cannot, developing maladaptive behaviours that lead to an increased risk of disability and adverse health outcomes.

It is interesting to note that negative effects arising from the environment can happen at both edges of the environmental press spectrum (Figure 2.3). When competence far surpasses the environmental press, boredom and atrophy occur, and behaviour can be as maladaptive as when press exceeds competence (Glass & Balfour, 2003).

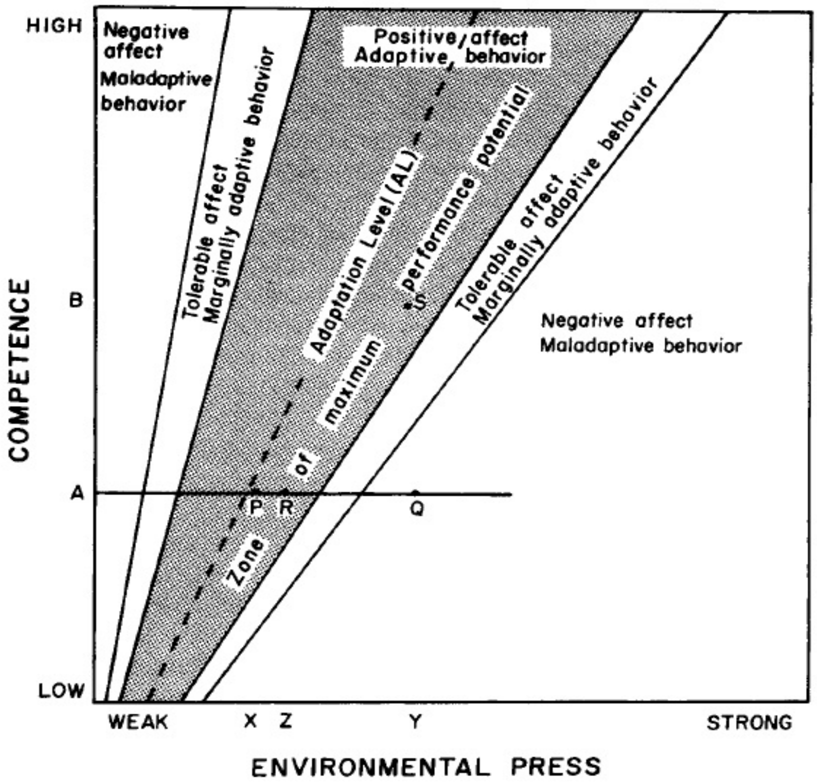

Figure 1.2 Diagrammatic representation of the behavioural and affective outcomes of person-environment transactions [Adapted from Lawton, M. P., & Nahemow, L. (1973). Ecology and the aging process. In C. e. Eisdorfer & M. P. e. Lawton (Eds.), *The psychology of adult development and aging.* (pp. 619-674), page 661.]

In order to operationalise and extend the EMA, Glass and Balfour (Glass & Balfour, 2003) proposed four specific dimensions of neighbourhood that shape the environment-person fit, and introduced the concept of *environmental buoying*. They suggest that, as well as the negative aspects of the environmental press, the environment could also foster improvement in individual competencies (Lawton & Nahemow, 1973).

The four domains of neighbourhood characteristics believed to be related to the ageing process are:

- socioeconomic conditions
- neighbourhood social integration
- the physical environment
- the availability of services and resources.

The effects of area-level socioeconomic conditions, independent of individual socioeconomic characteristics, on the health of older adults is well documented in the literature in regards to several health outcomes including frailty (Stolz, Mayerl, Waxenegger, Rasky, & Freidl, 2016; Woo, Zheng, Leung, & Chan, 2015). It is plausible that socioeconomic factors may drive the availability of services and resources, the quality of the physical environment and levels of social integration, but the other three dimensions may equally independently influence the person-environment fit of an older adult.

Using the same ecological principles proposed above, one theoretical model has been used to investigate an environmental influence on the development of frailty related to the constriction of *life-space* (Xue, Fried, Glass, Laffan, & Chaves, 2008). Life-space can be defined as the areas one individual travels through in their daily life, ranging from within their immediate living space to places outside their local geographical region or town (Baker, Bodner, & Allman, 2003). The constriction of one's life-space is understood to be the result of individual changes, such as acquiring a disease, age-related physiological decrease in function, environmental challenges, such as socioeconomic area deprivation, an unappealing built environment and a lack of social cohesion.

The constriction of life-space is theorised as a behavioural adaptation to increased environmental challenges and a reduction of individual capacities. In terms of health and wellbeing among the ageing, constriction of life-space is a precursor to and a marker of conditions such as frailty.

1.2.2 Frailty

Frailty is characterised by a state of increased vulnerability to intrinsic and extrinsic stressors, and is strongly associated with adverse outcomes, including institutionalisation, hospitalisation, morbidity and mortality (Dent, Kowal, & Hoogendijk, 2016; Fried et al., 2001). It is an established clinical condition, and presents itself as dramatic changes in an individual's state of health after apparent small events (Clegg, Young, Iliffe, Rikkert, & Rockwood, 2013).

The consequences of these insults are disproportionate to what would be expected for a robust individual of the same age and changes the individual's ability to function independently and age healthily. Frailty is the opposite of the intrinsic capacity construct proposed by the WHO (WHO, 2015b). Frailty focusses on loss of capacity, while the WHO concentrates on the presence of individual physical and mental functions throughout the ageing process.

The effect of life-space constriction on wellbeing and frailty was demonstrated in the Women's' Health Ageing Study (WHAS), where individuals who left their neighbourhood less frequently were 1.7 times more likely to become frail, as well as experience an increase in frailty-free mortality risk (Xue et al., 2008). Interestingly, women who had a slight decrease in life-space, and not those who were moderately or severely constricted, were at the most increased risk of frailty. This observation points to the fact that slight decreases in mobility through the life-space might be an overlooked precursor to the development of frailty, and be of greater importance in terms of the development of strategies to prevent and treat frailty in the community than might be expected.

1.3 Healthy ageing and the age-friendly cities movement

The importance of local environments to the health of older adults has been emphasised by the World Health Organization (WHO) for the past two decades as a top public health priority and a factor to be considered in urban planning. WHO started with the Active Ageing Public Health Policy Framework (*Active Ageing: A Policy Framework*, 2002; Beard & Petitot, 2010), and officially launched the Age-Friendly Cities Movement in 2006 (WHO, 2007).

By definition, an age-friendly city is a city that encourages active ageing by optimising opportunities for health, participation and security in order to enhance quality of life as people age (WHO, 2007). The initial project asked older adults in 33 cities around the world what they saw as the advantages and barriers to living in urban areas. The eight domains identified were:

- transportation
- housing
- social participation
- respect and social inclusion
- civic participation and employment
- communication and information
- community support and health services
- outdoor spaces and buildings.

A checklist of essential features of age-friendly cities ("Checklist of Essential Features of Age-friendly Cities," 2007) was formed to guide cities in creating age-friendly initiatives. In 2009, the Global Network of Age-friendly Cities was established to foster initiatives and provide technical support, putting the older person at the centre of the efforts to create an age-friendly world, with 760 participating communities and cities by September 2018 (WHO, 2018). The network has enabled connections between different centres, and the measurement of practices being performed, in order to enable individual functional abilities, such as meeting older adults' needs, mobility, building and maintaining relationships, making decisions and contributing.

In 2014, the WHO released the *World Report on Ageing and Health* (WHO, 2015b), providing a new conceptual framework for initiatives and substituting the active ageing concept with the idea of healthy ageing (WHO, 2018). Healthy ageing is considered holistically, and includes life-course and functional perspectives, and is defined as 'developing and maintaining functional ability that enables well-being in older age'(WHO, 2015b, p. 28).

Two important conceptual factors can be seen in this definition. Firstly, it distinguishes health from the mere absence of disease, since multi-morbidity, physiological changes and dynamic changes in health states are not captured by traditional disease classifications. Secondly, it defines well-being and maintaining functional ability as one ages as major goals.

Functional ability is the combination of two important factors: individual intrinsic capacity, which encompasses all physical and mental functions, and the environment where one lives. The public health framework proposed in the *World Report on Ageing and Health* states that local environments could promote behaviours that would increase an older individual's intrinsic capacity. In stages where a person's functional ability declines, barriers to participation could be removed, reducing the loss of such capacity (Beard et al., 2016).

1.4 Neighbourhood physical environment and health of older adults

Acknowledging the dynamic inter-relationships between the four domains of neighbourhood characteristics related to the health of older adults described by Glass and Balfour above (Glass & Balfour, 2003), this section focusses on studies investigating the physical environment of neighbourhoods in relation to older adults. The physical environment, although an understudied topic for public health and social scientists in the past, has received greater recognition, especially considering its effects on physical activity (Cunningham & Michael, 2004). The physical environment includes both natural elements, such as climate, green (trees, parks, gardens & and natural vegetation) and blue (oceans, lakes & rivers) spaces, and the man-made or built environment, including all aspects shaped by human living, such as housing, land use, urban design and transportation systems.

Although several health outcomes have been investigated in relation to neighbourhood environments, such as mental health (A. Barnett, Zhang, Johnston, & Cerin, 2018), cognition (Besser, McDonald, Song, Kukull, & Rodriguez, 2017), physical health (Annear et al., 2012; Garin et al., 2014), disability (Beard et al., 2009) and quality of life (Garin et al., 2014), this section focusses on the studies dealing with physical activity, walking and frailty, discussed further in Chapters 5, 7 and 8.

1.4.1 Physical activity and walking

The influence of the physical environment on physical activity and walking is the topic that has received the most attention from environmental health researchers in the past five years, including researchers in transportation, public health, gerontology and physical activity (D. W. Barnett et al., 2017; Cerin et al., 2017; Edwards & Dulai, 2018; Haselwandter et al., 2015; Moran et al., 2014; Van Cauwenberg et al., 2018).

Physical activity participation is shaped by a complex set of factors that include individual, social and environmental factors, and older adults report several barriers to physical activity arising from the physical environment (Franco et al., 2015). Issues such as poor access to transportation, climate and safety concerns, and unavailability of exercise facilities and equipment were reported in 72 (out of 132, 55%) studies as barriers for physical activity participation of older adults in a systematic review of qualitative studies (Franco et al., 2015).

Physical activity behaviours are expected to change for older adults, who are reported to spend less time in active travel (Cerin et al., 2017), and more time in leisure focused physical activity after retirement (Van Cauwenberg et al., 2018). It is expected that specific characteristics of the environment would have different effects on physical activity levels of older adults. A meta-analysis focusing on leisure-time activities showed positive associations between walkability, land use mix access and aesthetically pleasing scenery and leisure-time walking among older adults, while negative associations were found between barriers for cycling or walking and levels of walking (Van Cauwenberg et al., 2018). A substantial amount of evidence indicates a positive relationship between residential density, walkability, street connectivity, access to destinations/services, land use mix, pedestrian-friendly features and walking for transport, while littering and vandalism were associated negatively with walking for transport (Cerin et al., 2017).

Since the total amount of physical activity is ultimately also correlated with health benefits, another meta-analysis evaluated the specific effects of built environment characteristics on total physical activity in older adults (D. W. Barnett et al., 2017). The overall walkability of the environment, including access to destinations, services and recreational facilities, as well as aspects of crime-related personal safety, were positively associated with older adults' total physical activity (D. W. Barnett et al., 2017). Similar themes were retrieved from a systematic review of qualitative studies investigating the effects of the physical environment on physical activity in which pedestrian infrastructure, safety, access to amenities, aesthetics, and environmental conditions were positively associated with older adults' physical activity (Moran et al., 2014).

In Japan, the perceived, as well as the objectively assessed physical neighbourhood environment, have been investigated in relation to the physical activity levels of older adults. In a cross-sectional study in three Japanese cities, perceived access to exercise facilities, aesthetics and the social environment have been associated with increased walking for transportation in older adults (Inoue et al., 2011). Another study found that GIS acquired residential density and proximity to green spaces had positive associations with frequency of sports activities among community-dwelling older adults from Aichi, Japan (Hanibuchi, Kawachi, Nakaya, Hirai, & Kondo, 2011). In a group of frail older adults, a higher perception of crime safety in the neighbourhood was associated with higher levels of physical activity in Japan (Harada et al., 2017). The Harada et al. study suggests that frail older adults have worse perceptions of crime safety than less frail older adults. However, no specific associations between neighbourhood perceptions and frailty levels were investigated. This gap was addressed during the research for this thesis and is in Chapter 7.

In Australia, in a random sample of 449 older Australians, the presence of safe footpaths for walking and access to facilities were associated with being physically active (Booth, Owen, Bauman, Clavisi, & Leslie, 2000). In Sydney, neighbourhood walkability, determined by GIS assessment of residential density, intersection density, land use mix, amount of green space and lower crime rates, was associated with achieving sufficient levels of moderate-to-vigorous physical activity (MVPA) and sufficient walking in adults aged 45 and above (Astell-Burt, Feng, & Kolt, 2014, 2015; Mayne, Morgan, Jalaludin, & Bauman, 2017). This study included participants 45 years and over, and 35.8 % of the sample were older adults (65 years and over).

1.4.2 Frailty and the built environment

Although many researchers have acknowledged the increased vulnerability of frail older adults to environmental conditions in their neighbourhood and home environments (Morley, 2012), and the desirability of introducing special universal environmental design choices to increase accessibility and independence for this group (Crews & Zavotka, 2006), very few studies have investigated the associations between environmental characteristics and frailty.

A review of the Medline and Web of Science databases, using ‘frailty’, ‘neighbourhood environment’, ‘built environment’ and ‘physical environment’ as search terms revealed eight studies that have used specific assessments for frailty, and investigated the effects of the social and physical environment. The frailty instruments used in these studies were the frailty phenotype (five studies), the Identification of Seniors at Risk of functional loss scale (ISAR) (one study), Tilburg frailty indicator (one study) and the FRAIL scale (one study). Only three studies investigated the effect of neighbourhood characteristics on frailty longitudinally (Aranda, Ray, Snih, Ottenbacher, & Markides, 2011; Caldwell, Lee, & Cagney, 2019; Yu et al., 2018) and the remaining were cross-sectional investigations (Cramm & Nieboer, 2013; Espinoza & Hazuda, 2015; Etman et al., 2014a; Harada et al., 2017; Ye, Gao, & Fu, 2018). Three studies were conducted in the USA, two in China, two in the Netherlands and one in Japan.

A longitudinal analysis conducted in the USA investigated the role of the neighbourhood in terms of its physical and social characteristics in the development of frailty (Caldwell et al., 2019). Physical disorder, represented by the deterioration of buildings, streets, sidewalks and other visible characteristics, was associated with higher odds of frailty (OR 1.20, 95% CI 1.03, 1.39) since disorder discourages walking outside, social interaction and physical activity, all of which might be protectors against frailty. Perceptions of aesthetic quality were also associated with frailty among community-dwelling Chinese older adults investigated using the FRAIL scale (Ye et al., 2018). Signs of physical disorder are related to perceptions of personal and crime safety in a neighbourhood, and two studies have investigated the association of safety from crime with frailty. In the Netherlands, feeling more secure was protective against frailty

(Cramm & Nieboer, 2013), while lower levels of crime safety was associated with less physical activity in frail older adults in Japan (Harada et al., 2017).

The most recent longitudinal study investigating physical environment characteristics and frailty considered the presence of green spaces in the neighbourhood (Yu et al., 2018). Older adults living in neighbourhoods with more green spaces were more likely to improve their frailty status over two years than older adults living in areas with a low percentage of green spaces. Yu et al (2018) investigated the mechanisms linking green space and frailty and path analysis revealed the direct influence of green spaces on frailty, but also the mediating factor of physical activity.

Social cohesion and ethnic neighbourhood composition have also been the focus of neighbourhood environment and frailty studies. Social cohesion, defined as the presence of mutual trust and solidarity between neighbours, is believed to discourage unhealthy behaviours and encourage health promoting behaviours and activities (McNeill, Kreuter, & Subramanian, 2006). Having a stronger sense of cohesion was associated with lower frailty levels in both a cross-sectional (Cramm & Nieboer, 2013) and a longitudinal analysis (Caldwell et al., 2019).

Additionally, living in a neighbourhood with an ethnically dense Mexican-American community was associated with less frailty in cross-sectional (Espinoza & Hazuda, 2015) and longitudinal studies (Aranda et al., 2011) in the USA. In both studies, the authors introduce the concept of 'barrio advantage', where the increased social capital by shared cultural, demographic and historic forces, increases social support among older adults (Aranda et al., 2011).

The review of the current literature revealed that there were no studies investigating the relationships between frailty and neighbourhood environment in Japan or Australia. Differences in built environment attributes on different societies and also how people interact with the surrounding environmental opportunities or barriers in Asian and Western societies justify a closer investigation of these relationships in both countries (Koohsari, Nakaya, & Oka, 2018).

Additionally, a great heterogeneity in research methodology was identified in the literature. While some studies have focused on objective measurements of the physical environment, others have used the older person's perceptions of the neighbourhood environment. Although it has been argued that objective measures of the environment yield stronger associations with health outcomes than subjective measures (Lin & Moudon, 2010), subjective environmental perceptions might have stronger associations with changes in behaviour than objectively collected data

1.5 The aim of the research

Focusing on several of the research gaps identified in relation of the investigation of the neighbourhood environment and frailty, it was hypothesised that neighbourhood environmental characteristics influence the development of frailty in community-dwelling older adults. The overarching aim of this doctoral research thesis was to investigate whether the physical environment of a neighbourhood is associated with frailty in older adults by comparing two cities located in different countries and cultures, Nagoya in Japan and Adelaide in South Australia.

While investigating the impact of the built environment, several related projects were pursued, including the development of an appropriate methodology for conducting research internationally, as well as an inquiry into medical education related to frailty.

1.6 The context and design of the research

Rarely do studies investigating the relationships between health and the environment have the opportunity to test the same hypothesis in two culturally and socioeconomically different societies. By matching sampling strategies and population settings, as well as trying to use the majority of the same instruments, the hypothesis could be tested in two different samples, providing robustness to the study findings. It was hypothesised that the worse the neighbourhood environment, the greater the incidence of frailty would be in the sample populations. It was furthermore expected that differences would appear in relation to specific aspects of the environment that would be associated with frailty.

In Nagoya, a sample of older adults from the Nagoya Longitudinal Study – Healthy Elderly (NLS-HE), a prospective cohort started in 2014 (Matsushita et al., 2017), was used for analysis. The NLS-HE recruited participants from a college for older adults and residents of Nagoya aged 60 years and older. The students take part in two years of club activities, and lectures on various subjects. It was expected that the sample of participants would be more sociable and engaged in health projects than the general population.

The cohort's initial inclusion criteria were an age of between 60 and 89 years, current resident status in Nagoya and the ability to walk independently. Exclusion criteria were incomplete data on frailty, and the presence of comorbidities believed to be leading to frailty, such as Parkinson's disease, stroke or dementia. The sample population was used to investigate the risk factors associated with a transition from a robust condition to pre-frailty, and from pre-frailty to frailty in Japanese older adults.

Yearly assessments of the older adults were performed, collecting data in regard to socio-demographic variables, physical function, physical performance, levels of physical activity, comorbidities, depression and frailty, using the Kihon checklist and frailty phenotype criteria.

The Kihon checklist is a multidimensional 25 item checklist developed in Japan for the assessment of older adults in need of services and validated as a frailty tool.

In 2017, a questionnaire assessing older adult's perceptions of the physical environment of their neighbourhood was introduced, using a validated international tool, the Neighbourhood Environment Walkability Scale (NEWS) (Inoue et al., 2009). This instrument evaluated perceived neighbourhood environment characteristics, derived from transportation and physical activity research, which were related to increased levels of walking and cycling (Saelens, Sallis, Black, & Chen, 2003).

In Adelaide, a cross-sectional study was developed in 2017 to investigate the relationships between frailty and the neighbourhood environment. The initial recruitment strategy targeted older adults attending the University for the Third Age, a group of non-profit organisations dedicated to providing educational courses and club activities to older adults. Recruitment was eventually broadened to include The Queen Elizabeth Hospital (TQEH) patients. Inclusion criteria for Adelaide were as follows: aged over 60 years, able to speak English, living in the Adelaide greater metropolitan area, and able to get out of the house. Participants filled out a questionnaire including socio-demographic variables, physical function, physical activity levels, comorbidities, depression screening and frailty. Participants also filled in the NEWS questionnaire, validated in Australia (Cerin, Leslie, Owen, & Bauman, 2008), and were invited to include their address in order to geocode responses to the participant's neighbourhood.

1.7 The organisation of the thesis

The thesis is organised as follows:

- **Chapter 2**
  This chapter reviews the current literature on frailty. It includes recent frailty definitions, epidemiology, diagnostic and screening tools and current proposed frailty interventions.
- **Chapter 3**
  Paper submitted for publication: **'**Fifth-year medical students' perceptions of the importance of frailty and competence in assessing, diagnosing and managing frailty before and after a geriatric medicine course'

  The paper reproduced in this chapter as an unpublished manuscript that presents the results of a study conducted to assess medical students' perception of the importance of and competence in assessing, diagnosing and managing frailty before and after a 5th year 4.5-week geriatric medical course at the University of Adelaide. The results indicate that being able to diagnose, correctly assess and manage frailty were very important for medical students before the course, but students had a low to moderate self-perceived competence in these topics. After the course, both overall importance and competence significantly improved.

- **Chapter 4**
  Published work in this chapter: 'Older adults' perceptions of the built environment and associations with frailty: a feasibility study'

  The published paper presented in this chapter reports the findings of a feasibility study evaluating recruitment rate, and acceptability and execution of several of the survey tools used to evaluate older adults' perceptions of neighbourhood environments, and to determine frailty scores, quality of life, physical activity level, physical capacity and comorbidities.

  Special considerations need to be determined in order to include frailty participants in research studies. The results of this study show that, although most tests are tailored to the older population, there are issues with the interpretation of some questions by the patients and other concerns related to the execution of the tests, which should be addressed. We were able to show, however, that the overall methodology was feasible and acceptable to the participants.

- **Chapter 5**
  Paper submitted for publication: 'A multidisciplinary exploratory approach for investigating the experience of older adults attending hospital services'

  The paper reproduced in this chapter as an unpublished manuscript reports on a multidisciplinary research project that investigated older adults' perceptions of the public spaces of the hospital, correlating with individuals' health and an indoor and outdoor hospital architectural audit. This architectural audit was developed to meet South Australian, Australian and the WHO's age-friendly guidelines.

  This was a mixed-method project, involving a walking observation, semi-structured interview, a comprehensive geriatric survey and an independent architectural audit. This multidisciplinary effort revealed how several built environment characteristics are relevant to older adults and shape their experiences in the hospital. Issues such as seating, wayfinding, transportation and access are issues of increased importance in hospitals, especially to individuals with decreased functional capacity and frailty.

- **Chapter 6**
  Published work in this chapter: **'**Prevalence using Frailty Index, associated factors and level of agreement among frailty tools in a cohort of Japanese older adults'

  The published work contained in this chapter reports on the construction of a frailty index (FI) in the Nagoya Longitudinal Study of Healthy Elderly (NLS-HE). We investigated a cohort of community-dwelling older adults in Nagoya, Japan, beginning in 2014 to determine risk factors associated with the development of frailty. The FI was developed using the guidelines by Mitninski and Rockwood (Mitnitski, Mogilner, & Rockwood, 2001), and agreement with the frailty phenotype (FP) and Kihon checklist

(Satake et al., 2016) was tested. We were able to identify the prevalence of frailty by FI in a Japanese sample of older adults; a useful tool that can be introduced into existing databases and successfully differentiate individuals at risk for frailty among healthier cohorts of older adults.

- **Chapter 7**
  Paper submitted for publication: 'Built environment and frailty: Neighbourhood perceptions and associations with frailty, experience from the Nagoya longitudinal study'

  The paper reproduced in this chapter as an unpublished manuscript reports on our investigation of perceptions of the neighbourhood environment associated with frailty in Japanese community-dwelling older adults, and the ways in which and to what degree the neighbourhood environment was associated with the level of frailty.

  The results indicate that overall the perceptions of the neighbourhood were inversely associated with the frailty index (FI). Diversity of land use and access, street connectivity, walking and cycling facilities, aesthetics and crime safety were associated with frailty, after adjustment to covariates. This was the first study to find associations between neighbourhood characteristics and frailty in the Japanese population.

- **Chapter 8**
  Paper submitted for publication: 'Objective and subjective measures of the neighbourhood environment are associated with frailty levels'

  The paper reproduced in this chapter as an unpublished manuscript that reports on investigations conducted in Adelaide related to the perceptions and objective characteristics of the neighbourhood environment associated with frailty in Australian community-dwelling older adults, and the ways in which and to what degree the neighbourhood environment was associated with the level of frailty.

  In Adelaide, not only older adults' perceptions of the built environment but also objectively recorded and assessed characteristics of the neighbourhood environment were assessed. Several individual characteristics and the overall neighbourhood environment were significantly associated with frailty in a cross-sectional analysis. These findings corroborate findings from Chapter 7 and provide robust adjustment to both subjective and objective assessments of the environment.

- **Chapter 9 Discussion**
  Chapter 9 discusses the key findings arising from the investigations in this thesis, the implications for environmental health research in the field of frailty and ideas for possible future research in this field.

1.8 References for Chapter 1

Please note that every chapter in this thesis is presented along with a list of references consulted during the writing of the chapter or journal article, either published or submitted. For the readers' convenience, however, a list of sources consulted throughout the research for the thesis has been included at the end of the document as 'Collected references'.

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Review of frailty

2.1 Frailty definition

A consensus statement written by delegates from international, European and US societies was proposed in 2013, and it defines frailty as:

> *a medical syndrome with multiple causes and contributors, characterised by diminished strength, endurance and reduces physiologic function, that increases individual's vulnerability for increased dependency and/or death. (Morley et al., 2013, p. 393)*

More importantly, the researchers stressed that frailty should be distinguished from disability and multi-morbidity (although these conditions can coexist) (Fried et al., 2001; Morley et al., 2013), and should be the focus of interventions designed to maintain older adults' autonomy and independence (Morley et al., 2013).

2.2 Frailty assessment methods

Screening and assessment are two different processes. Screening is used to evaluate the possible presence or absence of a condition prior to assessing its nature, determining a diagnosis, and developing recommendations for treatment. They are often considered together in frailty literature reviews, but there is no consensus gold-standard for screening and assessing for frailty (Bouillon et al., 2013; Buta et al., 2016; Dent et al., 2016).

Analysing the three most recent systematic reviews investigating frailty instruments, three frailty instruments can be identified:

- Fried's frailty phenotype (FP) model (Fried et al., 2001)
- the frailty index (FI) proposed as an accumulation of deficits (Rockwood & Mitnitski, 2007)
- multidimensional instruments that usually include a mix of specific physical and psychological variables, such as the Edmonton Frail Scale (EFS) and Kihon checklist (KCL) (Satake et al., 2016).

The FP and FI are the two most commonly used frailty tools in all three systematic reviews and have had the greatest number of articles cited over the years (Buta et al., 2016). These two instruments have had concurrent and predictive validity assessed in more than three different cohorts/samples (Bouillon et al., 2013). However, they have not been the two most extensively assessed instruments for their psychometric properties, so cannot be categorised as 'gold standard' for frailty assessment (Sutton et al., 2016).

Both tools have also been used for different purposes in the literature, ranging from:

- use as risk factors for adverse health outcomes
- use as risk factors for frailty
- in methodological papers
- in studies of biomarkers of frailty
- as inclusion and exclusion criteria for research
- estimating frailty prevalence
- a guide for decision making and as a target for intervention (Buta et al., 2016).

Experts currently recognise the strengths and weaknesses of each instrument, and the most common recommendations advise considering the feasibility, setting and aims when choosing the best tool (Dent et al., 2016).

The frailty phenotype and frailty index are now described in detail, along with the most common and recommended screening tools for frailty as per the Asia-Pacific and the International Conference of Frailty and Sarcopenia Research (ICSFR) *Clinical guidelines for frailty management* (Dent et al., 2017; E. Dent et al., 2019).

2.2.1 The frailty phenotype

The FP, first used in the Cardiovascular Health Study (Fried et al., 2001), represents a breakthrough in the operationalisation of frailty. It was the first tool that recognised a combination of manifestations of frailty that could be used to independently predict falls, worsening mobility (or loss of functional ability), hospitalisation and death (Fried et al., 2001), and that this combination had better predictive ability than each element alone. The original frailty phenotype consisted of five criteria indicative of frailty. To be frail, three or more criteria must be observed upon assessment, while the presence of one or two criteria indicate a pre-frail (or intermediate) state. Pre-frailty was associated with an intermediate risk for the same outcomes as frailty, and an increased risk of developing frailty.

The five original items assigned to the frailty phenotype and the cut-off criteria in the Cardiovascular Health Study were:

- *weight loss:* loss of more than 10 pounds (4.5 kg) in a year unintentionally
- *exhaustion:* using the Centre for Epidemiological Studies – Depression scale (CES-D), a positive answer to either of the following statements:

(a) I felt that everything I did was an effort, and
(b) I could not get going.

- *low physical activity:* low *level of physical activ*ity on the Minnesota Leisure Time Activity Questionnaire, classified as <383 Kcal/week of physical activity for men and <270 Kcal/week for women
- *SLOW walking speed:* gait speed < for men 0.65 and 0.76 m/s (height: ≤173cm />173cm, respectively), for women
- *weakness/low grip strength*: maximum grip strength in the dominant hand < 29-32kg (for men, according to BMI), and < 17-21kg (for women, according to BMI)

As previously noted, FP is the most common frailty measure in all systematic reviews and its five criteria have been regularly modified and adapted for various situations (Theou et al., 2015). The most common changes are related to changes from performance based to self-reported measures of variables (grip strength, walking speed and weight loss) and changes in questions phrasing, and may take into account the need for reduced question burden or use of specialized equipment and training of different types of research studies These changes may unfortunately limit the comparability between research studies and, therefore, these modifications were systematically assessed by Theou et al., who found 223 different studies with at least one modification to the original version of FP. The current study further investigated over 262 different combinations of criteria for the frailty phenotype in the same European cohort and found that frailty prevalence ranged from 12.7% to 28.2% according to the criteria adopted.

2.2.2 The frailty index

The accumulation of deficits approach considers ageing as a heterogeneous process, where the individual's health status can be quantified by the evaluation of the presence or absence of health deficits, a set of signs, symptoms, functional impairments and laboratory abnormalities (Mitnitski et al., 2001). On the spectrum between fitness and frailty, frailty is understood as the presence of multiple physiological failures in systems which are responsible for responding to environmental pressures. When system failures dominate, they correspond to a decrease in physical function, adverse outcomes and death (Mitnitski et al., 2001). An important characteristic of this instrument is that it is the number of health deficits, and not specific deficits which is the most important feature for determining frailty, providing the opportunity for creating this index using any existing database (Searle, Mitnitski, Gahbauer, Gill, & Rockwood, 2008).

In order to standardise the construction of the database, variables chosen should follow a few rules:

- All variables must be health related.
- The prevalence should increase with age; and not saturate too early. (For example, presbyopia is almost universal by the age of 55, so would not show any discrimination as a health variable for adults aged 65 and over.
- The range of variables should cover multiple physiological systems.
- If used serially, the same items must be used (Searle et al., 2008).
- A minimum of 30 variables is required to predict adverse outcomes (Searle et al., 2008).

Each health variable is characterised as a dichotomous response, 0 or 1, indicating the absence or presence of the health deficit. The FI is then calculated as the number of health deficits over the total number of variables considered; for example, if 15 out of 40 variables were present, the final FI score would be 0.37, with higher values related to worse frailty.

Although FI was developed as a continuous variable, to determine frailty and pre-frailty prevalence in a population it is necessary to determine cut-off points, and several were used by the original researchers (Mitnitski et al., 2001) and others (Orkaby, Hshieh, Gaziano, Djousse, & Driver, 2017); and 0.21, 0.25 and 0.35 can be found as cut-offs for frailty. A validation of the cut-offs using a stratum-specific likelihood ratio in a population sample of more than 13,000 subjects found cut-offs for the following categories; using as outcomes a set of hospital-related events (including hospitalisation, discharge to long-term care facility and in-hospital death):

- non non-frail (0 to ≤0.1)
- pre-frail (>0.1 to ≤0.21)
- more frail (>0.30 to ≤0.35) (women only)
- most frail (frail-group subset) (0.45 or more).

The distinction between the frailty phenotype and the frailty index can be seen in Figure 2.1.

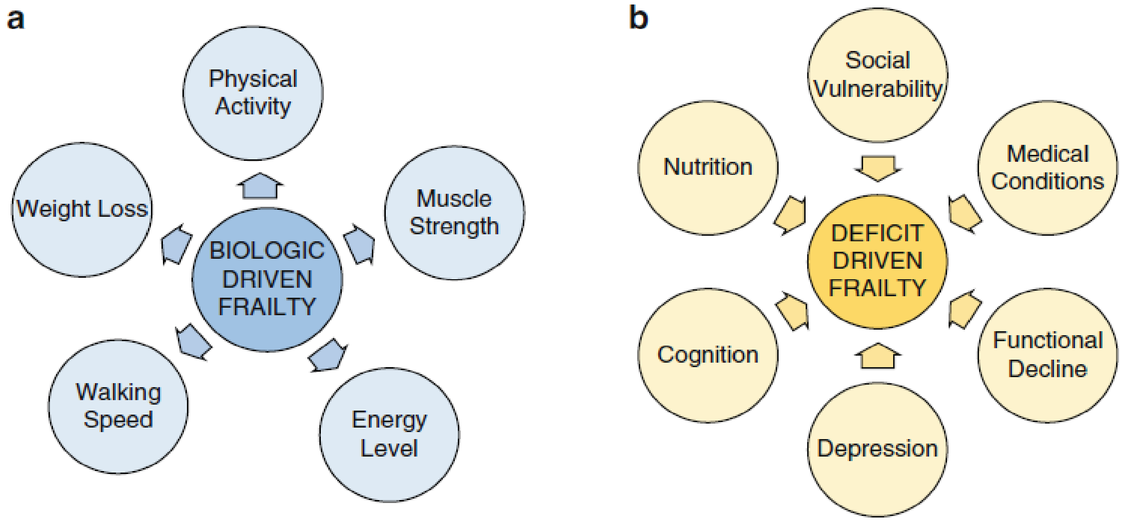

Figure 2.1 Two conceptualisation of frailty

Phenotypic frailty. Phenotypic frailty is conceptualised as a clinical syndrome driven by age-related biologic changes that drive physical characteristics of frailty and eventually, adverse outcomes.

Deficit accumulation frailty. The deficit model of frailty proposes that frailty is driven by the accumulation of medical, functional and social deficits, and that a high accumulation of deficits represents accelerated ageing . An important distinction between these two conceptualisations of frailty is that biologic driven frailty causes the physical characteristics of frailty (arrows pointed outward). In contrast, deficit accumulation frailty is caused by accumulated abnormal clinical characteristics (arrows pointed inward).

[Adapted from the Journal of the American College of Surgeons, Volume 221, Issue 6, Robinson TN, Walston JD, Brummel NE et al., Frailty for Surgeons: Review of a National Institute on Ageing Conference on Frailty]

According to the FP concept, a biological driven frailty causes the physical characteristics of frailty (the phenotype), that in a vicious cycle lead to adverse outcomes. In FI, frailty is caused by the characteristics outlined, also creating the state of vulnerability (Robinson et al., 2015).

Besides this distinction in its construct, a difference in objectives can also be noted. FP is focused on the physical components of frailty (Robinson et al., 2015). It provides a clinically meaningful picture of non-disabled older adults, but reaches saturation and a ceiling effect in the most advanced cases (Cesari, Nobili, & Vitale, 2016). FI on the other hand, can be used in the context of disablement and various levels of health (since they can form part of the components of FI), and is suitable for use in retrospective analysis of cohorts and economic analysis (Cesari, Nobili, et al., 2016).

2.3 Frailty screening tools

2.3.1 Edmonton Frail Scale (EFS)

The Edmonton Frail Scale (EFS) (Rolfson, Majumdar, Tsuyuki, Tahir, & Rockwood, 2006) is a multidimensional screening tool with nine components:

- functional limitation
- self-reported health
- general health status
- cognition
- social support
- mood
- functional performance
- polypharmacy, and
- continence.

It is most commonly used in the hospital setting, but is suitable for use in the community (E. Dent et al., 2019). The total score ranges from 0-17, and the following cut-offs have been used to classify frailty severity: not frail (0-5); apparently vulnerable (6-7); mildly frail (8-9); moderately frail (10-11); and severely frail (12-17). An adapted reported EFS has also been developed for use in acute care (Hilmer et al., 2009). This tool, although including several domains of health, has only been tested for reliability, and has not received high methodological ratings in a review study (Sutton et al., 2016).

2.3.2 The Clinical Frail Scale (CFS)

The Clinical Frail Scale is a screening tool recommended by the ICSFR guidelines (E. Dent et al., 2019). It is based on clinical judgement of robustness/frailty, ranging on a scale from 1 (very fit) to 7 (severely frail). Each point represents a specific pictorial description of frailty, and a score ≥5 is considered to be frail. It has been validated in the hospital setting, and has also been recommended by the International Consortium for Health Outcome Measurement (ICHOM) as an objective tool to be used in settings with no electronic health records (Akpan et al., 2018). It has been tested for its reliability and validity in several studies ((Rockwood et al., 2005), but some concerns were raised regarding the methodological quality of such studies

(Sutton et al., 2016). It has its applicability in the clinical setting, being able to be derived from medical charts (Dent et al., 2016).

2.3.3 FRAIL Scale (FRAIL)

The five item FRAIL scale was developed by Morley et al. (2012) as a simple and fast questionnaire, including elements from FP and FI. The acronym FRAIL corresponds to the five items with one point assigned to each item:

- fatigue
- resistance
- ambulation (slow walking speed)
- illnesses (presence of four or more comorbidities)
- loss of weight (loss of 5% of body weight in the previous year).

A score of 3 and above characterises frail, while a score of 1 to 2 classifies the subject as pre-frail. It has been recommended by the International Academy on Nutrition and Ageing (IANA), the ICSFR Clinical Guidelines (E. Dent et al., 2019), and in Australia's Department of Health (Burgess & Hercus, 2017). The FRAIL Scale has been validated in a sample of older Australian women (Lopez, Flicker, & Dobson, 2012), and has been used widely in several settings, both clinical and population samples (Dent et al., 2016), and is readily available for use with clinical data obtained with the Comprehensive Geriatric Assessment (CGA) (Morley et al., 2012). It has proved to be comparable to other frailty tools in predicting mortality and physical limitations (Woo, Leung, & Morley, 2012), but further validation for hospitalised and community-dwelling people is warranted. The feasibility of using the FRAIL scale was tested during research for Chapter 4, and used for research reported in Chapters 5 and 8 as a measure of frailty in Australian samples.

2.3.4 Kihon checklist (KCL)

The Kihon checklist (KCL) was developed in 2000 in Japan as a screening tool for older adults in need of government support (Arai & Satake, 2015) and later validated as a screening tool for frailty (Satake et al., 2017). The KCL is able to predict long-term care needs and mortality

(Kojima, Taniguchi, Kitamura, & Shinkai, 2018). It consists of 25 items, covering the domains of:

- activities of daily living
- physical strength
- nutrition
- oral function
- social isolation
- memory, and
- mood.

All questions are binary coded (yes=1 and no=0), and scores between 4-7 indicate pre-frailty. Above 7 is frail (Satake et al., 2016).

2.4 Frailty prevalence

Frailty is highly prevalent in older adults worldwide, but a review of current literature shows that the world prevalence varies greatly, depending on the definitions used and settings considered in different reports (Hoogendijk et al., 2019).

A systematic review of studies in high income countries found a frailty prevalence ranging from 4.0-59.1% for community dwelling older adults (Collard, Boter, Schoevers, & Oude Voshaar, 2012), and a pooled frailty prevalence of 10.7% (95%CI 10.5%-10.9%), with frailty ranging from 4.0% to 59.1%. Collard et al.'s review, however, selected studies using several different measures of frailty, including the FP, frailty index and other definitions of frailty; and studies have shown that, although similar at predicting outcomes, each measurement might select slightly different profiles of older adults at risk (Theou et al., 2015).

When the studies are grouped by the type of frailty tool used, prevalence ranges narrow, with studies using FP (range 4.0%-17.1%) narrower than those using other definitions of frailty (range 4.2%-59.1%), and a statistically significant difference in the pooled prevalence of each group of studies categorised by frailty tool (Collard et al., 2012). This prevalence of frailty measured by FP was later confirmed in another systematic review that retrieved population-based samples of community dwelling older adults from several different countries, in which the prevalence of frailty ranged from 4.9% to 27.3% (Choi, Ahn, Kim, & Won, 2015). Taiwan exhibited the lowest found prevalence (4.9%), with countries in the south of Europe showing the highest prevalence (Italy 23% and Spain (27.3%) (Choi et al., 2015).

In low- and middle-income countries, a comprehensive systematic review of 56 studies found a pooled prevalence of frailty of 17.4% (95% CI 14.4%-20.7%) by any assessment method. A supplementary analysis found a prevalence of frailty in high income studies of 8.2% (95% CI 5.7%-11.2%), significantly less than prevalence in middle income countries at 12.3% (95% CI

10.4-14.0%). Even after adjustments for age, prevalence is statistically signicantly greater in middle income countries than in those where the income is higher (Siriwardhana, Hardoon, Rait, Weerasinghe, & Walters, 2018).

In all the systematic reviews discussed above, only one Australian study was included for analysis (Collard et al., 2012), and no Japanese studies were included. In Australia, few studies have investigated frailty prevalence in large community-dwelling populations. One of the first Australian studies, investigating frailty prevalence among 2087 men and women aged 65 years and above, found a prevalence of frailty by FP of 8.8% and by FI of 17.5%, using baseline data from 1992 (Widagdo, Pratt, Russell, & Roughead, 2015). Comparatively, the Concord Health Study in Sydney, with a population sample of 1670 men aged 70 years and over, in 2005 found a prevalence of frailty of 9.5% by FP and 23.1% by FI (Noguchi et al., 2016).

But a pooled analysis of four Australian population-based studies, totalling 8804 participants found a substantially higher frailty prevalence of 21% using FP (Thompson, Theou, Karnon, Adams, & Visvanathan, 2018), which could be due to a higher number of female participants than other studies, and the use of self-reported items to form the FP criteria. Self-report items have been reported to produce higher estimates of frailty in a comparative study of frailty measure modifications (Theou et al., 2015).

A systematic review of Japanese studies reporting the prevalence of frailty by FP in community dwelling older adults aged 65 years showed a frailty prevalence ranging 4.6% to 9.5% amongst five different studies (Kojima et al., 2017). The pooled prevalence of frailty was 7.4% (95%CI 6.1- 9.0%), pre-frailty of 48.1% (95% CI 41.6-54.8%) and robustness of 44.4% (95% CI 37.2%-51.7%) (Kojima et al., 2017). The pooled prevalence in Japan (7.4%) was lower than had been previously reported in Collard et al.'s systematic review (Collard et al., 2012), of 9.9% (considering studies using FP criteria only), but consideration must be given to the fact in Kojima's study (Kojima et al., 2017) recruited participants from health check-ups events, and not representative population samples, which means that Kojima et al. could have selected a healthier cohort than previous systematic reviews.

2.5 Contributors to frailty and clinical consequences

Identifying the risk factors that lead to frailty could help direct public health and preventive strategies (Hoogendijk et al., 2019). Frailty has been associated with several geriatric syndromes, and potential contributing factors that have been identified are polypharmacy, depression, nutritional status, falls and physical inactivity.

Frailty has been associated with polypharmacy in several observational studies, but it is difficult to establish causality and determine what occurs first (Gutierrez-Valencia et al., 2018). Although the use of more than four medications daily has been associated with a higher probability of becoming frail in longitudinal cohorts (Woo et al., 2015), a number of the components of frailty, including multi-morbidity, weight loss and poor nutrition, are also associated with polypharmacy. And some studies suggest that polypharmacy and frailty might interact to produce an increased risk of adverse outcomes, such as mortality (Herr, Sirven, Grondin, Pichetti, & Sermet, 2017).

A reciprocal relationship has also been found between depression and frailty in a recent meta-analysis (Soysal et al., 2017), where depression was prevalent in the frail population. Frail older adults were at risk of increased depression, while depressed older adults were at risk of being frail (Soysal et al., 2017). Poorer nutritional status is a recognised determinant of frailty, and low specific micronutrients, overall dietary quality, protein intake levels and presence of malnourishment have been independently associated with frailty risk in older adults (Lorenzo-Lopez et al., 2017). Physical inactivity among community dwelling older adults is a recognised major risk factor for frailty, while the risk of developing frailty is lower in older adults who walk over 5000 steps/day or exercise at least 7.5 minutes/day in moderate to vigorous physical activity (Yuki et al., 2019).

Two systematic reviews with meta-analyses have found frailty to be a significant predictor for future falls (Cheng & Chang, 2017; Kojima, 2015). Frailty has also been associated with increased risk of developing cognitive impairment and a faster rate of cognitive decline than robust older adults (Robertson, Savva, & Kenny, 2013).

The clinical consequences of frailty have been documented in several large cohort studies, and frailty has been found to be a strong predictor of hospitalisation, disability and poor survival (Bandeen-Roche et al., 2006; Bilotta et al., 2012; Fried et al., 2001). Frailty identification in primary care, acute services and medical and surgical specialities has been advocated to provide better patient-centred care and effects on primary, secondary and tertiary prevention (Hoogendijk et al., 2019). Although the effect of frailty identification at the primary care level is still controversial, identifying frailty at the emergency department has been shown to predict mortality, length of stay and post-discharge functional decline (Jorgensen & Brabrand, 2017). Frailty diagnosis has been reported to significantly increase healthcare costs in studies in EUA and Europe, in in-patient, outpatient and nursing care (Ensrud et al., 2018; Hajek et al., 2018; Sirven & Rapp, 2017).

2.6 Social and physical environment and frailty

As stated in frailty definitions, both intrinsic and extrinsic factors contribute to frailty. Extrinsic factors involve the effect of the social and physical environment.

The social dimensions of frailty are expected to be of increased importance to older adults, and have been incorporated in the multidimensional construct of frailty proposed by the frailty index, as well as other multidimensional screening tools (Bessa, Ribeiro, & Coelho, 2018). To explore the extent of the influence of frailty on the social environment, the concept of social frailty was developed, defined as a continuum of being at risk of losing, or having lost, one or more of elements of the social environment. These include social resources (e.g. spouse or children), social behaviours and activities (e.g. maintaining close relationships or social participation) and self-management abilities (e.g. feeling empowered, or having the ability to make important decisions) (Bunt, Steverink, Olthof, van der Schans, & Hobbelen, 2017).

Once established, social frailty increases the risk of adverse outcomes for the individual. Studies have shown an increase in the risk of mortality and disability (Garre-Olmo, Calvo-Perxas, Lopez-Pousa, de Gracia Blanco, & Vilalta-Franch, 2013; Makizako et al., 2015) in socially frail older adults. Social frailty is negatively associated with cognitive function, physical function and depressive symptoms (Tsutsumimoto et al., 2018), and social and behavioural characteristics contribute to worse frailty trajectories over time (Chamberlain et al., 2016).

An important topic of this PhD, the relationship of the physical environment and frailty has been addressed in detail in Chapter 1. A strong body of evidence indicates how the neighbourhood environment may play a role in achieving more positive goals in the later years of life, and, as proposed by the WHO's Active Ageing Framework, maintaining function, delaying disability and promoting independence (*Active Ageing: A Policy Framework*, 2002). In this context, the physical or built environment aspects of the neighbourhood, here defined as all buildings, spaces and objects that are man-made or modifiable, including home, work space and public spaces, are of increased relevance due to the increased urbanisation of the world (Beard & Petitot, 2010). Several longitudinal and cross-sectional studies have shown the effects of the built environment in shaping physical activity (Sallis et al., 2016), functional capacity (Balfour & Kaplan, 2002) and disability (Beard et al., 2009) of older adults.

To date, very few studies have investigated the effects of the neighbourhood environment on frailty, and in relation to the physical aspects of the environment, only a few characteristics of the neighbourhood have been investigated in relation to frailty. Living in neighbourhoods with a higher percentage of green space (Yu et al., 2018), perceived neighbourhood security (Cramm & Nieboer, 2013), higher aesthetic quality and overall walking environment (Ye et al., 2018) were independently associated with lower frailty levels. Despite the increasing acceptance of the importance of the physical neighbourhood environment on frailty, a comprehensive portrait of the physical elements of the neighbourhood is still lacking, not allowing for any robust interpretation of its role on the development of frailty to be drawn.

2.7 Frailty interventions

Frailty is recognised as a dynamic condition, with individuals varying from robust to frail in a continuum over time, and can be potentially prevented or treated (Morley et al., 2013). A recent systematic review of studies aimed at preventing or reducing frailty in older adults found 21 randomised control trials with a total of 5275 older adults evaluated between 2001 and 2015 (Apostolo et al., 2018). The range of interventions had mixed results in terms of effectiveness, and included:

- physical exercise programs
- nutritional supplementation
- hormone replacement
- individually tailored management of clinical conditions
- group sessions
- home visits
- psychological treatments
- cognitive training
- educational training with a geriatrician
- combined training programs (Apostolo et al., 2018).

Although most interventions showed positive results in several different outcomes, such as increasing mobility and physical function, improving muscle strength and balance, while reducing the risk of falls, the certainty of the evidence is still low, and further studies are warranted to ascertain the effectiveness of each intervention.

The Asia-Pacific and the ICSFR Clinical Practice Guidelines strongly recommend a focus on physical activity programs and nutritional interventions as core components of frailty management (Dent et al., 2017; E. Dent et al., 2019).

Exercise and physical activity are of increased importance for the maintenance of physical function in older adults. Besides the benefits of physical exercise on muscle health, strength and power, muscle changes at a cellular level lead to a down regulation of inflammatory cytokines that have been associated with frailty pathogenesis (Marzetti et al., 2017). Physical activity levels are independently associated with incident frailty and lack of participation in physical activities is independently associated with frailty progression (Peterson et al., 2009; Yuki et al., 2019).

Clinical practice guidelines recommend multi-component physical activity programs with an emphasis on resistance-based training as one of the major strategies for the management of physical frailty (Dent et al., 2017; E. Dent et al., 2019). Resistance-based training includes any type of physical activity that uses external resistance to produce skeletal muscle contractions, for example, dumbbells, machine-based weight training, or hydraulic resistance (E. Dent et al., 2019). A progressive, individually-tailored program is also recommended (Dent et al., 2017).

Participation in physical activity is a dynamic and complex process, and depends on individual factors, social support and environmental factors. A systematic review of motivators and barriers to older adults' participation and factors in the interpersonal, intrapersonal, community and environmental areas have been identified. Special consideration for individual preferences and fears, social support and constraints in the environment were noted. In more detail, issues such as personal and neighbourhood safety, lack of exercise facilities, and accessibility to recreational areas have been raised as issues arising from the physical environment (Baert, Gorus, Mets, Geerts, & Bautmans, 2011).

Nutritional supplementation, combined or not with physical activity, is also strongly recommended by clinical guidelines for older adults experiencing weight loss, and involve protein and caloric supplementation (Dent et al., 2017; E. Dent et al., 2019), but a firm conclusion on the type of supplementation, and what outcomes are to be expected, are still uncertain. Two systematic reviews suggest improvements in physical performance, strength, gait speed and levels of physical activity (Apostolo et al., 2018; Lozano-Montoya et al., 2017) with nutritional supplementation interventions.

The current recommendations for protein intake for older adults vary in the literature but appear to be higher than is the amount required by adults in general. The European Society for Clinical Nutrition and Metabolism (ESPEN) recommends at least 1.2g/kg of body weight/day of protein in the diet, which should be increased up to 1.5g/kg of body weight/day in frail older adults with malnutrition (Deutz et al., 2014). Special consideration should be given to individuals experiencing renal failure and not under replacement therapy. Importantly, there are differences in responses to supplementation seen in individuals from different populations.

Other interventions recommended in reviews and clinical guidelines include:

- addressing polypharmacy by de-prescribing or reducing unnecessary medications (Dent et al., 2017)
- vitamin D supplementation for individuals with frailty and vitamin D insufficiency (Dent et al., 2017; E. Dent et al., 2019)
- advice about the importance of oral health (E. Dent et al., 2019)
- advice for health behaviour improvement (Elsa Dent et al., 2019; E. Dent et al., 2019).

These are sensible interventions, but there remains a low level of evidence of the positive effect of these specific interventions on frailty outcomes, although they can be understood in terms of a geriatric holistic medical review involving the use of the Comprehensive Geriatric Assessment (CGA) (Turner, Clegg, British Geriatrics, Age, & Royal College of General, 2014). CGA is defined as a multidimensional, multidisciplinary process which identifies medical, social and functional needs, and develops an integrated care plan to address those needs (Parker et al., 2018). The CGA has been investigated against outcomes of death, institutionalisation and disability, but not frailty specifically (Parker et al., 2018). Nonetheless, it is recommended by British and Canadian clinical guidelines as the gold standard for care of older adults (Commitee, 2017; Turner et al., 2014).

2.8 Conclusion

In conclusion, frailty is a prevalent condition worldwide with important clinical consequences for the health and quality of life of older adults. The syndrome is expected to increase with population ageing, and understanding the intrinsic and extrinsic factors that lead to frailty is an important effort for the correct public health and clinical management of frailty. A great range of frailty instruments currently exists which might hinder the generalisability of research findings, but current clinical guidelines for frailty emphasise the importance of physical activity and nutrition as the main interventions for frailty. The role of neighbourhood environments in achieving positive goals in the later years of life is still poorly understood, and important if effective frailty interventions and public health efforts are to be achieved.

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Fifth-year medical students' perceptions of the importance of frailty and competence in assessing, diagnosing and managing frailty before and after a geriatric medical course

'Fifth-year medical students' perceptions of the importance of frailty and competence in assessing, diagnosing and managing frailty before and after a geriatric medical course' was **accepted for publication** in the *Australasian Journal of Aging.*

The statement of authorship and paper (.pdf) follow over the page. Additional tables and an appendix are provided in Chapter 3.4 Supplementary material for Chapter 3.

3.1 Summary

While the knowledge and implications of frailty are evolving, frailty screening has been shown to be prognostic in several medical contexts, such as preoperative risk, cardiologic procedures and oncologic treatments. This increase in the application of frailty knowledge by other medical specialists is evidence of the fact that all future medical professionals will need to effectively recognize and manage frail patients. Currently, evidence for the education and training of health professionals in the field of frailty is still scarce (Windhaber et al., 2018), and frailty is an under-represented topic in the medical curricula for undergraduate geriatric medicine from European, North American and Australian societies (Knight, Oliver, Wyrko, Gordon, & Turner, 2014).

In order to address this gap, the present study investigated the changes in fifth-year medical students' perceptions of the importance of and competence in assessing, diagnosing and managing frailty after a 4.5-week geriatric medicine course. Students' perceived importance and competence were assessed before and after the course using a 26-item Likert scale questionnaire with scores ranging from 1 to 6. The results demonstrate that students' perceptions of the importance of defining frailty ($P = 0.01$), explaining what frailty is ($P = 0.03$), advising on nutritional needs ($P = 0.001$) and exercise ($P = 0.001$), as well as prescribing an exercise program ($P < 0.001$), significantly improved after the course. Medical students' confidence in assessing, diagnosing and managing frailty was low to moderate pre-course. Post-course their perception of their competence was significantly increased (2.3 [1.2] vs. 4.9 [2.9], mean [IQR] $p<0.001$) across all items. The results indicate that an appropriate curriculum focusing on geriatric health conditions such as frailty can improve senior medical students' appreciation for the importance of diagnosing and managing frailty, as well as their competence in doing so.

3.2 Statement of authorship

Statement of Authorship

Title of Paper	Fifth-year medical students' perceptions of the importance of frailty and competence in assessing, diagnosing and managing frailty before and after a geriatric medicine course
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Principal Author

Name of Principal Author (Candidate)	Beatriz Arakawa Martins		
Contribution to the Paper	Study design, constructed dabase, performed statistical analysis, wrote the manuscript and acted as corresponding author		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

Name of Co-Author	Joanne Dollard		
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BRIEF REPORT

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Fifth-year medical students' perceptions of the importance of frailty and competence in assessing, diagnosing and managing frailty before and after a geriatric medicine course

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Abstract

Objective: To assess the changes in fifth-year medical students' perceptions of the importance of frailty and competence in assessing, diagnosing and managing frailty after a 4.5-week geriatric medicine course.

Methods: Students' perceived importance and competence was assessed before and after the course using a 26-item Likert scale questionnaire with scores ranging from 1 to 6.

Results: Students' perceptions of the importance of defining frailty ($P = .01$), explaining what frailty is ($P = .03$), advising on nutritional needs ($P = .001$) and exercise ($P = .001$) and prescribing an exercise program ($P < .001$) significantly improved after the course. Medical students' perceived competence in assessing, diagnosing and managing frailty was low to moderate precourse and increased significantly postcourse (2.3 [1.2] 4.9 [2.9], mean [IQR], $P < .001$) across all items.

Conclusion: An appropriate curriculum focusing on geriatric health conditions such as frailty can improve senior medical students' perceived importance and competence in assessing, diagnosing and managing frailty.

KEYWORDS

aged, competence, frailty, geriatrics, undergraduate medical education

1 | INTRODUCTION

To address the needs of an ageing population, future doctors will need to be better prepared in diagnosing, treating and managing geriatric health conditions such as frailty.

Frailty is defined as a state of increased vulnerability to stressors, leading to increased risk of disability, falls, hospitalisation and mortality.[1,2] Frailty is highly prevalent among older people, and current projections estimate an increase of 43% in the number of frail older adults by 2027 in Australia.[3] Frailty is associated with increased health-care costs,[4] which will represent a significant challenge for the Australian health-care system as 48% of all hospital admission days and 33% of non-admitted services are for older adults aged ≥65 years.[5] Current evidence shows that frailty can be prevented and in some cases, reversed.[6] Clinical practice guidelines[7] recommend the early identification of older people at risk of frailty, managing their various health conditions and reversible causes, as well as promoting adequate nutritional intake and physical activity (PA).[1,7]

The Australian and New Zealand Society for Geriatric Medicine[8] and the European Union of Medical Specialists—Geriatric Medicine Section[9] undergraduate curricula specifically mention that defining the concept of frailty is an essential area of knowledge for undergraduate medical students. However, a recent investigation of Australian general

Elizabeth Hospital campus in 2017 consented to participate in the survey. Two students did not complete the pre-course survey, and another two students did not complete the post-course survey, allowing for paired responses of 61 students (94% response rate).

Out of the 61 students, 28 (46%) were previously exposed to geriatric medicine. This exposure was most commonly obtained from a 3-week elective, the medical scientific attachments (n = 16 out of 28), usually possible in the fourth year and fifth year of the medical course.

Pre-course, all 26 items were considered as important (score ≥4), with the proportion of students who had a rating score of ≥4, ranging from 88% to 100% (Table 1). The overall importance significantly increased post-course (5.2 [0.6], 5.4 [0.9], median [IQR], respectively, $P = .007$). The proportion of students considering frailty as important remained high post-course (range 94%–98%) and had statistically significant improvements in the management of frailty through exercise and nutrition ($P = .001$ for both items).

Precourse, student ratings of perceived competence (score ≥4) ranged from 3.2% to 33.3%. Students' overall perceived competence significantly increased from pre- to postcourse (2.3 [1.2], 4.9 [2.9], $P < .001$, median [IQR] pre

TABLE 1 Perceived importance in frailty diagnosis, assessment and management

It is important to be able to		Minimally important N (%)	Moderately important N (%)	Important N (%)	Precourse Postcourse Median (IQR)	*P*-value
1. Define frailty	Pre	1 (1.6)	4 (6.6)	56 (91.8)	5.0 (1.0)	.01*
	Post	1 (1.6)	3 (4.9)	57 (93.4)	5.0 (1.0)	
2. Explain to the patient or their family what frailty is	Pre	0 (0)	3 (4.9)	58 (95.1)	5.0 (1.0)	.03*
	Post	0 (0)	1 (1.6)	60 (98.4)	5.0 (3.0)	
3. Explain to the patient or their family the consequences of frailty to their health	Pre	0 (0)	0 (0)	61 (100)	5.0 (1.0)	.1
	Post	0 (0)	1 (1.6)	60 (98.4)	6.0 (3.0)	
4. Assess that someone is frail	Pre	0 (0)	0 (0)	61 (100)	6.0 (1.0)	.4
	Post	0 (0)	1 (1.6)	60 (98.4)	6.0 (3.0	
5. Assess that someone is at risk for frailty	Pre	0 (0)	1 (1.6)	60 (98.4)	5.0 (1.0)	.8
	Post	0 (0)	3 (4.9)	57 (93.4)	5.0 (3.0)	
6. Treat or reverse frailty	Pre	4 (6.6)	1 (1.6)	56 (91.8)	5.0 (1.0)	.2
	Post	0 (0)	2 (3.3)	59 (96.7)	5.0 (3.0)	
7. Undertake a comprehensive assessment of patients to identify remediable health issues	Pre	0 (0)	0 (0)	61 (100)	6.0 (1.0)	.7
	Post	0 (0)	1 (1.6)	60 (98.4)	6.0 (3.0)	
8. Advice on the nutritional needs of an older person	Pre	0 (0)	2 (3.3)	59 (96.7)	5.0 (0.5)	.001*
	Post	0 (0)	1 (1.6)	60 (98.4)	6.0 (3.0)	
9. Advise on exercise	Pre	1 (1.6)	2 (3.3)	58 (95.1)	5.0 (2.0)	.001*
	Post	0 (0)	1 (1.6)	60 (98.4)	6.0 (3.0)	
10. Prescribe an exercise program including frequency, duration and intensity for an older person	Pre	2 (3.3)	4 (6.6)	55 (90.2)	5.0 (1.0)	<.001*
	Post	1 (1.6)	1 (1.6)	59 (96.7)	5.0 (4.0)	
11. Optimise the medications to reduce risk whilst maximising benefit	Pre	0 (0)	0 (0)	61 (100)	6.0 (1.0)	1.000
	Post	0 (0)	0 (0)	61 (100)	6.0 (2.0)	
12. Manage the emotional health of older people	Pre	0 (0)	1 (1.6)	60 (98.4)	5.0 (1.0)	.3
	Post	0 (0)	0 (0)	61 (100)	6.0 (2.0)	
13. Manage the cognitive health of older people	Pre	0 (0)	0 (0)	61 (100)	5.0 (1.0)	.2
	Post	0 (0)	0 (0)	61 (100)	6.0 (2.0)	
Overall mean score	Pre	NA	NA	NA	5.2 (0.6)	.007*
	Post	NA	NA	NA	5.4 (0.9)	

Note: Importance rated in a scale from 1 (not important) to 6 (very important) and classified as follows: minimally important (≤2), moderately important (2.01-3.99) and important (≥4).

Abbreviations: NA, not applicable; SD, standard deviation.

*Significant values with $p < .05$.

medical course significantly improved medical students' perceptions of the importance of the topic of frailty, especially among students with no previous exposure to geriatric medicine.

The improvements in medical students' competence across all items provide initial evidence that the course might be beneficial in introducing the topic of frailty. Frailty represents an important teaching topic for geriatric disciplines, and it is necessary to develop a set of complex clinical abilities, approached not in one, but several different tutorials during this course. Nonetheless, one area with lower scores was identified (treating and reversing frailty), allowing it to be more effectively addressed in future courses. Additionally, the high perceived competence observed in the item of prescribing for exercise (5.5 [1.0], median [IQR]), an established treatment for frailty, could be related to the successful PA module introduced to the geriatric medicine course in the previous year[15] (mean overall competence in prescribing exercise was 4.9 [1.0] in 2016, year of introduction of the PA module).

Even though students had an initial high perception of the importance of frailty, there was a significant increase in their perceived importance of defining frailty ($P = .01$), explaining to family and patient what frailty is ($P = .03$), advising on nutritional needs of the older person ($P = .01$), advising on exercise ($P = .001$) and prescribing exercise ($P < .001$). These findings are consistent with previous research regarding medical students' perceived importance of the topic of exercise prescription for older adults.[13] Several educational programs have advocated the need to increase medical students' awareness and attitudes towards ageing and geriatric medicine by inclusion of dedicated geriatric medicine modules during undergraduate training.[16,17] The evidence that geriatric medicine exposure changes medical students' perceptions of importance towards the topic is a relatively novel finding in geriatric medicine education and might demonstrate the process by which students recognise the complexities of these topics and how it will affect their practice in future.[18]

Our study has some limitations. Self-perceived competence is different from observed performance, with students often underestimating or overestimating their clinical performance.[19] Additionally, self-perception cannot show an objective profound change in behaviour towards a specific clinical skill. Nonetheless, competence is multidimensional and involves acquisition of knowledge, skills, attitudes, values and interpersonal factors. Self-assessments have the merit of showing individual awareness of strengths and weaknesses, and is one component of self-efficacy. There is a better correlation between self-perceived and objectively observed competence in 'soft skills' such as critical thinking and communication,[20] which are very important skills for frailty management. Future studies should evaluate objectively-assessed competence and retention over time of the topic of frailty when these students enter internship and advanced medical training.

5 | CONCLUSION

In conclusion, a comprehensive geriatric medicine course resulted in satisfactory improvements in senior medical students' perceived importance and competence in the topic of frailty, with room for improvement across specific items.

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CONFLICTS OF INTEREST

No conflicts of interest declared.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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3.4 Supplementary materials for Chapter 3

Appendix Table 1: The University of Adelaide Geriatric Medicine 2017 curriculum (Adapted and updated from Tam et al[1] and Jadczaz et al [2])

Tutorials (tutors)	Time commitment in hours (total 29.5 hours)
The topics for tutorials and the clinical exposure are based on recommendations by the Australian and New Zealand Society for Geriatric Medicine position statement[3]	
Introduction and Orientation, distribution of course materials (geriatrician)	0.5
Rehabilitation, Transition Care, Discharge Options, and Day Therapy Services (geriatrician)	1
Falls (geriatrician)	1
Urinary Incontinence in older people (geriatrician)	1
Polypharmacy and iatrogenesis (geriatrician)	1
Depression in older people (psychogeriatrician)	1
Cognition (geriatrician): Dementia, Delirium, Capacity Assessment and Legal Directives, Management of behavioural and psychological symptoms of dementia and acute agitation	4
Caring for Patients with Dementia (Alzheimer's Australia Geriatric Medicine Consultant)	3
Nutrition in older people (geriatrician)	1
Osteoporosis and bone health (geriatrician)	1
Parkinson's Disease in older people (geriatrician)	1
Pharmacology in elderly and medication review(clinical pharmacist)	1
Oral health in Older People (Dentist)	1
Management of dysphagia and dysphasia (speech therapist)	1
Physiotherapy assessments, role in Geriatric Medicine and Discharge Planning (physiotherapist)	1
Occupational therapy functional, safety and cognitive assessments, discharge planning (occupational therapist)	1
Malnutrition and Nutritional Supplements in Elderly (Dietician)	1
Elder Abuse (Aged Rights Advocacy Service)	1
Advance care planning, respecting patient choice (specialist nurse)	1
Aged Care Assessment Programs and Community Services (geriatrician and Domiciliary Care Service)	2.5
Exercise Assessment and Prescription (exercise physiologist)	1
Campbelltown Keep Fit class for elderly – exercise interview with consumers (Exercise Professional)	1
Student Presentation and Discussions regarding exercise history from consumers (geriatrician and psychologist)	1
Physiology of Ageing – Brief notes and headings provided to guide student in their study	Self-directed learning

Clinical attachments with preceptors (geriatrician) – Two blocks of 2-week clinical attachments (one preceptor for each 2-week block). End of rotation assessments (MCQs – 50 questions 60 minutes to answer; OSCE – 10 stations 10 minutes per station with immediate feedback included). Student grading for rotation: MCQ 25%; OSCE 25%; first preceptor assessment 25%; second preceptor assessment 25%. MCQ, multiple-choice question; OSCE, objective structured clinical examination.

Appendix Table 2: Ordinal Generalized Estimating Equation

	No Previous Attendance		Time	
IMPORTANCE:	OR (95%CI)	P value	OR (95%CI)	P value
1. Define frailty	1.6(0.8,2.2)	0.219	2.5(1.3,4.6)	0.004
2. Explain to the patient or their family what frailty is	1.2(0.6,2.7)	0.635	1.9(1.1,2.4)	0.02
3. Explain to the patient or their family the consequences of frailty to their health	1.3(0.6,2.8)	0.488	1.8(0.9,3.2)	0.05
4. Assess that someone is frail	1.3(0.6,2.7)	0.494	0.8(0.4,1.5)	0.4
5. Assess that someone is at-risk for frailty	0.9(0.4,1.8)	0.744	1.3(0.7,2.4)	0.4
6. Treat or reverse frailty	1.2(0.5,2.5)	0.739	1.4(0.8,2.4)	0.2
7. Undertake a comprehensive assessment of patients to identify remediable health issues	1.3(0.6,2.9)	0.546	1.1(0.6,1.9)	0.8
8. Advice on the nutritional needs of an older person	0.9(0.4,2.1)	0.906	2.5(1.5,4.2)	0.001
9. Advise on exercise	0.9(0.4,1.9)	0.725	2.5(1.5,4.0)	<0.001
10. Prescribe an exercise program including frequency, duration and intensity for an older person	1.4(0.6,3.0)	0.469	2.9(1.8,4.7)	<0.001
11. Optimize the medications to reduce risk whilst maximizing benefit	0.7(0.3,1.7)	0.437	0.9(0.5,1.7)	0.8
12. Manage the emotional health of older people	0.5(0.2,1.1)	0.091	1.5(0.9,2.6)	0.2
13. Manage the cognitive health of older people	0.6(0.6,1.2)	0.130	1.7(0.9,3.1)	0.1
Overall Mean Score	1.1(0.5,2.3)	0.816	2.3(1.4,3.7)	0.001
COMPETENCE:				
1. Define frailty	2.3(1.1,4.6)	0.024	79.1(29.9,209.7)	<0.001
2. Explain to the patient or their family what frailty is	2.5(1.3,5.1)	0.009	57.8(19.2,173.4)	<0.001
3. Explain to the patient or their family the consequences of frailty to their health	2.0(0.9,4.2)	0.06	42.7(16.7,109.3)	<0.001
4. Assess that someone is frail	2.0(0.9,4.2)	0.060	42.7(16.7,109.3)	<0.001
5. Assess that someone is at-risk for frailty	2.4(1.2,4.7)	0.013	52.9(20.2,138.5)	<0.001
6. Treat or reverse frailty	2.1(1.1,4.1)	0.024	67.1(25.4,177.2)	<0.001
7. Undertake a comprehensive assessment of patients to identify remediable health issues	2.8(1.4,5.8)	0.004	92.9(29.2,295.1)	<0.001
8. Advice on the nutritional needs of an older person	1.7(0.8,3.3)	0.151	39.0(16.8,90.7)	<0.001
9. Advise on exercise	1.4(0.7,2.8)	0.403	36.7(14.9,90.6)	<0.001
10. Prescribe an exercise program including frequency, duration and intensity for an older person	1.1(0.6,2.2)	0.774	48.1(18.9,122.5)	<0.001
11. Optimize the medications to reduce risk whilst maximizing benefit	1.5(0.8,2.8)	0.193	119.7(36.1,397.3)	<0.001
12. Manage the emotional health of older people	1.3(0.6,2.7)	0.462	24.9(10.6,59.1)	<0.001
13. Manage the cognitive health of older people	2.0(1.0,4.1)	0.044	44.1(18.9,102.5)	<0.001
Overall Mean Score	2.0(1.0,3.9)	0.038	166.9(52.4,531.4)	<0.001

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Older adults' perceptions of the built environment and associations with frailty: a feasibility study

'Older adults' perceptions of the built environment and associations with frailty: a feasibility study' was **published** in the *Journal of Frailty & Aging.* The statement of authorship and paper (.pdf) follow over the page. This article presented research that evaluated the feasibility and acceptability of the self-complete survey used in Chapters 5 and 8. The identified issues made it possible to adapt study procedures, reduce the length of some of the survey tools (e.g. from a 68-item NEWS to its abbreviated version) and resolve layout issues to improve execution.

4.1 Summary

For the research presented in this chapter medical students in the fourth and fifth years of medical study at the University of Adelaide were again recruited while they were undertaking a three week Medicine and Scientific Attachment. Including medical students in geriatric medicine research projects could potentially increase the enrolment of future doctors in the study of geriatrics and enhance the learning of geriatric topics throughout general medical practice (Bragg, Warshaw, Meganathan, & Brewer, 2012).

The correct representation of older adults in research studies requires the correct assessment of the condition of the older adult, often through the use of survey tools, both guided and self-administered. The study reported here evaluated several aspects of the use of a survey tool with a group of older adults admitted to a post-acute residential aged care-based transitioning program. The study evaluated the: 1) recruitment rate; 2) time to complete questionnaires and difficulties encountered; and 3) acceptability of the tools to the participants. Several survey tools evaluating patients functional status were assessed, including the:

- FRAIL Scale,
- Charlson's Comorbidities Index
- Life-Space Assessment
- NEWS Walkability Scale.
- EuroQoL 5D-5L
- Baecke's Physical Activity Questionnaire
- Katz and Lawton ADL

Twenty-five older patients (63% recruitment rate) of a residential Transition Care Program in Adelaide, South Australia were interviewed. Although not statistically different, time to complete the overall questionnaire differed between robust, pre-frail and frail participants. Overall, the survey was considered acceptable and feasible, but with some consideration given to modifying the length, phrasing and layout of the NEWS and Life-Space assessment.

Statement of Authorship

Title of Paper	Older Adults' Perceptions of the Built Environment and Associations with frailty: A feasibility and acceptability study
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Principal Author

Name of Principal Author (Candidate)			
Contribution to the Paper	Designed the study, collected the data with help from medical students, performed statistical analysis, wrote the manuscript and acted as corresponding author.		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	22/10/2019

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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ORIGINAL RESEARCH

OLDER ADULTS' PERCEPTIONS OF THE BUILT ENVIRONMENT AND ASSOCIATIONS WITH FRAILTY: A FEASIBILITY AND ACCEPTABILITY STUDY

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Abstract: It is essential to evaluate frail older adults understanding and execution of survey tools to improve data quality and accurate representation in research. The study tested the feasibility and acceptability of a survey that assesses various measures of functional status in frail older people. The study evaluated: 1) recruitment rate; 2) time to complete questionnaires and difficulties encountered; and 3) acceptability by participants. Validated tools including: FRAIL Scale, EuroQoL 5D-5L, Charlson's Comorbidities Index, Baecke's Physical Activity Questionnaire, Life-Space Assessment, Katz and Lawton ADL and NEWS Walkability Scale were assessed. Twenty-five older patients (63% recruitment rate) of a post-acute restorative program (residential Transition Care Program) in Adelaide, South Australia were interviewed. Although not statistically different, time to complete the overall questionnaire differed between robust, pre-frail and frail participants. Overall, the survey was considered acceptable and feasible, with consideration with NEWS and Life-Space assessment regarding length, phrasing and layout.

Key words: Frailty, feasibility, neighborhood, built environment.

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Introduction

The under-representation of older people in research remains an important but neglected issue (1). In order for studies with older adults to be relevant, they must be designed to ensure that those who might stand to most benefit from new evidence are included (1).

Older adults may respond to targeted interventions to prevent or reverse frailty, especially interventions that focus on physical activity and socialisation (2). The role of neighbourhood environments in influencing frail older adults' physical activity levels, social participation and accessibility has not been fully investigated. For such research to be successful, it is necessary to utilise survey instruments that can be completed by older people across various settings and varying frailty status. This study builds on research where older people found difficulties with the comprehension and completion of geriatric assessment questionnaires, despite these being validated for use with older people (3).

The aim of this study was to examine the feasibility and acceptability of a survey that assesses perceptions of the built environment and use of space as well as social support, quality of life and physical status in patients admitted to a residential Transition Care Program (rTCP) (4) following acute hospitalization. The study evaluated: 1) recruitment rate; 2) time to complete the questionnaires; 3) difficulties encountered; and 4) acceptability.

Methods

Participants were recruited from the Central Adelaide Local Health Network (CALHN) rTCP at two residential aged care sites. rTCP is a post-acute restorative program focused on optimizing patients' functional capacity, reducing hospital stay and enabling recipients to return home (4). This study was approved by the CALHN Ethics Committee (HREC/17/TQEH/62).

A customised survey questionnaire consisting of 150 items was developed from a combination of validated clinical assessment tools. To evaluate participant's mobility through space and perceptions about the walkability of neighbourhood environment, the Life-Space Assessment (LSA) (5) and the Neighborhood Environment Walkability Scale- Australian version (NEWS-A) (6) were included. Other assessments included socio-demographic information, the EuroQoL 5D-5L tool (7), the short-form self-report Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE-SR) (8), Geriatric Depression Scale (GDS 4) (9), Beacke's Physical Activity Scale (10), Lubben's Social Support Abbreviated Scale (11), the Charlson's Comorbidity Scale (12) (with list of medical conditions adapted to common language), the Activities of Daily Living (ADL) (13), FRAIL Scale (14), KIHON Checklist (15) and Mini-Nutritional Assessment Short Format (MNA-SF) (16) (adapted to remove duplicated questions and avoid repetition).

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Table 1
Assessment tools – Times to complete (seconds), comprehension and execution issues by Frailty Status

Assessment Tools	Comprehension Issue (CI) Execution issues (EI)N (%)	Robust Time (mean ±SD) n=7	Pre-frail n=7	Frail n= 11	Total time (mean ±SD) n = 25
Socio-demographical	CI: 2(8)	135±21	225±90*	140±17	177±73
EuroQoL	CI: 1(4)	168±99	326±183	270±154	265±158
ADL Katz and Lawton	CI:3(12)				
	EI: 2(8)	156±91	249±127	243±176	225±145
IQCODE-SR	CI: 2(8)				
	EI: 2(8)	156±117	360±174*	292±122	280±150
Charlson's Comorbidities Index	CI: 1(4)	192±107	288±143	292±122	212±113
Frail Screens		165±57	200±135	154±68	173±92
GDS 4		84±54	168±182	64±25	98±104
Lubben's Social Network Scale		114±61	165±75	190±122	159±92
Baecke's Physical Activity Scale	CI: 1(4)	145±55	204±68	360±469	251±312
	EI: 1(4)				
Life-Space Assessment	CI: 8(32)	240±120	514±205*	291±295	350±188
	EI: 8(32)				
NEWS- A	CI: 2(8)	684±364	732±403	785±452	737±386
	EI: 1(4)				
Total time spent		2406±1000	2970±1222	2637±609	2688±896
Need of substantial help from researcher		1(14.3)	3(42.9)	4(36.4)	8 (100)
Patients with comprehension issues– n (%)		6(85.7)	2(28.7)	4(36.4)	12(100)
Patients with execution issues – n (%)		3(42.9)	3(42.9)	4(36.4)	10(40)

CI: comprehension issues, EI: execution issues; EuroQoL: Euro Quality of Life 5 domains; ADL – Activities of Daily Living; IQCODE-SR – Informant Questionnaire on Cognitive Decline in the Elderly – Self-Response; FRAIL Screens – multiple frailty screenings performed : FRAIL scale and Kihon Checklist; GDS4 – Geriatric Depression Scale 4 questions; NEWS-A – Neighborhood Environment Walkability Scale- Australian version; * Statistical significance between pre-frail and robust groups at p< 0.05

Nine senior (4th and 5th year) University of Adelaide medical students, as part of their Medicine and Scientific Attachment (MSA) elective program in ageing research, recruited and collected data.

The study's principal investigator and the rTCP case manager screened participants for eligibility; participants aged 65+ years old, present in the residential aged care facility at the time of interview, able to converse and read in English and provide informed consent were included. Those with moderate to severe dementia (Mini Mental State Evaluation score < 22) were excluded.

Participants were given a paper survey to complete under the observation of a medical student and each questionnaire was administered in the same order to each participant. Students timed completion of each survey section, recorded issues encountered and marked on the survey where they started assisting participants. Comprehension issues were determined as any difficulties related to language, understanding or phrasing of instructions. Execution issues were defined as comments related to layout and printing that prevented correctly completing the survey or task. After 30 minutes, the student assisted participants to complete the survey. At the end, an acceptability survey was administered to capture participants' perceptions of the process.

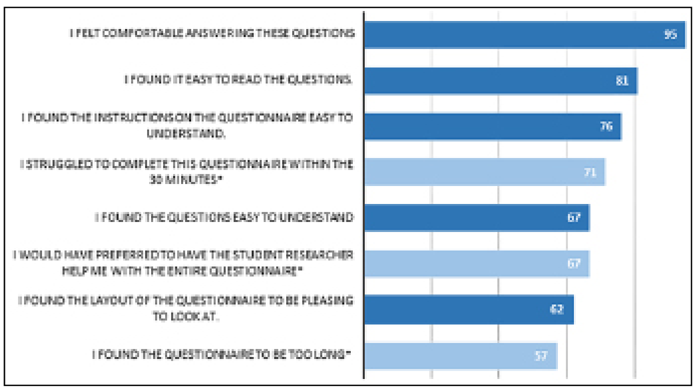
Data Analysis

Descriptive statistics were performed using IBM SPSS Statistics 24. Issues observed during survey implementation were collated, categorised and summarised. Participants were grouped according to their frailty status using the 5-item FRAIL Scale, which includes Fatigue, Resistance, Ambulation, Illness, and Loss of weight (14). To be considered frail, patients need to have 3 or more of the 5 items, and pre-frail either 1 or 2 items. Differences between frail, pre-frail and robust in completion time and comprehension and execution issues were tested with Kruskall-Wallis for continuous variables and Fisher-exact test for categorical variables.

Results

From April to October 2017, 40 out of 65 patients were screened as eligible. Most common reasons for being ineligible were being unavailable at the time of assessments (35.4%), not fluent in English (32.2%), moderate to severe dementia (16. 2%) and acute clinical issues (16.2%). Out of 40 eligible patients, 25 participants (62.5% recruitment rate) with an age range from 66 to 100 years old consented; seventeen were female. Seven participants were classified as pre-frail and 11 as frail. On average, participants reported using 8.7 medications regularly. Fifteen (60%) participants were moderate to highly dependent for activities of daily living (IADL) and 9 (48%) had a Charlson's Comorbidities Index of 4 or above (indicating a moderate or high mortality risk).Most common reasons for refusal to participate were feeling tired (40%), unwillingness to sign consent form (20%), a lack of interest in the study (13.3%) and unspecified reasons (13.3%).

Figure 1
Acceptability Survey - Percentage of Agree and Strongly Agree



* *Negative assertions about the survey*

The complete assessment took on average 44:48 ±14:56 minutes, ranging from 24:30 to 75:00 minutes. Only one pre-frail participant was able to independently complete the survey in under 30 minutes. Participants classified as robust took 40 minutes on average to fill out the survey while pre-frail and frail participants took 47 minutes ($p = 0.410$). The questionnaire that required the longest time to complete was NEWS-A (12 minutes), with 68 items; followed by the LSA (5:50 minutes), with 16 items.

Twelve participants reported comprehension issues, with no differences between frailty status. The most common issue was interpreting if the questions related to their current physical performance or to their condition before hospitalization. Ten participants reported execution issues, the most common were aligning questions to the corresponding checkboxes and following a grid layout. Eight participants asked for substantial help to fill out the survey, even before the allocated 30 minutes; three being pre-frail and four frail (Table 1).

The tool with most execution issues was LSA. Many participants felt they could not accurately assess their home environment because they had been hospitalised for a significant duration. Eight participants had execution difficulties (e.g. skipping questions and following the grid layout).

Twenty-one participants returned an acceptability survey; the majority found the allocated 30 minutes insufficient, and 16 preferred having assistance with the questions. Over half of the participants found the questionnaire too long (Figure 1).

Discussion

This study obtained three important key findings. Firstly, although challenging to participants, it was possible to recruit a substantial proportion of frail participants through this protocol. Secondly, length of questionnaire and need of assistance were important factors to participants and lastly NEWS-A and LSA received most of the understanding and executions issues, suggesting better adaptation is needed for older research participants.

The recruitment rate in this study was comparable to a previous study involving a community-based TCP program in Australia (4).This suggests that, given the right circumstances, frail older people can be willing and valuable research participants.

Over half of participants found the questionnaire to be too long whilst seven needed, and asked for substantial help from the student from the start of survey. Although self-complete questionnaires can reduce costs and facilitate the implementation in larger groups, it might not be the preferred choice by frail older adults and might deter their participation in research or increase the likelihood of non-completion.

Students assisted frail participants earlier in the questionnaire than pre-frail participants. As a result, pre-frail participants had a longer completion time (49 minutes) compared to frail ones (43 minutes), although this difference was not statistically significant.

The help of the researcher to fill out the survey also influenced participant's reporting of issues, as more robust participants (6 out of 7 -85%) reported issues than pre-frail (2 out of 7, 28.7%) and frail ones (4 out of 11, 36.4%) and only 1 robust participant received help from the researcher. Receiving assistance may reduce the number of comprehension and execution issues, and improve data quality.

We tested two tools (NEWS-A and LSA) which had not been investigated in detail in frail populations. To the best of our knowledge, only one study tried to adapt NEWS-A to a group of older adults, with conflicting results (17). In our sample, although NEWS-A was the longest tool used with most items to complete it was not the questionnaire with most issues. Participants considered it to have repetition of themes, which could have caused fatigue when answering the larger number of questions. Although overall feasible, an abbreviated version of the test should be chosen in further studies to improve data quality.

Documenting mobility and need of assistance in different spaces is vital information, especially in the setting of a restorative program, where patients' goal is returning home; and was obtained through the LSA. Although developed for older populations, this assessment had not been tested in frail and residential care patients in the current format. Participants were unsure if the questions were related to current mobility (after a long hospitalization period) as opposed to their previous mobility levels at home. In the rTCP setting, the use of this tool needs to be reformulated to better define patients' mobility and capture the changes in performance during rehabilitation.

Lastly, the field of geriatric and gerontology research is often seen as lacking visibility when compared to other fields (18). Involving medical students in a training program focused at improving geriatric research is vital for shaping their attitudes towards older people and their interest in this field.

In conclusion, the development of a comprehensive survey to assess multiple domains of geriatric assessment, frailty and neighbourhood perceptions entails substantial challenges. This study suggests that many geriatric tools need to be customized to specific settings and population of interest and implemented with lots of support, in order to maintain high rates of understanding and successful completion by frail older adults.

Conflicts of Interest Statement: BAM, HB, JD and NM have nothing to disclose. RV discloses that is the Medical Head of Service that holds medical governance of the TCP.

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Conflicts of Interest: Authors declare no conflict of interest.

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A multidisciplinary exploratory approach for investigating the experience of older adults attending hospital services

'A multidisciplinary exploratory approach for investigating the experience of older adults attending hospital services' was **submitted** for publication and is under review in the *Health Environments Research & Design Journal (HERD).*

The statement of authorship and paper (.pdf) follow over the page. Additional table(s) are available in 5.4 Supplementary material for Chapter 5.

5.1 Summary

Given that populations are ageing worldwide, it is expected that older adults with varying levels of frailty, mobility and independence will be major users of hospital facilities. The physical environment of the hospital plays an important role on the age-friendliness of this public space.

This exploratory, multidisciplinary pilot study investigated the relationship between the physical environment and the design of hospital spaces and older people's outpatient experience. Sixteen participants were recruited from a geriatric outpatient clinic at a metropolitan public hospital in Australia.

Participants were engaged in a mixed-method approach, consisting of a comprehensive geriatric survey, walking observation, semi-structured interview and an independent architectural audit. Several elements arising from the hospital environment were identified as facilitators or barriers for its utilisation and intrinsically related to participants' physical capacity. The following themes were identified: lighting, noise, seating, temperature, aesthetics, wayfinding and access and transportation.

Age-friendly hospital design needs to consider strategies to remove barriers for older adults of different capacities, thus reducing stress, promoting a sense of wellbeing and encouraging healthy ageing.

5.2 Statement of authorship

Statement of Authorship

Title of Paper	A multidisciplinary exploratory approach for investigating the experience of older adults attending hospital services
Publication Status	☒ Published ☒ ~~Submitted for Publication~~ ☐ Accepted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
Publication Details	~~Article submitted to Health Environments Research & Design Journal - HERD~~ Arakawa Martins, B., Barrie, H., Visvanathan, R., Daniel, L., Arakawa Martins, L., Ranasinghe, D., . . . Soebarto, V. (2020). A Multidisciplinary Exploratory Approach for Investigating the Experience of Older Adults Attending Hospital Services. HERD, 1-23. doi:10.1177/1937586720920858

Principal Author

Name of Principal Author (Candidate)	Beatriz Arakawa Martins		
Contribution to the Paper	Study design, constructed dabase, collected data, performed statistical analysis, wrote the manuscript and acted as corresponding author		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	07/11/2019

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Signature		Date	

5.3 Published article in the *Health Environments and Research Design Journal*

Research

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A Multidisciplinary Exploratory Approach for Investigating the Experience of Older Adults Attending Hospital Services

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Abstract

Background: The public areas of the hospital built environment have hardly been investigated for their age-friendliness. **Objective:** This exploratory, multidisciplinary pilot study investigates the relationship between the physical environment and design of hospital spaces and older people's outpatient experience. **Methods:** Sixteen participants were recruited from a geriatric Outpatient Clinic at a metropolitan public hospital in Australia. Participants were engaged in a concurrent mixed-method approach, comprising a comprehensive geriatric survey, walking observation, semi-structured interview and an independent architectural audit. **Results:** Several elements arising from the hospital environment were identified as facilitators and barriers for its utilization and intrinsically related to participants' physical capacity. **Discussion:** Age-friendly hospital design needs to consider strategies to remove barriers for older adults of different capacities, thus promoting healthy aging.

Keywords

hospital design, environment design, age-friendly hospital, frailty, mixed-method

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Hospital design is focused on the provision of rapid medical and surgical responses to acute conditions, often with younger patients or patients with a single disease presentation in mind. For older patients, particularly those with increasing comorbidities, disability, and frailty, navigating through this complex environment can add an extra challenge and can represent a barrier to accessing medical care (Wong et al., 2014). In the early 2000s, the World Health Organization (WHO, 2007) Age-Friendly Cities movement promoted age-friendly environments that fostered individuals' physical and mental capacity and removed barriers for individuals with reduced functional abilities. These barriers can include accessing complex built environments such as hospital facilities.

There is growing evidence of the influence of the environment on older adults disability (Beard et al., 2009), and in the maintenance of their individual intrinsic capacity, defined by all the physical and mental capacities of the individual (Beard et al., 2016). Frailty in older adults is a clinical syndrome characterized by a reduced physiological reserve and increase vulnerability to endogenous and exogenous stressors that lead to adverse health outcomes such as hospitalization and death (Fried et al., 2001). The clinical phenotype of frailty is characterized by reduced walking speed, exhaustion, reduced physical activity, weight loss, and reduced grip strength (Fried et al., 2001). Frailty syndrome has been associated with malnutrition, multiple comorbidities, increased risk of depression, and worse quality of life (Artaza-Artabe et al., 2016; Clegg et al., 2013; Soysal et al., 2017).

Given the global increase in life expectancy and the growing presence of multiple noncommunicable chronic conditions, older people will increasingly seek access to hospital facilities. In 2017–2018 in Australia, for example, 48% of hospital admission days (days of patient care provided in a hospital bed) and 33% of nonadmitted services (including consultations with specialists, allied health, nurses, and diagnostic procedures) were for patients over 65 years old (Australian Institute of Health and Welfare, 2018).

Hospitals are increasingly considering consumer needs and well-being when designing new builds, but it is not unusual for hospitals to be a mix of older buildings and newer redevelopments. While there have been studies describing how good hospital design can reduce patients' stress, reduce depressive symptoms, improve patient privacy and social support, and reduce spatial disorientation, these studies have most often focused on the inpatient or emergency department (Ulrich et al., 2008). Few studies have focused on the ambulatory and public areas of a hospital, such as the outpatient departments, diagnostic and imaging areas, corridors, surrounding car parks, and entrance areas. A literature review focused on ambulatory care settings has identified several improvements in patient outcomes associated with physical environment features such as improved access and wayfinding, enhanced waiting experience, privacy and communication, reduced patient anxiety, and reduced risk of infection (Gulwadi et al., 2009). This review however did not focus specifically on older adults, and their needs and experiences are expected to vary depending on their physical function. A checklist of perceived inpatient and outpatient hospital environment quality at Veteran Army hospitals has shown that several aspects of the physical environment are important for older adults, and include cleanliness, signage, seating, non-overcrowding, and privacy (LaVela et al., 2016). Additionally, partnering with consumers and including them in decision making relating to the design and quality of healthcare is essential and one of the eight standards defined within the Australian National Safety and Quality in Health Care Standards (ACSQHC, 2017).

The purpose of this research study is to examine frail versus nonfrail older individuals use of public hospital areas by comparing their wayfinding techniques, walking speed, and distance while navigating, along with their perceptions regarding lighting, noise, aesthetics, temperature, and seating. Using the strengths of a multidisciplinary team in the fields of built environment and design, social sciences, geriatrics and gerontology and computer sciences, the researchers were particularly interested in the relationship between the objectively assessed physical environment and design of the hospital and the older person's experience and behavior within this context.

Method

This study was a pilot observational mixed-model study, and combined a walking observation experience, a semi-structured interview, and a health survey. Complementing this analysis, an independent architectural audit of the main areas frequented by participants was performed.

Setting and Participants

The Queen Elizabeth Hospital (TQEH) is a 300-bed acute care teaching hospital servicing a catchment area of 250,000 South Australians, with 14.6% of its population aged 65 years and older (SA Health, 2013). The hospital is located approximately 6 km (3.7 miles) northwest of the Adelaide central business district and provides emergency, inpatient, and outpatient services. It has been progressively upgraded since its original inauguration in 1958. Healing gardens—regarded as pioneering therapeutic landscapes in Australia—were created during the redevelopment of some areas of the TQEH (Forbes, 2005). The hospital incorporates over 10 distinct buildings; the General and Outpatients Buildings being the oldest (constructed in 1958 and redeveloped in 1968–1972), while the Hospital Street and Ward Blocks (completed in 2005), North East Buildings (completed in 2009), and Rehabilitation and Allied Health Building (completed in 2013) are newer areas of the hospital (Figure 1).

Participants were conveniently sampled from the Aged Care & Extended Services (Geriatric Medicine) Outpatient clinics between January and June 2017. On appointment days, participants, identified by the attending geriatrician as eligible, were approached by the researcher for interest in participating in the research. Eligibility criteria were participants aged 65 years or older, the absence of active decompensated clinical conditions that prevented participation in the research, and a predicted second visit to the hospital. All scheduled patients at the outpatient clinic were consecutively evaluated by the geriatrician, while the recruiting researcher had no involvement in the clinical care to avoid selection bias. The final inclusion criteria were verified by the researcher: able to speak English and able to be mobile outside of their home (with or without assistance). Family members could participate to any part of the research if required by participants. Each participant received a reimbursement for their participation in the form of an AUD 50.00-gift voucher. The project obtained ethical review approval from the University of Adelaide Humans Research Ethics Committee (HREC, #2017-010) and the Central Adelaide Local Health Network The Queen Elizabeth Hospital HREC (#Q20161105).

Data Collection

Walking observation. The walking observation aim was to capture participants' experiences in the public areas of the hospital by following the participant on a typical appointment day (with minimum researcher interference). It was focused on observing participants' navigation through the space, identifying barriers and enablers to navigation and mobility, and any need for assistance. The walking observation was arranged by the participant and researcher in a second visit to the hospital after initial recruitment and started and ended at either the parking lot or main entrance, depending on the form of transportation to allow for full representation of participants' experience. Using scaled maps of the interior and exterior of the hospital buildings, a researcher took note of the participants' routes and actions (e.g., wayfinding activities, need for rest, and engagement with others) and the use of assistive devices. Participants were aware that they were being observed, and the researcher did minimum interference to the planned walk. When reaching private areas, the recoding of time and activities was stopped, and a meeting point was arranged between participant and researcher. Temperature and humidity indoors at the time of the walk were recorded (details in the built environment audit section). Using scaled drawings and floor plans of the site as a guide and recording time taken to complete the route allowed total walking distance (inside the building), and average walking speed to be calculated for each participant.

Semi-structured interview. A postobservation semi-structured interview was administered to obtain

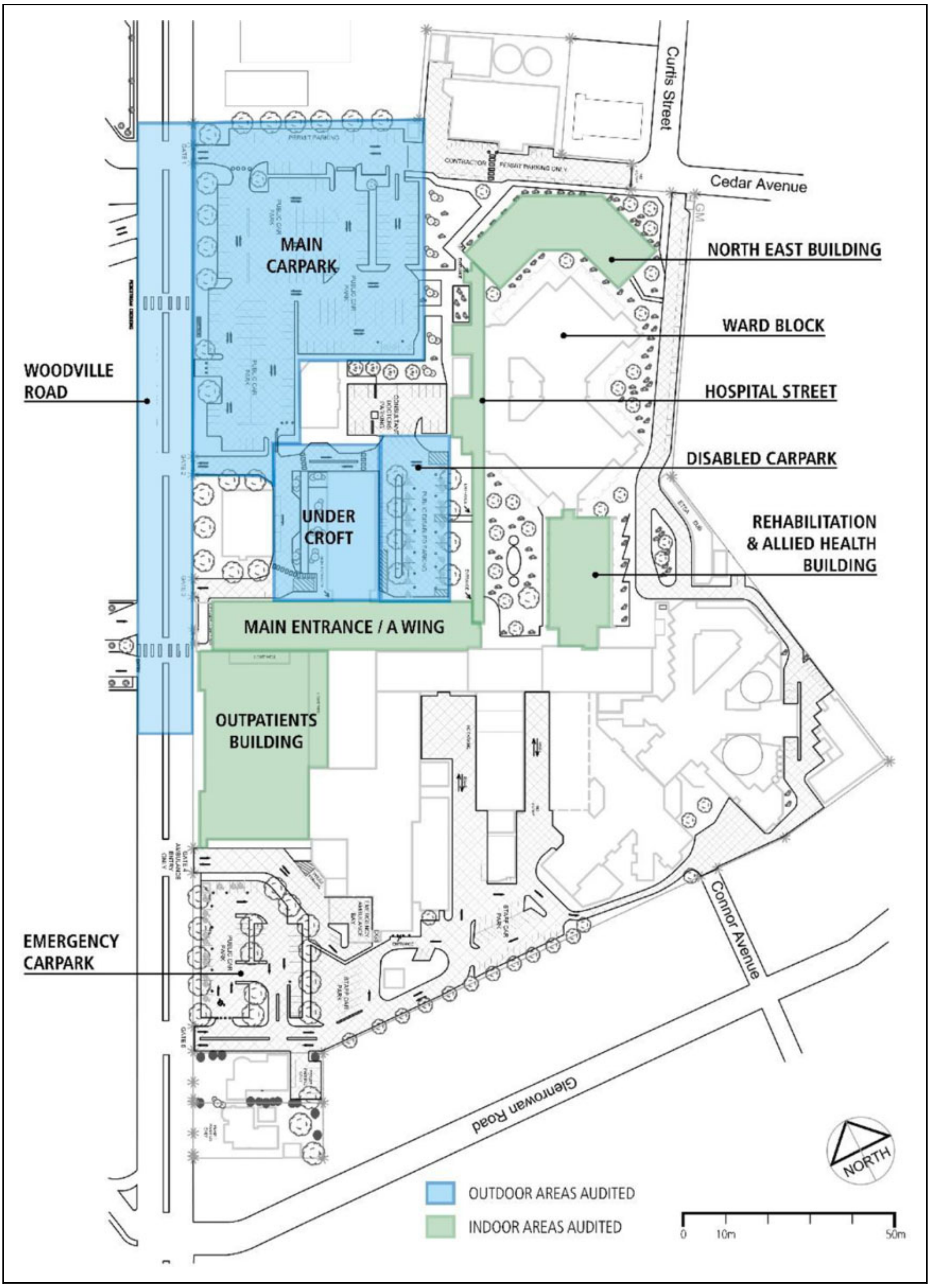

Figure 1. The Queen Elizabeth Hospital external and internal audit areas (map adapted from SA Health, Government of South Australia). *Note*. Blue and green areas denote outdoor and indoor areas audited, respectively.

insights about perceptions and experiences of participants' use of the hospital public spaces, reflecting specifically on the walking observation experience, but also incorporating their experiences of this environment more broadly. In order not to extend participants' time and tiredness in the

Table 1. Semi-Structured Interview Guide.

Question Theme	Questions
Route	Do you usually come alone or accompanied? How often do you go there/how many times have you been there? Do you always take the same route as you did today/yesterday? Could you tell us why you always take that route?
Driving	If the participant went by car to the premise – What can you tell us about the car parking? – If you could choose where you park, based on what aspect would you choose your car park spot? Other prompt questions included specific aspects such as distance to buildings, size of car park spot, surface, disability parking permit, use of pay machine, lighting at night, and safety.
Walking	If the participant walked to the premise – Could you tell us about your journey from your house to this building? – Is it easy to walk from your house to a destination?/Does anything bother you along the way? Other prompt questions included specific aspects such as footpaths, shade, trees, litter, cars along the way, crossing the street, safety.
Public transportation	If the person took a bus or train to the premise – Did you find that it is easy to walk to a transit stop (bus/train)? – What do you think about the bus stop (or train station)? – How easy is it to access or get on/off the bus or train? Other prompt questions include specific aspects such as time taken to reach a transit stop, time taken waiting for the bus/train, bus/train stop condition: shade, litter, seating, timetables.
Journey/ wayfinding	– Tell us about your journey from arriving point to the building – Was it easy to find the consultation room?/Did you ever get lost in the building? – What do you rely on to navigate through space? (prompts: signs, read maps, ask around) – What do you like or dislike about the hospital? Other prompt questions included a specific aspect such as resting areas, toilets, lighting, room temperature, noise.
Technology	Do you use technology to help you navigate through public spaces?

hospital, a visit to participants' home 24 hr after the visit to the hospital was arranged to conduct the interviews and took between 15 min and 1 hr to complete. Questions were developed by the research group, based on experience in qualitative design projects. Questions tried to prompt participants to reflect on several different aspects of the physical environment of the hospital. (Table 1)

Survey questionnaire. A customized survey, developed from a combination of validated clinical assessment tools of older adults' health, was implemented to provide a comprehensive geriatric assessment of study participants. This combination of validated questionnaires was previously tested for its feasibility and acceptability in an older and frail population (Arakawa Martins et al., 2018). The survey was distributed at the end of the walking observation experience and collected the next day at the interview; incomplete surveys were reviewed and completed with the help of the researcher.

Frailty was assessed using the FRAIL screen described by Morley et al. (2012), a 5-item scale, including five components: fatigue, resistance, ambulation, illnesses, and loss of weight. Scores range from 0 to 5, with 3–5 points representing frail, 1–2 prefrail and 0 robust health status. For all analyses, prefrail and robust participants were grouped into a nonfrail group.

Other tools used were the EuroQoL 5D-5L tool (Oppe et al., 2014) to capture older adults' quality of life and the Beacke's Physical Activity

Scale (Baecke et al., 1982), evaluating levels of physical activity. The Charlson's Comorbidity Index (CCI; Charlson et al., 1987) evaluated a list of comorbidities. The Mini-Nutritional Assessment Short Format (Kaiser et al., 2011) evaluated participants' nutritional status. The Geriatric Depression Scale with 4 items was chosen to screen for depressive symptoms, with a cutoff of 1 for a positive screen (Pocklington et al., 2016). The risk of cognitive impairment was evaluated through the short-form of the Informant Questionnaire on Cognitive Decline in the Elderly (Jansen et al., 2008; Jorm & Korten, 1988). The questionnaire also included questions about the number of prescribed medications, choice of transportation and other socio-demographical variables.

Built-environment audit. An audit tool was developed to assess whether the hospital indoor and outdoor areas met international, Australian and South-Australian age-friendly guidelines (Australian Local Government Association, "Age-friendly built environments: Opportunities for local government," 2006; Government of South Australia, 2012; WHO, 2007). An audit tool specific for the environment of health facilities (Black et al., 2006) and a local Age-friendly checklist developed by the Unley City Council, a member of the WHO's Age-friendly cities network (WHO, 2017) among other tools, were also reviewed and relevant items were incorporated (Table 2). Observations and measurements were conducted during three visits to the hospital complex (Figure 1), and covered five main areas visited by the participants: General Building (main entrance and A-wing), Outpatient Building (ground floor), Hospital Street (ground floor), North East Building (first floor, Oncology outpatient section) and Rehabilitation and Allied Health Building (ground floor). Noise levels in dB (A) were acquired using a Precision Sound Level Meter (type 2232, IEC 651 type 1, Bruel & Kjaer), capturing noise levels for 1 min. For the quantitative evaluation of lighting, illuminance levels, in lux, were measured using a digital lux tester (Model BN-2000LTE, National, Matsushita Electric Industrial Co., Osaka, Japan), and the brightness/luminance levels, in candela/m2, and were measured using a Luminance Meter 1o Digital (Minolta Camera Co., Tokyo, Japan). Temperature and relative humidity were acquired every 1 s, using a HOBO data logger by Onset (Model U12-013, Massachusetts, USA).

Analysis

Qualitative analysis. Responses from semi-structured interviews were analyzed by two researchers using a Qualitative Descriptive Design and data analysis approach (Colorafi & Evans, 2016). The researchers' written notes of the interviews and transcribed audio recordings were analyzed using NVivo (Version 12; QSR International 2017). This process was staged, iterative, and guided by two other researchers, with extensive experience in qualitative interviews. The description of findings in this article centers on the analysis at category and theme levels, supplemented by direct quotations from researchers' notes or participants' responses, to illustrate pertinent themes and issues.

Statistical analysis. Participants' sociodemographic and health variables, as well as objective walking observation data, were summarized as mean and standard deviation (for continuous variables) and as percentages or ratios (for categorical variables), and divided according to their frailty level, using IBM SPSS Statistics for Windows (Version 24.0, IBM Corp., Armonk, NY). Differences between frail and nonfrail groups was assessed using two-tailed independent samples *t*-test for continuous variables and χ^2 test for categorical variables. Although a small sample size, all variables showed acceptable normality distribution on visual Q-Q plots and statistical significance on Shapiro–Wilk test, and for this instance, parametric tests were chosen. This information was added to the statistical analysis section (page 7, line 146).

Results

Study Participants

Of the 20 participants who agreed to participate, 16 completed all components of the study. The reasons for noncompletion included a change in

Table 2. Built Environment Audit Measurements, Recommendations, and References.

Theme	Measurements or Conditions Analyzed	Evaluation Basis Used	Standard References Used	Summary of Findings	Recommendation
Lighting	Illuminance (lux)	Sufficiently lit: more than 50 lux for simple orientation for short visits or more than 100 lux for working spaces where simple visual tasks are performed Insufficiently lit: less than 50 lux for simple orientation for short visits or less than 100 lux for working spaces where simple visual tasks are performed	Recommended illuminance levels—IESNA Lighting Handbook, (Grondzik, 2010)	• Sufficiently lit throughout most of observed areas • Insufficiently lit in isolated corridor areas	• Surface treatments (colors and texture) for walls, floors, and ceilings must be considered in addition to maintaining adequate lighting to avoid glare through all the spaces.
	Luminance or brightness ratio for flooring surfaces (cd/m^2)	Glare: Luminance ratio for flooring surfaces and adjacent surroundings is more than 1 to one third No glare: Luminance ratio for flooring surfaces and adjacent surroundings is less than 1 to one third	Recommended maximum luminance ratios between task and adjacent surroundings—IESNA Lighting Handbook, (Grondzik, 2010)	• Glare observed in all analyzed areas' floorings, except for the Outpatients Building and General Building (7th floor)	• The surface treatments (colors and texture) for walls, floors, and ceilings should avoid glare. Reflective surfaces should be avoided particularly for areas within the user's (staff and patients) direct line of sight.
Noise	Sound level (dB(A))	Very faint: between 0 and 20 dB(A) Faint: between 20 and 40 dB(A) Moderate: between 40 and 60 dB(A) Loud: between 60 and 80 dB(A)	Sound level subjective evaluation according (Egan et al., 1989)	• All observed areas' sound levels are moderate noise levels, commonly expected for daily indoor activities.	• Consider grouping and confining noisy functional areas together to minimize noise "spill" into quieter functioning areas. • Use materials with effective Sound Reduction Index to minimize external noise or noise from other rooms and use absorptive materials strategically to reduce reflective noise within a space.
Seating	Presence and number of benches or seating	No benches or seating/some benches or seating	Street-Audit Instrument—ELANE study (modified version) (Etman et al., 2014; Prins et al., 2014)	• Some benches or seating provided, with most seating located in specific waiting areas	• Adequate number of seating must be provided to ensure that older people have somewhere to rest while waiting or during longer routes. • Ergonomically designed seating specifically to enable older people to sit comfortably, sit down safely, and stand up easily
	Design of benches or seats	Height of the benches/seats, presence/absence of arm rests, and seating layout		• Benches/seats are too low and/or do not have armrests. • No space to place walking aids and assistive devices while seated	• The design of the seats must allow older people to sit comfortably and be able to sit down and stand up easily. • Enough space around seating areas must be destined for accommodating walking aids and assistive devices while patients are sited.
	Distance of benches or seating	Irregular/regular		• Irregular seating arrangements throughout the hospital • Regular seating in Rehabilitation and Allied Health Building	• Every consultation and examination room must provide adequate seating in the waiting room. • Seating must be provided at least every 10 m in corridors.
	Maintenance of seating	Insufficient/reasonable/sufficient/not applicable		• Reasonable throughout the hospital • Sufficient in Rehabilitation and Allied Health Building	• Seating must be regularly cleaned and maintained.

(continued)

Table 2. (continued)

Theme	Measurements or Conditions Analyzed	Evaluation Basis Used	Standard References Used	Summary of Findings	Recommendation
Thermal environment	Temperature (°C)	Acceptable: between 21 °C and 24 °C Not acceptable: less than 21 °C and more than 24 °C	Acceptable indoor temperature and relative humidity according to Ventilation of Health Care Facilities Standards (ANSI/ ASHRAE/ASHE Standard 170-2013)	• Acceptable in all areas	• Avoid extreme temperature ranges by controlling temperatures centrally • Avoid significant temperature changes from one space to the other to accommodate older people's differences in thermoregulation • Controlling air speed around entrances to avoid wind tunnel effects
	Relative humidity (%)	Acceptable: less or equal to 60% Not acceptable: more than 60%		• Acceptable in all areas	
Aesthetics and design	Overall aesthetic impression	Pleasant/neutral/unpleasant Provide written description	NA	• Unpleasant impression in older areas and main entrance outside area • Pleasant impression for new areas and Northeast Building entrance	• Consistency in design aesthetic or design elements throughout facility • Notable architectural features are useful as a point of reference. • Include green spaces within and outside the building, which are accessible visually and/or physically. • Consider including architectural elements at human scale.
	Litter (presence and quantity)	A lot/some/none	Street-Audit Instrument—ELANE study (modified version) (Etman et al., 2014; Prins et al., 2014)	• None in indoor areas • Some in outdoor areas	
	Vandalism (presence and quantity)	A lot/some/none		• None in indoor and outdoor areas	
	Graffiti (presence and quantity)	A lot/some/none		• None in indoor and outdoor areas	
Wayfinding and navigation strategies	Signage information hierarchy	Adequate Inadequate Provide written description	NA	• Inadequate, except for corridor connecting the old building to the new building on the ground floor	• The location/position and lettering used for signage must be in such a way that the signs can be seen and read easily by older people. • The use of smart technologies on mobile devices may be useful in some circumstances, but they should not replace the presence of humans to provide assistance to older people.
	Signage lettering and background color	Adequate: Dark lettering on light background Inadequate: Different combinations of colors other than dark lettering on light background	Australasian Health Facility Guidelines (2015)	• Inadequate, except for corridor connecting the old building to the new building on the ground floor	

(continued)

Table 2. (continued)

Theme	Measurements or Conditions Analyzed	Evaluation Basis Used	Standard References Used	Summary of Findings	Recommendation
Access and transportation	Type of path and consistency	Pavement/no path/path forms useful and direct route/ path is disjointed Provide written description	NA	• Disjointed paths, not always clearly marked	• Provide great number of disability car parking, closer to the main entrance. • Consider shading the car park and walkway from the car park to the destination. • If the car park cannot be located closer to the entrance or main destination, provide seating so that older people can rest while walking between the car park and the main destination. • Provide adequate lighting on car park for nighttime usage • Ensure that walkways or footpaths have even surfaces to avoid higher risks of falls.
	Slope of path	Mostly level/slight gradient/steep (difficult to walk)	"Assessment of the local Outdoor Environment for falling over" (modified version; Curl et al., 2016)	• Mostly leveled or with slight gradient	
	Path condition and smoothness	Poor/moderate/good/under repair		• Poor	
	Path material	Tarmac/Black surfacing (e.g., car park)/paving blocks (small)/paving slabs (large)/tactile paving/setts/ cobbles/loose gravel mud/earth/unpaved/grass/ other		• Varied surfaces, forming heterogeneous routes	
	Path width	Suitable for only one person/suitable for two people/ suitable for more than two people		• Suitable for two people to walk abreast, or for one person to navigate easily using a walking aid	
	Path temporary obstructions	Leaves/leaf litter/seedpods/gumnuts/sitting water puddles/dustbins/litter/scaffolding/construction/ other		• Signboards	
	Steps and handrails	Height and number of steps/presence of and height of handrail/consistency of height and depth of steps and handrail		• No handrails	
	Path maintenance	Insufficient (poor)/reasonable/sufficient/not applicable	Street-Audit Instrument—ELANE study (modified version; Etman et al., 2014)	• Poor or reasonable	

Note. IESNA = Illuminating Engineering Society of North America; ELANE Study = Elderly and Their Neighborhood Study (Etman et al., 2014; Prins et al., 2014).

Table 3. Baseline Characteristics.

Baseline Characteristics	Total (n = 16)	Nonfrail [a] (n = 10), Robust n = 2 (12.5%), Prefrail n = 8 (50%)	Frail [a] (n = 6, 37.5%)	p Value
FRAIL screen—mean (*SD*)	2.2 (1.51)	1.2 (0.79)	3.8 (0.75)	<0.001
Age—mean (*SD*)	80.36 (7.93)	80.3 (8.76)	80.5 (7.48)	0.955
Gender (female)	10 (62.5)	5 (50)	5 (83.3)	0.307
Education (higher than secondary school)	6 (37.5)	4 (40)	2 (33.3)	1.000
Marital status (married)	8 (50)	5 (50)	3 (50)	1.000
Residential status (lives alone)	6 (37.5)	5 (50)	1 (16.7)	0.307
Current driver's license	7 (43.7)	4 (40)	3 (50)	1.000
Preferred mode of transportation				1.000
Car (as a driver)	7 (43.8)	4 (40)	3 (50)	
Car (as a passenger)	8 (50)	5 (50)	3 (50)	
Bus/train	1 (6.3)	1 (10)	0 (0)	
Using assistive device	4 (25)	3 (30)	1 (16.7)	1.000
Nutritional assessment [b]				
Normal	4 (25)	3 (30)	1 (16.7)	1.000
At risk of malnutrition	12 (75)	7 (70)	5 (83.3)	
Malnourished	0 (0)	0 (0)	0 (0)	
Number of prescribed medications	5.4 (3.5)	4.6 (3.8)	6.6 (2.9)	0.347
Charlson Comorbidities Index				0.332
≤3 low mortality risk	3 (18.8)	3 (30)	0 (0)	
4–5 moderate mortality risk	2 (12.5)	1 (10)	1 (16.7)	
≥6 high mortality risk	11 (68.8)	6 (60)	5 (83.3)	
Geriatric Depression Scale (range 0–4)				0.007
0 points	7 (46.7)	7 (77.8)	0 (0)	
≥1 point	8 (53.3)	2 (22.2)	6 (100)	
IQCODE (positive screen) [†]	6 (37.5)	2 (20)	4 (66.7)	0.118
Physical activity level (range 3–15) [‡]	6.68 (1.01)	6.67 (0.9)	6.69 (1.26)	0.967
Quality of life score (0–1) [c]	0.68 (0.16)	0.74 (0.16)	0.56 (0.04)	0.032
Quality of life VAS (0–100) [c]	64.38 (22.2)	70 (24)	55 (16.4)	0.201

[a] Frail assessment FRAIL screen: Frail (3–5 points), nonfrail (0–2 points), combining robust and prefrail participants. [b] At risk of malnutrition: Mini-nutritional Assessment between 8 and 11 points malnourished below 8 points, and normal nutritional screen above 11 points. [c] EuroQoL—quality of life assessment five domains and five levels, and Visual-Analytical Scale (VAS). [†] IQCODE: Informant Questionnaire Cognitive Decline in the Elderly (range 0–16), cutoff > 3.31 for positive screen, [‡] Physical Activity Level was assessed using the Baecke's Physical activity questionnaire, ranging from 3 to 15 points.

health status (n = 1) and time constraints (n = 3). As such, the following analyses are reported for 16 participants.

Sociodemographic and clinical characteristics of the participants are presented in Table 3. Participants' mean age was 80 years, ranging from 69 to 91 years, with 62.5% (10) female. Six (37.5%) participants were classified as frail, eight (50%) prefrail and two (12.5%) robust. Multimorbidity was highly prevalent in this group of participants, with 68.8% of participants with a CCI score above 6. Frail participants had a significant worse self-rated quality of life score (p = .032) and more positive screening for depression (p = .007), factors strongly associated with frailty (Kojima et al., 2016; Soysal et al., 2017; Table 3).

Walking Observation

No statistical differences were found between frail and nonfrail participants regarding the total walking distance during the observation or walking speed, with mean values of 269.1 m (*SD* = 150.9) (882.9 ft., *SD* = 495.1) and 0.43m/s (*SD* = 0.2) (1.41 ft./s, *SD* = 0.6), respectively. On average, participants stopped 4.25

Table 4. Walking Observation by Frailty Status.

Walking Observation Variables	Total (n = 16)	Nonfrail [a] (n = 10), Robust n = 2 (12.5%), Prefrail n = 8 (50%)	Frail [a] (n = 6, 37.5%	p Value
Total walking distance—mean (*SD*)—m	269.14 (150.9)	290.57 (175.9)	233.44 (100.8)	0.483
Average walking speed—mean (*SD*)—m/s	0.43 (0.2)	0.48 (0.3)	0.34 (0.2)	0.227
Accompanied by family member—count (%)	10 (62.5)	6 (60)	4 (66.7)	1.000
Number of destinations	1.2 (0.6)	1.3 (0.7)	1.0 (0)	0.347
Number of stops—mean (*SD*)	4.25 (2.8)	5.1 (3.3)	2.8 (0.8)	0.122
Asked for directions- count (%)	10 (62.5)	6 (60)	4 (66.7)	1.000
Looked around for directions—count (%)	9 (56.3)	6 (60)	3 (50)	1.000
Looked for signage—count (%)	4 (25)	4 (40)	0 (0)	0.234
Directions from carer—count (%)	6 (37.5)	4 (40)	2 (33.3)	1.000
Took a rest—count (%)	8 (50)	7 (70)	1 (16.7)	0.119

[a] Frail assessment FRAIL Screen: Frail (3-5 points), Non-frail (0-2 points), combining robust and pre-frail participants.

times during their walk for different reasons, as described in Table 4. Participants used varied strategies for wayfinding. Of the 30 wayfinding events recorded, 10 related to asking for directions while walking, 9 were looking around for directions, 6 related to use of signage, and 6 listening to directions from their carer. During their visits/walks, 10 participants (62.5%) took a rest during their walk, one being frail, five prefrail, and two robust. (Table 4 and Appendix Table A1 for imperial system) When participants' actions are mapped, "hot spot" areas for wayfinding actions and stops are identified. Two end-corridor corners and in front of a round column in the Main Building were common areas of stops or looking for directions (Supplementary Figure 1). In the Main Building upper floors, a hot spot at the end corridor coming out of the elevators was identified (Supplementary Figure 1).

Among frail participants (n = 6), additional strategies were taken to mitigate the impact of the hospital visit: Family members accompanied four participants, and strategies were taken to reduce walking distance either by being dropped off at the entrance door, or by parking their car in the disabled or emergency car park, which was located closer to the Outpatient Building entrance.

Theme Analysis and Built Environment Audit

Participants identified several issues related to the physical environment of the hospital that could be perceived as facilitators and barriers for its utilization. (Appendix Figure A1).

Lighting. Participants' perception in the Outpatients Building was that it was dull, with dark corridors. These characteristics were identified as especially prejudicial if a person had any reduction in their visual capacity: "If a person has a bit of trouble with their eyes, it might not be adequate" (H020, female, 71–74 years old). A clear distinction was made between the lighting in the old and new areas of the hospital (General and Outpatient Buildings vs. North East, Rehabilitation and Allied Health, and Hospital Street). Participants referred to the new areas of the hospital as "brighter" than the older areas (Figure 2). Opinions between frail and nonfrail participants were similar, and participants did not mention any issues with glare from reflective surfaces interfering with their wayfinding.

> *"If a person has a bit of trouble with their eyes, it might not be adequate".*

The built environment audit reported indirect glare as a potential issue in the main entrance, with lighting reflecting off the laminated flooring. In this area, luminance ratios between reflecting flooring areas and adjacent surroundings reached 44 to 4 cd/m2, exceeding the 1 to one third recommended maximum luminance ratio between task surfaces and adjacent

Figure 2. Differences in lighting in the corridors of the new sections of the hospital (photo on the left, Hospital Street, first floor) and old area of the hospital (photo on the right, Outpatients building corridor, ground floor).

surroundings (Grondzik, 2010). Potential indirect glare was also noted in the Hospital Street and the Rehabilitation Building flooring. In addition, although no glare was observed at the times of the visits, the audit considered it might occur on sunny days in the North East Building areas because of the large areas of glazing.

The built environment audit revealed varied indoor illumination levels and related issues. The main entrance and corridors in Wing A of the General Building presented an average illuminance of 226.6 lux (range 122–319 lux). The Outpatients Building and Hospital Street were considered mostly sufficiently lit, with average illuminance of 224 lux and 463 lux, respectively. However, both areas presented isolated corridor areas with illuminance levels as low as 37 lux. Finally, the Rehabilitation & Allied Health Building and the North East Building were considered sufficiently lit (average of 1,032 lux and 274 lux, respectively). Please see Table 2 for guideline recommendations.

Noise. Although the majority of participants (10 out of 16 participants) did not have any concerns about noise levels, frail participants were more likely to consider the visited areas to be noisy than nonfrail participants. It was interesting to note that participants sometimes associated increased noise levels to poor architectural design. For example, one participant felt that the fact that seats were too close to one another and far from the doctor's office in a specific waiting area increased the noise level (H02, female, 71–75 years old).

Twenty-two location points within the audited indoor areas were measured for noise levels during one single visit to the hospital between 10 a.m. and 12.30 p.m., compatible with the time of the walking observation visits. The noise levels in the main entrance and A-Wing ranged from 53.1 to 57.3 dB(A), Outpatients Buildings (ground floor) from 44.0 to 59.8 dB(A), Hospital Street from 50.8 to 59.6 dB(A), and the North East Building first floor noise levels from 38.8 to 50.0 dB(A). All observed areas' sound levels are moderate noise levels (between 40 and 60 dB), commonly expected for daily indoor activities (Egan et al., 1989).

Seating. Eight participants (50%) referred to the lack of seating in different areas of the hospital and how that affected their experience. Participants reported that both old (General and Outpatient Buildings) and new areas of the hospital (North East, Rehabilitation and Allied Health and Hospital Street) needed more seating and that people had to lean on the retaining wall, stand, or "wander around until you've found a place to sit" (H020, female, 71–75 years old). Prefrail and frail participants reported specific seating issues at Hospital Street: ". . . I wasn't feeling very well, and it was a long way to the main entrance and [. . .] there wasn't a seat [. . .], so I just leaned" (H01, female, 81–85 years old), and at the outside the main entrance "quite often, I've just sat on the retaining wall" (H014, female, 81–85 years old). One participant raised a concern that in some waiting areas, seats were too close together, and corridors could become obstructed by walking aids (H02, female, 71–75 years old). Although the built environment audit did not look specifically for this type of issue, the 2014 Guidelines for Design and Construction of Hospital and Outpatients Facilities require that public areas in outpatient facilities provide readily accessible wheelchair storage, but there is no specific mention to walking aids (Facility Guidelines Institute, 2014).

[You have to] "wander around until you've found a place to sit"

". . . I wasn't feeling very well, and it was a long way to the main entrance and [. . .] there wasn't a seat [. . .], so I just leaned".

The audit of seating and seating areas was congruent with participants' comments. The areas throughout the hospital were found to have irregular seating arrangements, with most seating located in specific waiting areas and not along the corridors. The Hospital Street had groups of approximately 5–8 seats separated by distances of 30–40 m (98.5–131.2 ft). The maintenance of the seating in the corridors and waiting rooms was considered reasonable by the audit, with fabric chairs stained but not broken. The newly constructed Rehabilitation/Physio area in the new building, on the other hand, presented seating with regular distances from each other, including outside of lifts and toilets, all with sufficient maintenance.

Temperature. Overall, the temperature inside the hospital was considered adequate, with the majority of participants feeling comfortable, and no differences between frail and nonfrail groups. Only four participants perceived the room temperature to be cold in specific areas of the hospital (ward, waiting rooms, at CT machine, and ED).

The built environment audit revealed that outdoor areas had little protection from wind and direct sun, with windy and hot conditions, especially likely in the car park areas. A strong wind tunnel effect was experienced around the main entrance of the hospital. The Hospital Street was noticeably warmer than the Outpatient area due to direct sun exposure, whereas the Outpatients sections in the new building of the hospital were found to be cooler, even with mild to warm outdoor conditions. The average indoor temperature and relative humidity recorded in the Outpatients building was 22.37 °C (20.66–24.26 °C) and 47.8% (37.6–55.9%) respectively; Main Building 22.79 °C (20.47–24.26 °C) and 48.4% (35.1–90.2%) and in the Hospital Street, North East Building and Allied Health Building it was 24.40 °C (23.32–26.43 °C) and 51.3% (46.2–55.3%). Please see Table 2 for guideline recommendations.

Aesthetics and design. Participants' overall perceptions of the hospital design were apparent when comparing the old (Main and Outpatient Buildings) and new sections (Rehabilitation and North East Buildings, and Hospital Street). The Main and Outpatient building was described as "looking pretty tired" (H04, female, 71–75 years old) and "dull and closed" (H012, female, 71–75 years old). Participants stated the need for the hospital to be renovated. The new areas of the hospital, on the other hand, were described as having "brighter lighting" with access to a garden from the ward section. The presence of windows with views to the outside brought "warm and nice" feelings to one participant, who felt that it was "a pleasant" area to be in, despite being nervous about her treatment (H02, female, 71–75 years old). Another patient related a good inpatient experience associated with the view of the garden from her room (H07, female, 91–95 years old).

The audit also revealed a considerable contrast between the older indoor areas and the newly constructed environments. While the older areas were reported as relatively outdated and worn, overfilled with furniture and equipment, the newer areas were described as more pleasant aesthetically, well presented and maintained. No litter, vandalism, or graffiti was noted in and of the indoor spaces. The main entrance outside area was regarded as poorly maintained; however, the outdoor area near the North-east Building entrance was found to be better maintained. No dog waste, vandalism, or graffiti was noted in any of the outdoor hospital areas, but some litter was observed.

Wayfinding and navigation strategies. Participants were asked about the routes taken to get to the appointment within the hospital. The majority of participants (15 of 16) reported being frequent and longtime users of the hospital (median of 5.5 years, range from 1 to 30 years) and reported familiarity with the route taken to reach the specific clinic or diagnostic department, describing it as the "quickest", "easier," and "straight." All participants reported that their first strategy for wayfinding was asking for directions, either to staff or to volunteers, with only one participant reporting looking for signage as well as asking for directions (H020, female, 71–75 years old). One participant self-identified as having difficulties with wayfinding situations (H019, female, 91–95 years) and found being accompanied by her husband or asking to be escorted by a volunteer was one of the strategies when arriving at the hospital.

Although expressing familiarity with the route and being long-term users of the hospital, most participants (9 of 16) reported one or more episodes of getting lost, with a higher proportion of frail participants recollecting episodes of being lost (66.7%) than nonfrail participants (40%). These nine participants also stated that they found issues with the number of signs and how signage made it confusing to get to the correct destinations. One participant reported that the fact that all passages "looked the same" made it difficult to tell whether they were in the correct area (H20, female, 71–75 years old). On the other hand, participants who usually went to the hospital accompanied by family members (7 of 16 participants) stated positive experiences when trying to find their way. The reasons for the positive experiences included family members guiding them, asking for directions from the hospital volunteers, and familiarity with the route.

The independent environmental audit also covered wayfinding and safety. For outdoor areas, although road-crossing aids (zebra crossing) were observed, the volume of pedestrians crossing the vehicular entry to the car park was considered a potential risk factor. Likewise, the researchers also identified potential risk factors in the area around the hospital, such as poor signage for vehicular access to car park from the road and poor signage to guide visitors from the car park to the main entrance of the hospital. Signage, in general, was for vehicular traffic control and not to assist pedestrian wayfinding (Figure 3).

The audit also evaluated the existing signage inside the hospital buildings. In the main entrance, signage was present but showed little clear information hierarchy considered important to wayfinding (Martins & de Melo, 2014). Signage in the same area of the hospital used different sizes of the lettering for information of the same level of hierarchy and had a mix of signs, only some with the recommended dark lettering on white background (Australasian Health Facility Guidelines, 2015). Other areas, such as outpatient sections in the old and new buildings, displayed insufficient and inadequate signage, demonstrated by the use of "informal" additional signage in some areas (Table 2). Adequate and clear signage was only observed in the corridor connecting the old building to the new building on the ground floor, with considerably less informal signage/information.

Figure 3. Signage for vehicular access to the car park (disabled parking, left-hand side) and pedestrians for main entrance (left-hand side) and the emergency department (right-hand side)

Access and transportation issues. The use of the car park presented a significant concern for the majority of participants, with several issues raised. Most participants reported a lack of parking places within the hospital grounds; the surface of the car park was considered to be "uneven" (H04, female, 71–75 years old) and "wobbly" (H01, female, 81–85 years old), and participants related issues with their mobility particularly increased feelings of unsafety while walking through the car park. One participant stated, "I've got to be looking down all the time because I'm so frightened of walking, and before you know it, you have a car coming straight in front of you" (H014, female, 81–85 years old).

"I've got to be looking down all the time because I'm so frightened of walking, and before you know it, you have a car coming straight in front of you".

Family members mentioned that aspects of the car park influenced how they planned their trip to the hospital. One family member mentioned that due to the car park's uneven surface, they would "swing in, unload, and then find a car park" (H013, male, 71–75 years old). Another said they would prefer to take a taxi because the taxi could drop the participant off at the entrance of the hospital, instead of walking the distance from the car park (H012, female, 76–80 years old).

Nevertheless, participants also described positive aspects about the use of car parks. Four participants (out of 16) used the disabled car parking areas of the hospital. The size of the disabled car parks was considered wide enough to allow the car door to open freely, and there were usually available places. It is important to note that the area where the disabled car parks were located is separate from the main car park and closer to the main entrance of the hospital (see Figure 1).

The built environment audit evaluated pedestrian access throughout the main car park (Figure 4). The pedestrian routes through the car park and around to the entrances were not marked. Most paths were leveled or presented only slight gradients; however, sloping paths to

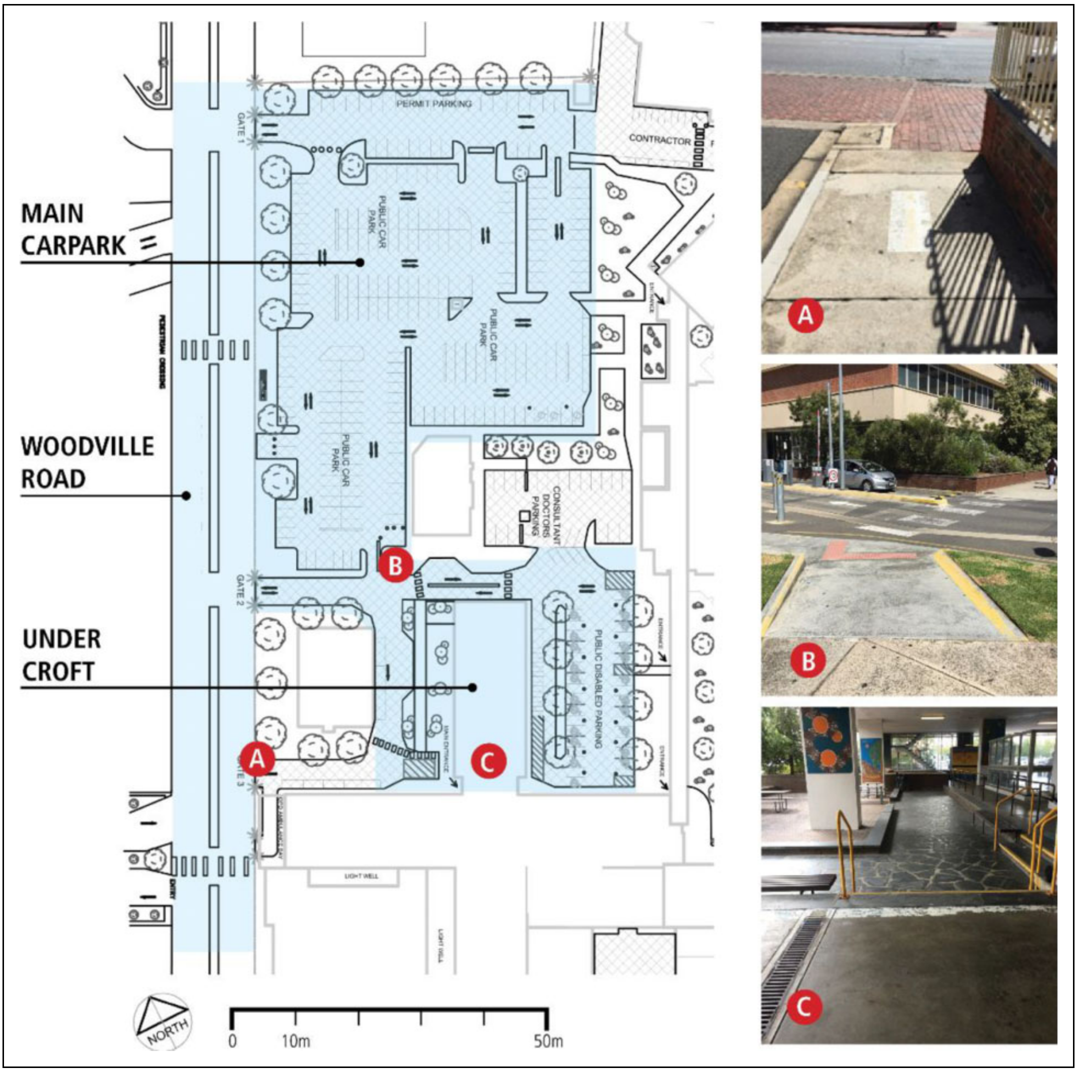

Figure 4. Main car park and entrance pavements. (A) Uneven and sloped pavement adjacent to access road, (B) surface change at car park access from main building, (C) surface and level change at the hospital main entrance undercroft.

the access road crossings (e.g., to/from the accessible parking area) had no handrails, potentially increasing the risk of falls. It was also noted that varied surfaces were used for paving (e.g., bitumen, concrete pavement, and brick pavers), forming heterogeneous routes to and from the hospital. A café signboard near the main entrance was also considered an issue, representing a permanent path obstruction. Path maintenance was considered between "poor" in some places and "reasonable" in others, with some raised concrete paving, edges observed, which could increase the chance of falls. The width of the paths was considered suitable for two people to walk abreast, or for one person to navigate easily using a walking aid, scooter, or wheelchair.

Use of technology. The use of technology for navigation through public spaces was a specific prompt included in our interview. Majority of the participants stated that they were not used to using technology to navigate through spaces but could be possibly helpful when navigating a new place.

Discussion

This study found that several aspects of the hospital environment influenced the access and use of complex hospital public spaces by older adults. This study revealed that features of the environment, such as seating, the aesthetics, and design, as well as wayfinding and transportation-related issues, can act as barriers or enablers when accessing and using a hospital as an outpatient.

Our research resulted in several significant findings as well as some recommendations to specific design issues based on architectural audit as well as participants' experiences (Table 2). First, our findings suggest that identified hospital environment issues could be related to individuals' limited physical capacities (e.g., sensory, mobility, cognition or vitality). As an example, frail participants in this study identified a lack of seating in specific areas of the hospital, and this could be related to symptoms of fatigue and lower walking speed, common in the frailty syndrome, making them at increased need for this environmental feature than nonfrail participants. Additionally, a higher proportion of frail participants had episodes of being lost than nonfrail participants. Family members had specific strategies to reduce their walking time and accompany patients to mitigate some of these issues. These findings illustrate how environmental features interact with the individual's intrinsic capacity (the composite of all physical and mental capacities) and determine her or his ability to function independently. This relationship between the individual and the environment is determinant for achieving healthy aging, as defined by the WHO (2015). One of WHO's proposed strategies to help older adults achieve healthy aging and optimize their functional abilities involves removing barriers to participation in public spaces, with hospital spaces being of critical importance for older people.

Second, the aesthetics and overall building design were deemed important by participants and influenced their experience at the hospital by creating better satisfaction with inpatient and outpatient healthcare provided. More attention has recently been given to the building, and room design of residential homes for older adults "aging in place," showing these well-designed spaces can generate positive experiences and improve their sense of place (Andersson, 2011). Recent hospital design surveys have also identified that building aesthetics, spatial–physical comfort, and green spaces are elements crucial to older adults (LaVela et al., 2016).

Finally, navigating through parking lots, public areas, waiting rooms, and hallways in a health facility is recognized as a particular source of anxiety by patients, visitors, and staff (Ulrich et al., 2004). Even though participants in this study reported being longtime users of the hospital, this familiarity still did not allow them to feel comfortable navigating the hospital without the aid of staff, volunteers, or family members. Wayfinding design and systems, such as appropriate floor planning and environmental cues, are of increased importance in complex spaces such as large healthcare facilities like the case study of this investigation. Wayfinding features have often been overlooked in hospital architectural planning (Devlin, 2014). Current evidence shows that symmetry of layout, repetition of architectural elements, and complexity of circulation can be a disadvantage to wayfinding strategies in healthy adults and older adults (Tao et al., 2018). When considering environmental cues inside buildings, several elements have been shown of importance to increasing wayfinding, for example, how destinations are named, the density and hierarchy of signage, and issues with context, placement, and visibility (Devlin, 2014). In addition to the challenges arising from the physical environment, age-related changes in navigation strategies are found in healthy older adults, and include difficulties in switching from using landmarks as a point of reference (an allocentric strategy) to following a familiar route, using the memory of body position and orientation (an egocentric strategy; Harris & Wolbers, 2014).

In this study, older people were more likely to rely on others (staff, volunteers, carers, and family members) for assistance with wayfinding than using other environmental cues or landmarks.

This is consistent with previous findings in older adults' strategies for wayfinding in community settings (Marquez et al., 2017), where transit officials, police, family, and friends were trusted sources of information in wayfinding. This reliance on trusted sources advocates for keeping the "person-to-person" assistance in modern complex circulations public spaces in order to promote the age-friendliness of these spaces rather than relying on smart technologies, such as smart boards, maps, or phone apps, for wayfinding.

Strengths and limitations. This study has several strengths. This study was a multidisciplinary collaborative effort by professionals within medicine, geography, and architecture to develop a new interdisciplinary methodology to investigate appropriate and age-friendly public spaces for older adults. A mixed-method approach evaluated older adults' experiences and perceptions contrasted with an independent built environment audit, as well as capturing individuals' intrinsic capacity through validated clinical tools. Additionally, the study sample included a higher proportion of participants with frailty, multiple comorbidities, and mobility issues, a group often underrepresented in clinical research (Arakawa Martins et al., 2018).

However, some limitations can also be pointed out. This study was limited to a small convenience sample of patients that attended the geriatric outpatient clinic in one hospital setting, and this limited the walking observation experiences to specific public areas of this hospital, and selection bias cannot be excluded. Additionally, for the same reason, it is not possible to guarantee an ethnically representative sample of Australians. Other participants, if recruited from other hospital clinics or departments and the inclusion of non-English speaking participants, could provide increased diversity of responses and participation and entail more generalizability.

Conclusion

In conclusion, this exploratory multidisciplinary research has investigated aspects of the environment that are considered important for older adults and identified how these perceptions might be linked to their intrinsic capacities. As proposed by the Age-friendly cities guidelines (WHO, 2017), hospitals need to be designed to be accessible and inclusive to older adults, and special efforts need to be made to remove barriers for individuals with decreased intrinsic capacity. The hospital setting in this study is currently undergoing planning for redevelopment, and therefore, this research is timely and could contribute to planning and design for the new redevelopment while providing information for consideration concerning the maintenance of the older buildings. Future research should investigate how specific environmental aspects detected, such as glare, lighting or noise influence on wayfinding strategies, and the potential impact of these environmental characteristics on older person's well-being and health status in order to guide effectively age-friendly designs.

Implications for Practice

- Older adults are frequent users of hospitals as outpatients, and their experiences in the hospital are often overlooked.
- Patients' interview revealed that adequate lighting, noise levels, sufficient seating, overall design, accessibility, and wayfinding strategies were raised as important issues by older adults when navigating through hospital public spaces such as waiting rooms, clinics, car parks, and entrances.
- Older adults with reductions in their functional capacity and frailty are more vulnerable to environmental issues, determining their ability to function independently, and achieve healthy aging.
- Hospital building design was important for older adults and impacted on their satisfaction with healthcare.
- Wayfinding systems have been overlooked in hospital design but are of increased importance in large healthcare facilities for older adults of different functional capacities.

Appendix

Table A1. (Table 4. Information in Imperial System)—Walking Observation by Frailty Status.

Walking Observation Variables	Total (*n* = 16)	Nonfrail [a] (*n* = 10), Robust *n* = 2 (12.5%), Prefrail *n* = 8 (50%)	Frail [a] (*n* = 6, 37.5%	*p* Value
Total walking distance—mean (*SD*)—ft.	883.01 (495.1)	953.31 (577.1)	765.9 (330.7)	0.483
Average walking speed—mean (*SD*)—ft./s	1.41 (0.6)	1.58 (0.98)	1.11 (0.6)	0.227
Accompanied by family member—count (%)	10 (62.5)	6 (60)	4 (66.7)	1.000
Number of destinations	1.2 (0.6)	1.3 (0.7)	1.0 (0)	0.347
Number of stops—mean (*SD*)	4.25 (2.8)	5.1 (3.3)	2.8 (0.8)	0.122
Asked for directions—count (%)	10 (62.5)	6 (60)	4 (66.7)	1.000
Looked around for directions—count (%)	9 (56.3)	6 (60)	3 (50)	1.000
Looked for signage—count (%)	4 (25)	4 (40)	0 (0)	0.234
Directions from carer—count (%)	6 (37.5)	4 (40)	2 (33.3)	1.000
Took a rest—count (%)	8 (50)	7 (70)	1 (16.7)	0.119

[a]Frail assessment FRAIL Screen: Frail (3-5 points), Non-frail (0-2 points), combining robust and pre-frail participants.

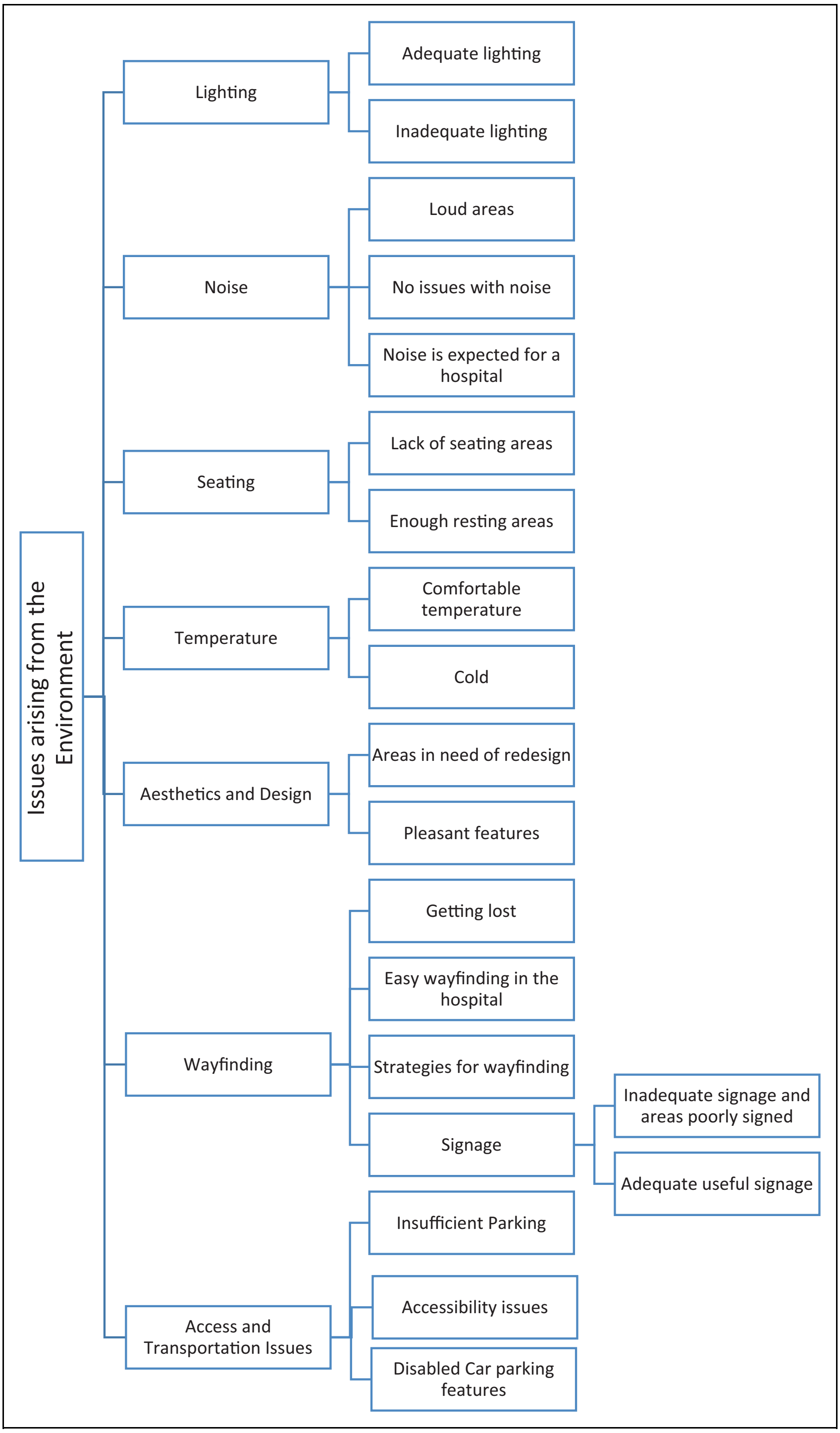

Figure A1. Hierarchical linear chart of themes, categories, and codes use.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Supplemental Material

Supplemental material for this article is available online.

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Frailty prevalence using Frailty Index, associated factors and level of agreement among frailty tools in a cohort of Japanese older adults

'Frailty prevalence using Frailty Index, associated factors and level of agreement among frailty tools in a cohort of Japanese older adults' was **published** in the *Archives of Gerontology and Geriatrics.* The statement of authorship and paper (.pdf) follow over the page.

This research led to the publication of the article by Watanabe et al, which I co-authored (2019). Another analysis investigating the associations between nutrition and frailty, also used the frailty index, as indicated in this chapter. The article entitled 'A 3-year prospective cohort study of dietary patterns and frailty risk among community-dwelling Japanese elderly' was submitted in December 2019 to the journal *Clinical Nutrition* by Huang et al, and myself as one of the co-authors.

6.1 Summary

Frailty prevalence defined by the deficit accumulation model (Frailty Index) has limited exploration in a Japanese population. The objective of the research reported in this chapter was to investigate the prevalence of frailty using the Frailty Index with a cohort of healthy Japanese older adults, and define risk factors associated with pre-frailty and frailty status, as well as evaluate the Frailty Index's agreement with the Frailty Phenotype and the Kihon checklist.

Data from 673 participants of the 2014 wave of the Nagoya Longitudinal Study - Healthy Elderly were used. Annual assessments included the investigation of mood, memory, health status, nutrition, physical performance and oral health. The Frailty Index was compared to the Frailty Phenotype and the Kihon checklist, and factors associated to the Frailty Index were investigated through univariate and multivariate logistic regression. Frailty prevalence was 13.5% (n=91) according to the Frailty Index, 1.5% (n=10) when using the Frailty Phenotype and 4% (n=27) when applying the Kihon checklist. Although the correlations between the three scales were moderate to high, the agreement between the scales was poor. In terms of risk factors, age, polypharmacy and physical activity level were associated with being pre-frail and frail. Having a higher waist circumference was associated with being pre-frail, and lower handgrip strength and lower walking speed were associated with being frail.

6.2 Statement of authorship

Statement of Authorship

Title of Paper	Frailty prevalence using Frailty Index, associated factors and level of agreement samongfrailty tools in a cohort of Japanese older adults
Publication Status	☒ Published ☐ Accepted for Publication ☐ Submitted for Publication ☐ Unpublished and Unsubmitted w ork w ritten in manuscript style
Publication Details	Arakawa Martins, B., Visvanathan, R., Barrie, H., Huang, C. H., Matsushita, E., Okada, Satake, S., Uno, C., Kuzuya, M. (2019). Frailty prevalence using Frailty Index, associated factors and level of agreement among frailty tools in a cohort of Japanese older adults. Arch Gerontol Geriatr, 84, 103908. doi:10.1016/j.archger.2019.103908

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Name of Principal Author (Candidate)			
Contribution to the Paper	Study design, constructed database, performed statistical analysis, wrote manuscript and acted as corresponding author		
Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
Signature		Date	22/10/2019

Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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Frailty prevalence using Frailty Index, associated factors and level of agreement among frailty tools in a cohort of Japanese older adults

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ABSTRACT

Frailty prevalence defined by the deficit accumulation model (Frailty Index) has limited exploration in a Japanese population. The objective of this paper is to investigate the prevalence of frailty by Frailty Index among a cohort of healthy Japanese older adults, define risk factors associated with pre-frailty and frailty status and evaluate Frailty Index's agreement with Frailty Phenotype and Kihon checklist.

Methods: Data from 673 participants of the 2014 wave of the Nagoya Longitudinal Study - Healthy Elderly were used. Annual assessments include investigation of mood, memory, health status, nutrition, physical performance and oral health. The Frailty Index was compared to Frailty Phenotype and Kihon Checklist, and factors associated to Frailty Index were investigated through univariate and multivariate logistic regression.

Results: Frailty prevalence was 13.5% (n = 91) by Frailty Index, 1.5% (n = 10) by Frailty Phenotype and 4% (n = 27) by Kihon Checklist. Although the correlations between the three scales were moderate to high, the agreement between the scales was poor. In terms of risk factors, age, polypharmacy and physical activity level were associated with being pre-frail and frail. Having a higher waist circumference was associated with being pre-frail, and lower handgrip strength and lower walking speed were associated with being frail.

Conclusions: The Frailty Index showed similar metrics and agreement comparable to findings of previous studies, and was able to identify a higher number of individuals who were pre-frail and frail. Age, polypharmacy, physical activity, waking speed and waist circumference were associated with pre-frailty and frailty by frailty index.

1. Introduction

Japan remains the country with the highest proportion of older adults in the world, with the 2018 estimate being 28.2% of the population aged over 65 years old (Japan Statistics Bureau, 2018). This phenomenon will continue and is expected to reach its peak of 37% in 2042, when the second baby boomer cohort enters this older age group (National Institute of Population and Social Security Research, 2017). This large proportion of older adults will require a dramatic shift from previous concepts of "disease-oriented", hospital-based care to integrated models of care focused on community based and preventive care (Arai et al., 2015; Tinetti & Fried, 2004).

To address these demographic changes, Japan has invested in promoting preventive care and identifying individuals at higher risk of frailty (Fukutomi et al., 2013). Frailty is a geriatric syndrome determined by a reduced capacity to recover from health stressors due

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reduced "strength, endurance and physiologic function" (Topinkova, 2008). This state of vulnerability leads to an increased risk of adverse outcomes, such as functional decline, multiple hospitalizations and death (Topinkova, 2008). Although increasing in prevalence with age, frailty is not a synonym of ageing, and lies in the other end of the spectrum of the "healthy ageing" definition (Beard et al., 2016).

Although several health tools have been developed in the past three decades to identify frail subjects, no consensus exists to the optimal detection of frailty either for clinical practice or research studies (Clegg, Young, Iliffe, Rikkert, & Rockwood, 2013; Topinkova, 2008). The two most often used frailty assessments are the Frailty Phenotype (FP) (Fried et al., 2001) and Frailty Index (FI) (Mitnitski, Mogilner, & Rockwood, 2001), but multiple screening tools have been developed. FI followed the concept that the accumulation of multiple health deficits through life were predictors of hospitalization, disability and death (Mitnitski et al., 2001). The operationalization of this methodology allows the selection of multiple health deficits as long as established criteria are fulfilled thus making it possible for the index to be constructed from existing research and administrative databases retrospectively (Searle, Mitnitski, Gahbauer, Gill, & Rockwood, 2008). The criteria to be met include: (1) variables had to be related to health status, (2) health issues had to increase with age, (3) variables did not saturate too early within the aging process, (4) covered a range of health systems and (5) when used serially over time in the same population, the same items are used. At least 30 variables must be selected, and the higher the number, the more precise the estimate becomes. Although FI was developed as a continuous variable, studies have used various number of items to classify people as frail or pre-frail (Hoover, Rotermann, Sanmartin, & Bernier, 2013). A study investigating the ideal cut-off points for frailty in a representative national sample of the Canadian community dwelling older population has shown that the likelihood of hospitalization start to increase with an FI of 0.10 and are significantly higher when reaches levels above 0.21, establishing the pre-frail (between 0.10 and 0.21) and frail (above 0.21) strata, which have been used in several cohort studies (Hoover et al., 2013; Orkaby, Hshieh, Gaziano, Djousse, & Driver, 2017; Rockwood, Song, & Mitnitski, 2011).

In Japan, the Kihon checklist (KCL) was developed in 2000 by the Japanese Ministry of Health, Labour and Welfare to identify older adults at risk of requiring care or support in the near future (Arai & Satake, 2015). This questionnaire evaluated physical strength, nutrition, eating and oral function, socialization, memory, mood and lifestyle to detect patients at-risk of becoming dependent (Sewo Sampaio, Sampaio, Yamada, & Arai, 2016). It was initially validated against the FP for use as a screening tool for frailty (Satake et al., 2016).

Although one study conducted in a Japanese population has created a FI using the established methodology to identify older adults at risk of hospitalization and mortality (Kojima, Taniguchi, Kitamura, & Shinkai, 2018), it was not able to describe its relationship with the FP, the most frequently used tool to detect frailty (Dent, Kowal, & Hoogendijk, 2016). Additionally it did not investigate which socio-demographical and clinical variables were associated with frailty, as defined by the frailty index, assessing its usefulness in this population. In this study, a high correlation between the FI and KCL (Spearman rho = 0.88, $p < 0.001$) was seen and both were able to predict long-term care insurance certification and/or mortality (HR 1.04, 95% CI 1.02–1.06, $p < 0.001$ and HR 1.03 (1.01–1.04), $p < 0.001$, respectively for FI and KCL).

Whilst also describing the construction of a FI for the Nagoya Longitudinal Study-Healthy Elderly (NLS-HE), the aim of this study is to investigate the prevalence of frailty, the risk factors associated with pre-frailty and frailty as well as to describe the agreement between FI, KCL and FP in a cohort of Japanese older adults from Nagoya, Japan.

2. Methodology

2.1. Study design and participants

This study was a cross-sectional analysis of the Nagoya Longitudinal Study – Healthy Elderly (NLS-HE), and initial baseline characteristics of participants have been published elsewhere (Matsushita et al., 2017). The NLS-HE is an observational cohort of healthy older adults recruited from students of a 2-year course at a community college for older adults in Nagoya, Japan. The students attend several weekly lectures and take part in club activities.

The initial cohort commenced in 2014, with 712 participants, with an inclusion criteria of age between 60–89 years old, being resident of Nagoya city and able to walk independently. Participants were excluded if they had incomplete data on frailty and had comorbidities that predisposed them to frailty such as Parkinson's disease, stroke or dementia. All participants provided informed consent. The study received institutional review board approval from the Nagoya University Graduate School of Medicine (approval number 2013-0055-2), and followed the principles of the Helsinki declaration.

2.2. Frailty Index

The FI in this study was constructed based on the criteria described by Rockwood et al. (2005) and Searle et al. (2008) (as described in Section 1). Whilst individual questions from geriatric assessment scales were considered, overrepresentation or repetition of themes were minimised and duplicated items or items with more than 5% of missing values were discarded (Rockwood et al., 2005). The final FI included 54 items (Appendix A Table A1). The domains covered by FI include physical strength, fatigue, physical activity (PA), nutrition and oral health, activities of daily living (ADL), falls, social network and isolation, memory, mood, and comorbidities. The index is constructed by assigning one point for the presence of each deficit, with the total value divided by the total number of variables present to create a score. If participants had more than 20% of missing items, they were excluded from the analysis (Theou, Brothers, Mitnitski, & Rockwood, 2013). Some ordinal and continuous variables were recoded to include an intermediate value of 0.5. Particular care was taken to consider the cut-off value for pre-frailty (> 0.10 and ≤ 0.21) and frailty (> 0.21), as discussed above (Section 1), given that these values have been shown to be correlated with a higher risk of adverse outcomes (Hoover et al., 2013; Rockwood et al., 2011).

2.3. Kihon Checklist (KCL)

The Kihon Checklist (KCL) consists of 25 items, in the following domains: ADL, physical strength, nutrition, oral function, isolation, memory and mood. Each answer has dichotomous answer as "yes" or "no", and a point given if depicted the presence of a deficit in this domain. (Appendix A Table A1). A score between zero and three was considered robust, between four and seven was considered pre-frail and eight and above as frail, as previously used in the validation studies (Satake et al., 2016).

2.4. Frailty Phenotype (FP)

The FP criteria used were determined by the Cardiovascular Health Study (Fried et al., 2001) with adaptation established in the Obu Study of Health Promotion for the Elderly (Makizako, Shimada, Doi, Tsutsumimoto, & Suzuki, 2015). FP includes five components: loss of weight, low walking speed, low handgrip strength, exhaustion and low PA levels. Modifications to original study (Fried et al., 2001) were limited to the question for weight loss, defined by the question: "Have you lost more than 2–3 kg in the past 6 months?" and low PA level, defined by the questions: "Do you engage in moderate levels of PA aimed at health? And "Do you engage in low levels of PA aimed at health?" Each item scored one point and participants were determined as robust if they scored zero out of five items, pre-frail if 1 or two positive items and frail if three or more items. Additionally, the cut-off for low walking speed and low hand grip strength defined as appropriate in the Japanese older population by the Obu Study of Health Promotion for the Elderly were used (respectively < 1.0 m/s and < 26 kg for men and < 18 kg for women) (Makizako et al., 2015).

2.5. Covariates

The covariates investigated for its relationship with frailty index included age, gender, education (less or more than 10 years of education), marital status (currently married or other [never married, divorced, separated or widowed]), living arrangements (living alone or with family or friends), smoking status (never smoked and ever smoker, combining previous and current smokers), multimorbidity (presence of 2 or more comorbid conditions), polypharmacy (using 5 or more medications daily), PA (assessed by Baecke Physical Activity Questionnaire) (Baecke, Burema, & Frijters, 1982), walking speed (m/s), waist circumference (cm), appendicular muscle mass index (kg/m^2), (analysed as appendicular muscle mass over height squared), subcutaneous fat thickness (in cm),dementia screening (by the 5-Cog assessment, where scores below 14 were suggestive of dementia) (Sugiyama et al., 2015) and hand grip strength (in Kg). A bioelectrical impedance analysis system (InBody 430, Biospace, Tokyo, Japan) was used to measure appendicular skeletal muscle. Appendicular muscle mass index was calculated as appendicular skeletal muscle (in kilograms, divided by height in meters. Subcutaneous fat thickness was measured in centimetres on the left triceps using a skinfold calliper twice and an average of the two measurements was considered. Geriatric depression scale-15 (GDS), multimorbidity and the Mini-Nutritional Assessment (MNA) were analysed as descriptive data, but since the majority of its items are part of FI, they are not included in the logistic regression.

2.6. Statistical analysis

Continuous variables are presented as mean and standard deviation, while categorical variables are presented as frequencies and ratios (%). Differences in descriptive data between frailty groups was assessed using 2-tailed, independent samples one-way ANOVA for continuous variables, and Chi-square test for categorical variables. Post-hoc Tukey analysis was conducted to investigate specific differences between the three groups, assuming homogeneity of variances. Statistical significance was determined by an alpha value of 0.05. The distribution of FI was assessed using histogram (Fig. 1). Agreement between the three scales for the at-risk of frailty was measured using kappa statistic and correlations between the three scales was assessed using Spearman rho's correlation.

The associations between risk factors and frailty status was determined using binary logistic regression. Univariate logistic regression was carried out as a first step and variables with $p < 0.10$ were included in the multivariable logistic regression. A backwards eliminations process of non-significant variables from the initial model was carried out to establish the final multivariate model, with exit $p < 0.05$.All analysis were performed in SPSS 25 (IBM Corp, Armonk, NY, USA). Potential multicolinearity were analysed by Pearson correlation and analysing variance inflation factor between covariates over five. BMI and abdominal circumference had a potential cofounding effect (Pearson correlation 0.810, p value < 0.001) and VIF of 3.185. To avoid potential cofound factors, only abdominal circumference was kept in the logistic regression model.

3. Results

The FI was calculated for 673 out of 771 (87.3%) participants. Of the 673 included participants, 635 (92.4%) had no missing values on 54 items, 27(4.0%) participants had one missing item, six (0.9%) participants had between 2–5 missing items, and only five participants had 6–8 missing items (0.7%). Participants that were excluded due to more than 20% of missing items (98 participants) did not differ from the participants included in the study in regards to marital status, or educational status. However, they were significantly older (mean ± SD, 70.8 ± 5.1 years vs 69.4 ± 4.4 years, p = 0.037), with slower walking speed (1.30 ± 0.22 m/sec vs 1.39 ± 0.22 m/sec, p = 0.019), larger abdominal circumference (86.6 ± 9.3 cm vs 83.6 ± 8.2 cm, p = 0.030), and higher BMI (23.5 ± 3.6 kg/m^2 vs 22.5 ± 2.7 kg/m^2, p = 0.031) than participants where FI was possible to be calculated (data not shown).

Participants mean age was 69.4 ± 4.5 years old, 56.8% were female, 72.8% married and 19.5% living alone. Using FI criteria, 13.5% and 37.3% were classified as frail and pre-frail respectively (Table 1). Significant differences were found between participants by frailty status using the FI definition (Table 1). Participants with a higher frailty status were significantly older, used more medications, had a higher number of chronic diseases and were more at risk of malnutrition. Participants classified as pre-frail and frail had lower PA levels (7.4 ± 1.2 and 7.0 ± 1.2 vs 7.9 ± 1.2, respectively, $p < 0.001$, and post-Hoc Tukey analysis: $p < 0.001$, between robust and pre-frail and robust and frail groups). Pre-frail participants had significant higher abdominal circumference ($p < 0.001$) and higher BMI ($p < 0.001$) than robust participants. Frail participants also showed a weaker handgrip strength than robust participants (p = 0.006) (Table 1).

The mean FI was 0.12 ± 0.08 (SD), with a histogram distribution skewed to the right (gamma distribution) (Fig. 1). Scores ranged from 0 to 0.50, similar to that reported by other frailty indices (Rockwood, Andrew, & Mitnitski, 2007). KCL ranged from 0 to 15 (2.95 ± 2.38) and FP scores ranges from 0 to 4 deficits (0.50 ± 0.71) with no individuals scoring five points (maximum score). None of the measures showed any ceiling effect, with the 99th percentile score for FI 0.378, 11.26 for KCL and 3.0 for FP. Only FP demonstrated a floor effect with 61.2% demonstrating a score of zero. The correlations between the three scales was moderate to high (Spearman rho = 0.361 between FI and FP, $p < 0.001$; rho = 0.689 between FI and KCL, $p < 0.001$; rho = 0.435 between KCL and FP, $p < 0.001$). The agreement between three scales in classifying individuals within frailty status was poor (KCL and FI: kappa = 0.386 (SE = 0.03, $p < 0.001$), FP and FI: kappa = 0.218, SE = 0.031, $P < 0.001$ and FP and KCL (kappa = 0.291, SE = 0.035, $p < 0.001$).

Comparing the prevalence of frailty among three instruments to identify frailty, 13.5% were classified as frail (n = 91) using FI criteria, 1.5% (n = 10) using the FP criteria, and 4.0% (n = 27) of the sample using KCL. (Table 2).Considering pre-frailty prevalence, 37.7% (257), 37.3% (251) and 29.3% (197) were classified as pre-frail by FI, FP and KCL respectively. Of participants categorized as frail by KCL, all participants were also frail by FI, while 6 out 10 participants (60%) classified frail by FP were also classified as frail by FI. However, considering the participants classified as robust by KCL (n = 449) and FP (n = 412), one third of participants, 38.8% and 33.6% respectively, where classified as pre-frail or frail by the FI criteria (Table 2).

Several individual factors were individually associated with pre-frailty and frailty in the univariate multinomial logistic regression (Table 3). Prefrailty (vs robust) was positively associated with age (Odds ratio (OR): 1.04, 95% confidence interval (95%CI): 1.00–1.08, p = 0.038), polypharmacy (OR: 2.48, 95%CI:1.44-4.26, $p < 0.001$), body mass index (BMI) (OR: 1.14, 95%CI: 1.07–1.21, $p < 0.001$), and waist circumference (OR:1.05, 95% CI: 1.03–1.07, $p < 0.001$). In addition, was negatively associated to PA level (OR: 0.71, 95%CI: 0.62-0.82, $p < 0.001$) and walking speed (OR: 0.28, 95%CI: 0.14-0.65, p = 0.002). Frailty (vs robust) was positively associated with age (OR: 1.08, 95%CI: 1.03–1.14, $p < 0.001$), living alone (OR: 1.82, 95%CI: 1.05–3.15, p = 0.033),

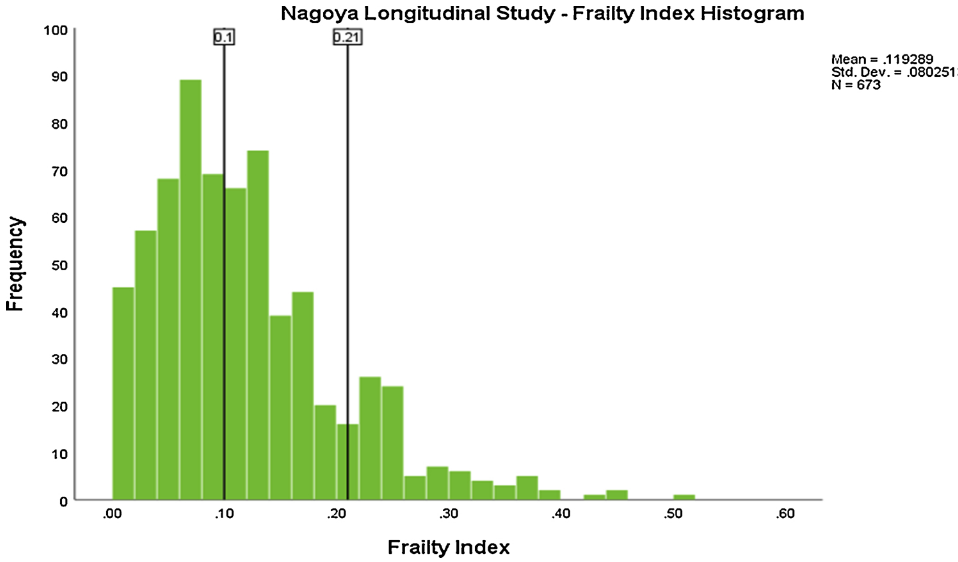

Fig. 1. Distribution of Frailty Index in the Nagoya Longitudinal Study of Healthy Elderly.

Table 1
Baseline characteristics of participants.

n (%)/ mean(SD)	Robust^	Pre-frail^	Frail^	Total	P value
Total	328(48.7)	254(37.7)	91(13.5)	673(100)	
Gender (Female)	187(57.0)	140(55.1)	55(60.4)	382(56.8)	0.673
Age (years)	68.9(4.3)*	69.7(4.2)	70.6(5.3)	69.4(4.5)	**0.003**
Education(10 years or more) †	313(95.4)	235(92.5)	86(94.5)	634(94.2)	0.325
Marital Status (Widowed/divorced/single)	80(24.4)	76(29.9)	27(29.7)	183(27.2)	0.277
Living Arrangement (Live Alone)	54(16.5)	53(20.9)	24(26.4)	131(19.5)	0.083
Smoking Status (Previous/current smoker)	129(39.3)	114(45.1)	38(41.8)	281(41.8)	0.381
Multimorbidity (2 or more chronic diseases)	92(28.0)*	145(57.1)**	69(75.8)***	306(45.5)	< **0.001**
Polypharmacy (5 or more medications)¶	23(7.0)*	40(15.7)**	24(26.4)***	87(12.9)	< **0.001**
Physical Activity (range 5-15 points)¶¶	7.9(1.2)*	7.4(1.2)**	7.0(1.2)	7.6(1.3)	< **0.001**
5- Cog Assessment (Positive screening)‡	116(37.5)	80(34.5)	24(28.9)	220(35.3)	0.332
MNA (At-risk of Malnutrition) ‡‡	33(10.1)*	37(14.6)	32(35.2)***	102(15.2)	< **0.001**
Waist circumference (cm)	82.2(8.0)	85.2(8.3)**	84.3(8.1)	83.6(8.2)	< **0.001**
BMI (kg/m^2) ‡‡‡	22.1(2.6)	23.1(2.7)**	22.4(2.5)	22.5(2.7)	< **0.001**
Low muscle mass ††	82(25.2)	60(23.6)	28(30.8)	170(25.3)	0.403
Subcutaneous fat thickness (cm)	14.3(5.6)	14.7(6.0)	15.5(5.9)	14.6(5.8)	0.236
Walking Speed (m/s)	1.4(0.2)	1.4(0.2)	1.3(0.2)	1.4(0.2)	0.135
Hand Grip Strength (kg)	29.5(8.3)*	28.8(8.2)	26.5(6.9)	26.5(6.9)	**0.009**

^ Frailty Index categories: robust 0 to ≤0.10, pre-frail between 0.10 to 0.21, frail > 0.21; one-way ANOVA for continuous variables, and Chi-square for categorical variables, p value < 0.05 is bolded.
* Post-hoc Tukey test – p value < 0.05 - differences between robust and frail groups.
** Post-hoc Tukey test – p value < 0.05 -difference between robust and pre-frail group.
*** Post-hoc Tukey test – p value < 0.05 – difference between pre-frail and frail group.
† 0 -9 years of education is equivalent to secondary education in Japan.
¶ Polypharmacy: use of 5 or more prescribed medications regularly.
¶¶ Baecke Physical Activity Questionnaire – continuous scale ranging from 5 to15 points, more points denoting higher physical activity level.
‡ 5-Cog Assessment: range from 5 to 15 points, with positive screening (5–14) for cognitive decline.
‡‡ Mini-nutritional Assessment – complete assessment; at-risk of malnutrition: less than 24 points, normal nutritional status: 24–30 points.
‡‡‡ BMI: Body Mass Index: weight in kilos/ height in metres squared.
†† Appendicular muscle mass index: Appendicular muscle mass/height^2 (Low muscle mass for men: < 7 kg/m^2 low muscle mass for women: < 5.7kg/m^2).

polypharmacy (OR: 4.75, 95%CI 2.53–8.92, p < 0.001), waist circumference (OR: 1.03, 95%CI: 1.00–1.07, p = 0.029), and negatively associated with PA scale (OR: 0.56, 95%CI: 0.45-0.69, p < 0.001), hand grip strength (OR: 0.95, 95%CI: 0.92-0.98, p < 0.001), and walking speed (OR: 0.10, 95%CI: 0.03-0.30, p < 0.001).

In a multivariate model (Table 4), being older, using five or more medications, and less PA were associated with being pre-frail and frail (vs robust). Having a higher waist circumference (OR: 1.04, 95%CI: 1.02–1.07, p < 0.001) was associated only with pre-frailty; while having lower handgrip strength (OR: 0.96, 95%CI: 0.92-0.99, p = 0.024) and lower walking speed (OR 0.25, 95%CI 0.07-0.91, p = 0.036) were associated only with frailty (vs robust). In the pre-frailty and frailty comparison, being frail was associated with lower BMI (OR: 0.86, 95%CI: 0.76-0.95, p = 0.004), doing less PA (OR: 0.76, 95% CI: 0.62-0.94, p < 0.001), and using five or more medications (OR: 2.47, 95%CI: 1.34–4.58, p < 0.001).

4. Discussion

Little is known of the prevalence of frailty by the FI and its associated factors in the Japanese population. We observed that in a population of older adults from Nagoya, the prevalence of frailty was

Table 2
Proportion of participants by each frailty category by Frailty Index, Frailty Phenotype and Kihon Checklist.

Frailty Phenotype	Frailty Index - n (%) [range]				Frailty Phenotype - n (%)			
	Robust^	Pre-frail^	Frail^	Total	Robust	Pre-frail	Frail	Total
Robust	252(76.8)	130(51.2)	30(33.0)	412(61.2)				
Pre-frail	75(22.9)	121(47.6)	55(60.4)	251(37.3)				
Frail	1(0.3)	3(1.2)	6(6.6)	10(1.5)				
Kihon Checklist								
Robust	298(90.9)	137(53.9)	14(15.4)	449(66.7)	327(79.4)	122(48.6)	0(0.0)	449(66.7)
Pre-frail	30(9.1)	117(46.1)	50(54.9)	197(29.3)	83(20.1)	110(43.8)	4(40.0)	197(29.3)
Frail	0 (0.0)	0 (0.0)	27(29.7)	27(4.0)	2(0.5)	19(7.6)	6(60.0)	27(4.0)
Total	328(48.7)	254(37.7)	91(13.5)	673 (100)	412(61.2)	251(37.3)	10(1.5)	673 (100)

^ Frailty Index categories: robust 0 to ≤0.10, pre-frail between 0.10 to 0.21, frail > 0.21.

13.5% by the FI, and frailty was significantly associated with being older, using five or more medications, doing less PA, and having lower walking speed and hand grip strength.

In our study, frailty prevalence (FI: 13.5%, FP: 1.5%, KCL: 4%) was considerably lower than previous meta-analysis (Kojima et al., 2017) of Japanese cohort of community-dwelling older adults (range 4.6%–9.5%) using FP criteria, and also lower considering a systematic review with mostly Caucasian population (FP: 14% and FI: 24%) (Shamliyan, Talley, Ramakrishnan, & Kane, 2013). This lower prevalence is best explained by the recruitment strategy in this study, where a convenience sample of older college students were recruited and therefore, participants might be younger (mean age 69.5 ± 4.5 years) and healthier when compared to previous meta-analysis of Japanese cohort studies (mean age 73.3–74.3 years old) (Kojima et al., 2017), where a mix of different studies were included, including locally representative cohorts and convenience samples. When looking more closely at the 65–70 years age bracket in various cohorts from around the world (Shamliyan et al., 2013), frailty prevalence ranged between 3–6% for the FP, and between 8–17% for the FI which is similar to the findings from our study.

Our FI (0.12 ± 0.08) has shown similar metrics of previous studies, showing closer mean scores (Kusatsu Longitudinal Study, FI mean 0.14) (Kojima et al., 2018), and similar skewed distribution to the right (Fig. 1) as previous studies in Japanese population. The low Kappa agreement score between FI and FP are consistent with previous cohorts (Theou et al., 2013; Thompson et al., 2018), and corroborate the perspective that whilst these instruments detect individuals at increased risk of adverse outcomes, different instruments result in different prevalence rates, and identify slightly different but overlapping groups of at-risk individuals (Theou et al., 2013). These differences in the ability to detect frailty have been described in multiple cohorts in different countries (Orkaby et al., 2017; Rockwood et al., 2007; Thompson et al., 2018). Furthermore, especially considering healthier and younger cohorts such as the NLS-HE study, FI has shown a stronger association with the risk of adverse outcomes than FP, and better discriminative ability in the lower to middle of the frailty spectrum (Blodgett, Theou, Kirkland, Andreou, & Rockwood, 2015).

The moderate agreement (kappa = 0.386, $p < 0.001$) and correlation (Spearman rho = 0.689, $p < 0.001$) found between FI and KCL, is also consistent with previous literature (previously described in Section 1 (Kojima et al., 2018)), and can be partially explained by the fact that both scales evaluate multiple overlapping health domains (see Appendix A Table A1) and FI included 13 out 25 questions of the original KCL. KCL shares the same concepts of multidimensionality of frailty as FI, and has similar predictive ability of adverse outcomes (Kojima et al., 2018). Some might argue that the longer the scale the

Table 3
Univariate multinomial logistic regression – Dependent Variable: Frailty Index.

	Pre-frail vs. Robust^		Frail vs Pre-frail^		Frail vs Robust^	
	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Gender (Female)	0.93 (0.67-1.29)	0.648	1.24 (0.76-2.03)	0.380	1.15 (0.72-1.85)	0.558
Age (years)	1.04 (1.00-1.08)	0.034	1.05(0.92-1.10)	0.096	1.08(1.03-1.14)	0.002
Education (10 years or more)†	0.59(0.30-1.19)	0.142	1.39(0.50-3.84)	0.525	0.82(0.29-2.33)	0.715
Marital Status (Unmarried)	1.32(0.92-1.91)	0.140	0.99(0.59-1.67)	0.964	1.31(0.78-2.19)	0.308
Living Arrangement (Live Alone)	1.34(0.88-2.04)	0.175	1.36(0.78-2.37)	0.280	1.82(1.05-3.15)	0.033
Smoking Status (Previous/current smoker)	1.27(0.91-1.76)	0.165	0.87(0.54-1.42)	0.587	1.11(0.69-1.77)	0.675
Polypharmacy (5 or more medications)*	2.48(1.44-4.26)	0.001	1.92(1.08-3.41)	0.027	4.75(2.53-8.92)	< 0.001
Physical Activity Scale (range 5-15 points)**	0.71(0.62-0.82)	< 0.001	0.80(0.65-0.97)	0.027	0.56(0.45-0.69)	< 0.001
5 –Cog Assessment (At risk of cognitive decline)‡	0.88(0.61-1.25)	0.464	0.77(0.45-1.34)	0.355	0.68(0.40-1.15)	0.147
BMI (kg/m^2)‡‡‡	1.13(1.07-1.21)	< 0.001	0.91(0.82-0.99)	0.035	1.03(0.94-1.13)	0.495
Waist circumference (cm)	1.05(1.03-1.07)	< 0.001	0.99(0.96-1.02)	0.344	1.03(1.00-1.07)	0.029
Skeletal Muscle index (kg/m^2) ‡	1.12(0.95-1.32)	0.167	0.77(0.59-1.00)	0.050	0.90(0.71-1.13)	0.363
Subcutaneous Fat Thickness (cm)	1.01(0.98-1.04)	0.408	1.02(0.98-1.06)	0.305	1.04(1.00-1.08)	0.090
Hand Grip Strength (kg)	0.99(0.97-1.01)	0.338	0.96(0.93-0.99)	0.019	0.95(0.92-0.98)	0.002
Walking Speed (m/s)	0.28(0.13-0.63)	0.002	0.38(0.11-1.02)	0.054	0.10(0.03-0.30)	< 0.001

Binary Logistic regression, between robust vs pre-frail, pre-frail vs frail and robust vs frail, p value below 0.10 (in bold) included in multivariate logistic regression.
‡Skeletal Muscle Index: defined as Appendicular Muscle Mass (kg)/ height (metres) squared.
^ Frailty Index categories: robust 0 to ≤0.10, pre-frail between 0.10 to 0.21, frail > 0.21.
† 0 -9 years of education is equivalent to reaching secondary education in Japan.
* Polypharmacy: use of 5 or more prescribed medications regularly.
** Baecke Physical Activity Questionnaire – continuous scale ranging from 5 to15 points, more points denoting higher physical activity level.
‡ 5-Cog Assessment: range from 5 to 15 points, with positive screening (5–14) for cognitive decline.
‡‡‡ BMI: Body Mass Index: weight in kilos/ height in metres squared.

Table 4
Multivariable Multinomial Logistic Regression - Dependent Variable: Frailty Index.

Multivariate logistic regression	Pre-frail vs. Robust^		Frail vs Pre-frail^		Frail vs Robust^	
	OR (95%CI)	P value	OR (95%CI)	P value	OR (95%CI)	P value
Age (years)	1.06(1.02-1.10)	0.007			1.08(1.02-1.15)	0.015
Polypharmacy (5 or more medications)*	2.21(1.25-3.93)	0.007	2.47(1.34-4.58)	0.004	4.99(2.38-10.5)	< 0.001
Physical Activity Scale** (range 5-15 points)	0.66(0.57-0.77)	< 0.001	0.76(0.62-0.94)	0.011	0.55(0.43-0.70)	< 0.001
BMI (kg/m^2) ‡			0.86(0.76-0.95)	0.004		
Waist circumference (cm)	1.04(1.02-1.07)	< 0.001				
Hand Grip Strength (kg)					0.96(0.92-0.99)	0.024
Walking Speed (m/s)					0.25(0.07-0.91)	0.036

Multivariate binomial logistic regression.
^ Frailty Index categories: robust 0 to ≤0.10, pre-frail between 0.10 to 0.21, frail > 0.21.
‡ BMI: weight in kilos over height in metres squared.
* Polypharmacy: use of 5 or more prescribed medications regularly.
** Baecke Physical Activity Questionnaire – continuous scale ranging from 5 to15 points, more points denoting higher physical activity level.

more accurate its predictive ability. In a previous study (Kojima et al., 2018), KCL alone (with 25 items) had an inferior ability to predict institutionalization than a 68-item FI that combined all KCL items, but was superior to a 32-item FI that excluded all KCL variables, suggesting that not only the number of items but also the domains covered are important in terms of detection of risk of adverse outcomes.

Two potentially modifiable factors have been associated with pre-frailty and frailty by FI: polypharmacy and PA. Polypharmacy has been consistently associated with frailty in cross sectional and longitudinal studies, independently of number of comorbidities (Gutierrez-Valencia et al., 2018; Mitnitski et al., 2001; Rockwood et al., 2011; Searle et al., 2008; Thompson et al., 2018) and de-prescribing and reducing inappropriate medications are strong recommendations from the Asia-Pacific Clinical Practice Guidelines for the Management of Frailty (Dent et al., 2017). Increasing PA levels, including lower levels of sedentary behaviour and higher levels of moderate to vigorous PA, have been associated with a reduction of frailty scores using FI (Blodgett, Theou, Kirkland, Andreou, & Rockwood, 2015). Additionally, PA levels, walking speed, and handgrip strength were independently associated with being frail by FI in the multivariate analysis, which illustrate the ability of FI to detect older adults at risk of reduced muscle power and strength. Current proposed PA interventions strategies targeting frailty have found improvement in lower limb muscle strength, number of daily steps and light-intensity PA, decrease in sedentary behaviour and reduction of frailty levels both in Japanese and European studies (Cesari et al., 2015; Nagai et al., 2018).

Finally, having a higher waist circumference was associated with pre-frailty in our study, in line with previous investigations of cardiovascular risk factors being associated with frailty (Ramsay et al., 2015), even in participants with normal BMI (Liao, Zheng, Xiu, & Chan, 2018). Elevated C-reactive protein and increased insulin resistance have been linked as mediating factors between abdominal adiposity and frailty in a longitudinal study (Garcia-Esquinas et al., 2015). In our logistic regression, BMI was also inversely associated with frailty (vs pre-frailty), with pre-frail participants showing a higher BMI than frail participants. BMI and frailty have a U-shaped relationship, with lowest FI appearing in BMI around 25 kg/m^2 (Hubbard, Lang, Llewellyn, & Rockwood, 2010), and higher FI levels associated with lower and higher BMI values. The partial association found in our results can be explained by the fact that within our sample a minority of participants had a BMI over 28 kg/m^2 (2.7%), and possibly only the descending part of the U-shaped curve between BMI and frailty can be observed, with only lower BMI being associated with higher frailty.

Our study has several strengths. Although most comparative studies require the use of substitutions of original questions, especially considering the feasibility of FP, our study was able to use minimum modifications to FP, by objectively assessing walking speed and handgrip strength in all participants and all original questions from KCL. Furthermore, this cohort provided a comprehensive assessment of health domains, to allow for enough variety of questions included in the final FI. Finally, our study adds to the literature as the first study to assess risk factors associated to FI in a Japanese population. A limitation of our study was the use of a convenience sample of older adults where participants might have higher health literacy and the results may not be generalizable to the Japanese population at large. Additionally, the cross sectional design does not allow for an assumption of cause and effect.

5. Conclusion

In this study, despite the recruitment of a healthier population, FI showed similar distribution, association with age, and agreement with other frailty scales. Age, polypharmacy, PA, waist circumference, BMI, handgrip strength and walking speed were associated with pre-frailty and frailty, and many of these factors may be amenable to intervention. This profile corroborates the use of FI as a useful tool that can be introduced into existing cohorts of older adults, and successfully differentiate individuals pre-frail and frail in healthier cohorts of older adults.

Author contributions

BAM – study concept, data analysis, interpretation, preparation of manuscript.

RV – study concept, data interpretation, preparation of manuscript.

HB – study concept, data interpretation, preparation of manuscript.

CHH - data analysis, interpretation, preparation of manuscript.

EM – acquisition of subjects and data, study design, preparation of manuscript.

KO - acquisition of subjects and data, study design, preparation of manuscript.

SS – study concept and design, preparation of manuscript.

CU – acquisition of data, preparation of manuscript.

MK – study concept and design, interpretation of data and preparation of manuscript.

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Appendix A

Table A1
Frailty Phenotype, Kihon Checklist and Frailty Index variables.

	Frailty Phenotype	Kihon Checklist Variables	Frailty Index Variables
Physical Strength	Handgrip score < 26 kg in men and < 18 kg in women;	Climbing stairs	Climbing stairs
		Stand up from a chair without help	Stand up from a chair without help
	Walking speed < 1.0 m/s		
Fatigue	Felt tired in the past 2 weeks	Difficulty in doing things usually did	Dropped usual activities
		Felt tired in the past 2 weeks	
Physical Activity	Engage in low levels of physical exercise	Walk continuously for 15 minutes	
Nutrition and Oral Health	Loss of weight (2 kg in past 6 months)	Eating tough/hard foods	Eating tough/hard foods
		Food decline in the past 6 months‡	Food decline in the past 6 months‡
		Loss of weight (2 kg in past 6 months)	Loss of weight (2 kg in past 6 months)
		Choke on tea or soup	Choke on tea or soup
		Dry mouth	Pressure sores or skin ulcers
			Number of teeth
			Self-rated nutritional Status‡
Activities of Daily Living		Use public transportation	Shopping Independently
		Shopping independently	Managing banking
		Managing banking	
Falls		Falls in the past year	Falls in the past year
		Fear of Falling	Fear of Falling
Social Network and Isolation		Go out less frequently	Go out less frequently
		Visit friends	Lives independently
		Turn to family and friends for advice	Preferred staying at home
		Go out at least once a week	
Memory		Family points out memory loss	Family points out memory loss
		Look up phone numbers	Look up phone numbers
		Not knowing today's date	Not knowing today's date
			More memory problems than most
Mood		Lack of fulfilment in daily life	Feel that people are better off than you
		Lack of joy doing things you used to enjoy	Life satisfaction
			Felt helpless
		Felt helpless	Empty life
			Felt Bored
			Felt in Good spirits
			Feel worthless
			Feel full of energy
			Feel hopeless
			Felt happy
			Afraid something will happen to you
			Wonderful to be alive
Comorbidities			Hypertension
			Ischemic Heart Disease
			Heart Failure
			Peripheral Vascular Disease
			Atrial Fibrillation
			COPD
			Diabetes mellitus
			Dyslipidaemia
			Chronic Kidney Disease
			Cerebral Infarction
			Malignant tumour
			Metastatic cancer
			Rheumatoid Arthritis
			Osteoarthritis
			Fracture
			Recent psychological distress or acute disease
Symptoms and self-health evaluation			Self-rated health‡
			Self-rated pain‡
			Vision problems
			Hearing problems
			Incontinence
			Constipation

Frailty Index: All variables answers were coded to 0 (absence of deficit), or 1 (presence of deficit), except when marked with ‡, which admitted the 0.5 to represent partial presence of the deficit, Kihon Checklist: All variables if positive receive 1 point; COPD: Chronic Obstructive Pulmonary Disease.

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Built environment and frailty: Neighborhood perceptions and associations with frailty, experience from the Nagoya Longitudinal study

'Built environment and frailty: Neighbourhood perceptions and associations with frailty, experience from the Nagoya Longitudinal study' was submitted for publication and is under review in the *Journal of Applied Gerontology.*

The statement of authorship and paper (.pdf) follow over the page. Additional tables are available in the Supplementary material for Chapter 7.

7.1 Summary

Using the frailty index created in Chapter 6, this paper evaluated whether neighbourhood environment characteristics were associated with the level of frailty of community-dwelling older adults in Nagoya, Japan. Using a cross-sectional analysis of 370 community-dwelling older adults who were studying at the college for the Third Age in Nagoya, this paper evaluated their perceptions of their neighbourhood environments using the Neighbourhood Environmental Walkability Scale (NEWS), along with their levels of frailty, using a frailty index. Univariate linear regressions were used to investigate associations between neighbourhood perceptions (dependent variable) and the frailty index (independent variable) and other covariates. All variables with P value < 0.250 were then included in the multivariable model.

In the univariate analysis, a higher result for the frailty index was a significant predictor of a lower NEWS composite index ($p < 0.001$), lower land use diversity ($p<0.001$), lower access to land use ($p <0.001$), lower street connectivity ($p=0.01$), lower aesthetics ($p=0.02$), fewer cycling and walking facilities ($p=0.02$) and a poorer sense of safety from crime ($p < 0.001$), and had P value less than 0.250 for residential density ($p=0.21$) and traffic safety ($p=0.22$). In the multivariable analysis, frailty remained inversely associated with the NEWS composite index ($p< 0.01$), land use diversity ($p<0.01$), land use access ($p=0.04$), street connectivity ($p=0.03$), walking and cycling facilities ($p=0.02$), aesthetics ($p=0.03$) and crime safety ($p < 0.01$), after adjustment for covariates.

Increasing frailty was associated with a poorer neighbourhood environment, independent of other cofounding factors. We hypothesised that poor perceptions of the neighbourhood environment resulted in additional constrictions of the life-space, including fewer social and physical engagements and the worsening of frailty status.

7.2 Statement of authorship

Statement of Authorship

Title of Paper	Built Environment and Frailty: Neighborhood perceptions and associations with frailty, experience from the Nagoya Longitudinal study
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Overall percentage (%)	80%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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Co-Author Contributions

By signing the Statement of Authorship, each author certifies that:

i. the candidate's stated contribution to the publication is accurate (as detailed above);

ii. permission is granted for the candidate in include the publication in the thesis; and

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Built Environment and Frailty: Neighborhood Perceptions and Associations With Frailty, Experience From the Nagoya Longitudinal Study

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Abstract

Neighborhood physical characteristics have been consistently associated with the health of older adults. This article investigates links between frailty and perceptions of the neighborhood environment. Using a cross-sectional analysis of 370 community-dwelling older adults from Nagoya, Japan, neighborhood perceptions were assessed using the Neighborhood Environmental Walkability Scale (NEWS) in addition to frailty, using a frailty index. Frailty was associated with the NEWS composite index, land use mix diversity, land use mix access, street connectivity, walking infrastructure, aesthetics, and crime safety, after adjustment for covariates. Older adults with increasing frailty have poorer perceptions of their neighborhoods, which could lead to further constriction of the life-space, less social and physical engagement, and worsening of frailty status.

Keywords

built environment, frailty index, healthy aging, neighborhood environment, physical activity

Introduction

Frailty is a state of reduced physiological reserves and increased vulnerability to endogenous and exogenous stressors (Morley et al., 2013), where increasing frailty is associated with poor health outcomes such as hospitalization and death (Fried et al., 2001). Two methods are commonly used to define frailty: the phenotypic (Fried et al., 2001) and cumulative deficit methods (Mitnitski et al., 2001). The likelihood of frailty increases with age, and represents a major public health priority, with a worldwide prevalence of frailty estimated at 9.9% and 44.2% for prefrailty (as per phenotype method) (Cesari et al., 2016).

There is growing evidence of the influence of the physical environment on the wellbeing, physical and mental health of older adults, and research focused on investigating the relationship between the environment and frailty should be encouraged (Beard et al., 2009). The World Health Organization has thus highlighted the important interaction between an individual's intrinsic capacity and the physical and social environment where they live (Beard et al., 2016). The surrounding neighborhood environment may play an important role in supporting active aging and preserving individual intrinsic capacity (Beard & Petitot, 2010).

Very little is known of how environmental attributes may influence aging in super-aged societies such as Japan (Koohsari et al., 2018). In a cross-sectional study of older adults of three cities in Japan, several aspects of perceived neighborhood environment have been associated with walking for transportation and recreational walking, such as access to exercise facilities, aesthetics, and social environment for older adults (S. Inoue et al., 2011). Using objectively assessed variables of the local environment, residential density and the presence of green spaces had positive associations with the frequency of sports activities

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for community-dwelling older adults living in Aichi, Japan (Hanibuchi et al., 2011). The associations between perceived neighborhood environment and physical activity were evaluated in a group of frail older adults from Obu, Japan, and higher perceptions of crime safety were associated with more physical activity (Harada et al., 2017).

Few studies have explored the relationship between frailty and the environment, but this is a research area of increased interest, given the expected increase in the number of older people living in the community with frailty or at risk of frailty (Taylor et al., 2019). Yu et al. (2018) proposed that neighborhood environments could influence physical activity and walking behavior of older adults, and thus positively influence frailty status. Yu's (Yu et al., 2018) longitudinal study confirmed that objectively assessed proximity to green spaces was associated with improvement of frailty phenotype in Chinese older people (Yu et al., 2018). The perception of poor neighborhood physical disorder, defined as the deterioration of buildings and other visible characteristics, was associated with a higher incidence of phenotypic frailty in a longitudinal study (Caldwell et al., 2017). Another cross-sectional study in China reported that perceptions of the neighborhood environment aesthetic quality and an overall walking environment were associated with less frailty as measured by the FRAIL scale (Ye et al., 2018). No study to date has explored the relationship between the built environment and frailty as defined using the cumulative deficit method. In addition, the Neighborhood Environment Walkability Scale (NEWS; Saelens et al., 2003), which evaluates eight different domains of physical environmental attributes, may be useful in providing a more comprehensive picture as to which environmental features are perceived to be associated with frailty. This may be important in terms of urban planning and policy development (Cerin et al., 2013).

To address the current gaps existing in neighborhood environmental and frailty research, the aim of this cross-sectional study was to investigate the association between frailty levels, as defined by the frailty index (FI), and perceptions of the neighborhood environment, using the NEWS domains, in community-dwelling older Japanese.

Methods

Study Population

The Nagoya Longitudinal Study—Healthy Elderly (NLS-HE) is a longitudinal cohort study of community-dwelling older adults initiated in 2014, from Nagoya, Japan. Recruitment processes and baseline study cohort characteristics have been described previously (Matsushita et al., 2017). Community college students aged 60 years old and above were recruited with the aim of investigating risk factors associated with frailty transitions. Inclusion criteria were as follows: aged between 60 and 89 years old, the ability to walk independently (including with a mobility aid), and current resident of Nagoya. Participants with Parkinson's disease, stroke, or dementia as comorbidities were excluded. Self-administered questionnaires and face-to-face interviews were conducted annually between 2014 and 2018. Ethical approval for this study was obtained from the Nagoya University Graduate School of Medicine (approval number 2013-0055-2), and the principles of the Helsinki Declaration were followed. This analysis includes the cross-sectional data from the 2017 wave consisting of 433 participants when neighborhood environment questions were included.

Due to the recruiting strategies used for this cohort, a healthier and younger population was obtained at baseline, as shown previously (Arakawa Martins et al., 2019). We hypothesized that a cohort less at risk for frailty would have better perceptions of neighborhood environment than a frailer cohort.

Measurements

Dependent variable

Perceptions of neighborhood built environmental attributes. The NEWS, developed by the International Physical Activity and Environment (IPEN) group, evaluates the perceived neighborhood attributes relating to walking and cycling (Saelens et al., 2003). This questionnaire has been shown to detect differences in the walkability perceptions of populations living in different environmental characteristics (Saelens et al., 2003), showing high test–retest reliability among several countries (Cerin et al., 2013), and in confirmatory factor analysis, both in individual questions and subscales (Cerin et al., 2009, 2013). The validated Japanese version (NEWS-J) (S. Inoue et al., 2011), with the following eight subscales, was used in this study:

1. Residential density (score 5–805, weighted sum of responses)—perceived number of residential dwellings in the neighborhood, ranging from single-family detached houses to high-rise buildings;
2. Land use mix diversity (score 1–5, mean of 23 different destinations)—perceived distances to a mixture of different land uses (residential, commercial, and public spaces), evaluated by the time taken to walk to that destination;
3. Land use mix access (score 1–4, mean of 4-point Likert-type scale)—perceived accessibility to different services and transportation;
4. Street connectivity (score 1–4, mean of 4-point Likert-type scale)—perceived connectivity of streets and roads;
5. Walking/cycling facilities (score 1–4, mean of 4-point Likert-type scale)—perceived infrastructure and safety for walking and cycling;
6. Aesthetics (score 1–4, mean of 4-point Likert-type scale)—perceived attractiveness of landscape and buildings;

7. Traffic safety (score 1–4, mean of 4-point Likert-type scale)—perceived safety from traffic hazards;
8. Crime safety (score 1–4, mean of 4-point Likert-type scale)—perceived safety from crime.

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

Independent variables

Nagoya Longitudinal Study—Frailty Index. The Nagoya Longitudinal Study—Frailty Index (NLS-FI) was constructed using previously standardized criteria, following the accumulation of deficit models (Searle et al., 2008); details can be found elsewhere (Arakawa Martins et al., 2019). The NLS-FI consists of 54 items across nine clinical domains of strength, fatigue, nutrition and oral health, activities of daily living (ADL), falls, memory, social network, mood, and comorbidities, with each variable coded as either 0 or 1 (deficit present). The final score is calculated as the proportion of deficits present over total number of deficits.

Covariates. Age, gender, education level (high school vs. college degree), marital status (currently married or having a partner vs. widowed, single or divorced), social isolation, economic situation, physical activity, anthropometric data, and physical performance were considered in this study. Where the Lubben Social Network Scale–6 score was less than 12, social isolation risk was taken to be present (Lubben et al., 2006). Economic situation was evaluated by the following question: "What is your current economic situation?" and responses were categorized as (a) wealthy, (b) not in economic trouble, and (c) partial government aid needed. The Modified Baecke Physical Activity Questionnaire (MBPAQ), a self-report questionnaire with three domains of physical activity (work, leisure time, and sports) that are summed to a final index score ranging from 3 to 15 was used to quantify participant's physical activity levels (Baecke et al., 1982). Appendicular muscle mass was assessed using bioimpedance analysis (InBody 470, InBody Japan Inc.), and appendicular muscle mass index was obtained by dividing appendicular muscle mass by height squared (ASM/h^2). Anthropometric measurements such as waist circumference (cm), height (m), and weight (kg) were assessed by trained staff. Handgrip strength (kg) was measured twice in each hand, while in a standing position, with a handheld dynamometer (TKK 5401 Grip-D; Takei, Tokyo, Japan), and the best performance of four measurements was used. Walking speed (m/s) was calculated by timing trials of a 5-m walk at the usual pace.

Statistical Analysis

Only those participants with complete data to determine frailty status and walkability attributes were included in the analysis. Continuous variables are described as mean and standard deviation and categorical variables by frequencies and percentages. Differences in variables between male and females, and between prefrail, frail, and robust participants, were assessed using two-tailed, independent *t*-tests or one-way analysis of variances (ANOVAs) for continuous variables, and chi-square tests for categorical variables. Post hoc analysis with Tukey adjustment for multiple comparisons was done to find differences between pair comparisons whenever appropriate. The cut-off for prefrailty (>0.10 and ≤ 0.21) and frailty (>0.21) were chosen based on previous studies, given that these values have been shown to be correlated with a higher risk for adverse outcomes (Hoover et al., 2013; Rockwood et al., 2011).

Univariate linear regressions were used to investigate associations between neighborhood perceptions (dependent variable) and FI (independent variable) and other covariates. Neighborhood perceptions include residential density, land use mix diversity, land use mix access, street connectivity, walking/cycling facilities, aesthetics, traffic safety, crime safety, and a composite index. Neighborhood environment subscales, composite index, and FI were analyzed as continuous variables in all regression models. Frailty index, age, gender, education level, marital status, living arrangement (living alone, or with family or friends), house ownership, risk of social isolation, economic situation, physical activity level, polypharmacy, waist circumference, body mass index (BMI), appendicular muscle mass, walking speed, and handgrip strength were individually assessed for its association with the dependent variables: composite index and subscales (Table 2). All variables with p value $< .250$ were then included in the multivariable model. Physical activity, although not significantly associated with any of the subscales or composite index, was included in the multivariable model due to known impact on perceived neighborhood attributes (Kerr et al., 2016). All multivariable regression models were assessed for collinearity of individual variables using the variance inflation factor (VIF). To reach final adjusted models for each dependent variable, three final models were established: Model 1 including age, gender, and NLS-FI; Model 2 including Model 1 and socio-demographical variables: educational level, marital status, risk of social isolation, and economic situation; and finally, Model 3 was evaluated adding to Model 2 physical activity levels.

Results

Three hundred and seventy (85.5% of 433) participants in the 2017 wave had a complete assessment of the NLS-FI and NEWS-J; with baseline characteristics found in Table 1. The 63 participants not included in this study due to either

Table 1. Characteristics of Participants.

	Female	Male	Complete sample	
	(n = 205, 55.4%)	(n = 165, 44.6%)	(n = 370)	
Participants' Characteristics	*M* (*SD*)/*n* (%)	*M* (*SD*)/*n* (%)	*M* (*SD*)/*n* (%)	*p* value
NEWS				
Residential density	328.62 (124.78)	324.96 (114.75)	326.99 (120.27)	.772
Land use mix diversity	3.33 (0.63)	3.44 (0.60)	3.38 (0.62)	.083
Land use mix access	3.08 (0.47)	3.06 (0.49)	3.07 (0.48)	.678
Street connectivity	2.86 (0.77)	2.91 (0.75)	2.88 (0.76)	.567
Walking/cycling facilities	2.49 (0.70)	2.45 (0.69)	2.47 (0.69)	.585
Aesthetics	2.56 (0.69)	2.48 (0.67)	2.52 (0.68)	.318
Traffic safety	2.53 (0.35)	2.57 (0.35)	2.55 (0.36)	.238
Crime safety	3.04 (0.51)	3.11 (0.44)	3.07 (0.48)	.182
Composite NEWS	0.12 (4.39)	0.15 (3.84)	0.00 (4.15)	.543
Age (years)	71.78 (4.30)	72.53 (4.31)	72.12 (4.31)	.095
Education (>13 years)	87 (42.4)	97 (58.8)	184 (49.7)	.002
Marital status—married[a]	110 (53.7)	158 (95.8)	268 (72.4)	<.001
At risk of social isolation[b]	34 (16.6)	38 (23.0)	72 (19.5)	.146
Economic situation				.383
Partial aid needed	3 (1.8)	4 (2.0)	7 (1.9)	
Not in trouble	141 (85.5)	164 (80.0)	305 (82.4)	
Wealthy	21 (12.7)	37 (18.0)	58 (15.7)	
Physical activity level[c]	7.50 (2.84)	7.45 (2.87)	7.60 (1.28)	.844
Waist circumference, cm	83.45 (8.07)	86.91 (7.34)	85.01 (7.93)	<.001
BMI, kg/m^2	21.93 (2.61)	23.12 (2.51)	22.47 (2.63)	<.001
ASM/h^2, kg/m^2	5.94 (0.51)	7.41 (0.66)	6.60 (0.93)	<.001
Walking speed (m/s)	1.44 (0.20)	1.42 (0.23)	1.43 (0.22)	.273
Handgrip strength, kg	23.01 (3.63)	36.26 (5.83)	28.92 (8.12)	<.001
Frailty index (0–1)	0.12 (0.08)	0.11 (0.08)		.615

Note. NEWS = Neighborhood Environment Walkability Scale; BMI = body mass index; ASM/h^2 = Appendicular Muscle Mass over height squared—evaluation of muscle mass.
[a]Married: currently married opposed to single, widowed, or divorced. [b]At risk of social isolation: 12 or more points in the Lubben Social Network Scale–6. [c]Physical activity level: evaluated by Modified Baecke Physical Activity Scale, range: 3–15.

incomplete NLS-FI (n = 9, 14.3% of excluded sample) or incomplete NEWS-J (n = 54, 85.7% of excluded sample), were significantly older, mean age (*SD*) 74.2 (4.9) vs. 72.1 (4.3); p = .001, and had slower walking speed, (mean speed 1.37 (0.26) versus 1.43 (0.22); p = .039), than participants included in the analysis. Participants from the 2017 wave were also compared to participants who were lost in the follow-up from the initial cohort recruitment (2014), and no statistically significant differences were found between groups (Appendix Table 1).

Significant differences were found between participants, depending on frailty status (Table 2). Prefrail and frail participants had significantly worse perceptions of land use mix diversity (p < .001), street connectivity (p = .001), walking and cycling facilities (p = .034), aesthetics (p = .032), and crime safety (p = .002) than robust participants. In addition, frail participants were significantly older (p = .006), and had a lower walking speed (p = .033) than robust participants. Prefrail participants had significantly lower hand-grip strength than robust participants (p = .018). There were significant differences in the risk of social isolation (p < .001) and socio-economic situation (p = .023) between frailty statuses.

In the univariate analysis (Table 3), a higher FI level was a significant predictor of a lower composite index (p < .001), lower land use mix diversity (p < .001), lower land use mix access (p < .001), lower street connectivity (p = .01), lower aesthetics (p = .02), lower cycling and walking facilities (p = .02), and lower crime safety (p < .001) perceptions. Nonsignificant predictors included residential density (p = .21) and traffic safety (p = .22).

Frailty index score, educational level, being at risk of social isolation, economic situation, and handgrip strength were considered for the multivariable models due to having, in most of the associations with neighborhood environmental outcomes, a p < .250. In the multivariable analysis (Table 4), frailty remained inversely associated with the NEWS composite index (p < .01), land use mix diversity (p < .01), land

Table 2. Participants Characteristics by Frailty Index.

Participants' Characteristics	Robust (*n* = 188, 50.8%)*	Prefrail (*n* = 138, 37.3%)*	Frail (*n* = 44, 11.9%)*	Complete sample (*n* = 370)	
	M (*SD*)/*n* (%)	*M* (*SD*)/*n* (%)	*M* (*SD*)/*n* (%)	*M* (*SD*)/*n* (%)	*p* value
NLS-FI	0.06 (0.03)	0.14 (0.03)*	0.28(0.07)**	0.12(0.08)	**<.001**
NEWS					
Residential density (range: 5–805)	328.09 (117.67)	335.76 (126.36)	294.80 (108.29)	326.99 (120.27)	.142
Land use mix diversity (range: 1–5)	3.52 (0.58)	3.22 (0.63)*	3.27 (0.59)*	3.38 (0.62)	**<.001**
Land use mix access (range: 1–4)	3.12 (0.47)	3.05 (0.48)	2.95 (0.49)	3.07 (0.48)	.087
Street connectivity (range: 1–4)	3.03 (0.75)	2.70 (0.78)*	2.84 (0.64)	2.88 (0.76)	**.001**
Walking/cycling facilities (range: 1–4)	2.50 (0.68)	2.51 (0.73)	2.22 (0.57)*	2.47 (0.69)	**.034**
Aesthetics (range: 1–4)	2.58 (0.65)	2.53 (0.70)	2.28 (0.71)*	2.52 (0.68)	**.032**
Traffic safety (range: 1–4)	2.53 (0.35)	2.56 (0.36)	2.59 (0.37)	2.55 (0.36)	.571
Crime safety (range: 1–4)	3.15 (0.47)	3.03 (0.48)	2.89 (0.48)*	3.07 (0.48)	**.002**
Composite NEWS (sum of z-scores)	0.76 (4.01)	−0.48 (4.39)*	−1.74 (3.16)*	0.00 (4.15)	**<.001**
Gender—female	96 (51.1)	85 (61.6)	24 (54.5)	205 (55.4)	.165
Age (years)	71.51 (4.06)	72.47 (4.4)	73.61 (4.69)*	72.12 (4.31)	**.006**
Education (>13 years—college, university degree or higher)	100 (53.2)	61 (44.2)	23 (52.3)	184 (49.7)	.258
Marital status—married[a]	141 (75)	98 (71)	29 (6.9)	268 (72.4)	.207
At risk of social isolation[b]	26 (13.8)	25 (18.1)	21 (47.7)	72 (19.5)	**<.001**
Economic situation					
Partial aid needed	0	6 (4.3)	1 (2.3)	7 (1.9)	**.023**
Not in trouble	154 (81.9)	112 (81.2)	39 (88.6)	305 (82.4)	
Wealthy	34 (18.1)	20 (14.5)	4 (9.1)	58 (15.7)	
Physical activity level[c] (range: 3–15)	7.56 (1.3)	7.62 (1.23)	7.74 (1.26)	7.60 (1.28)	.708
Waist circumference (cm)	84.10 (8.25)	85.96 (7.32)	85.90 (8.13)	85.01 (7.93)	.082
BMI (kg/m^2)	22.30 (2.72)	22.73 (2.59)	22.34 (2.31)	22.47 (2.63)	.329
ASM/h^2, kg/m^2	6.66 (0.96)	6.56 (0.91)	6.48 (0.91)	6.60 (0.93)	.422
Walking speed (m/s)	1.45 (0.20)	1.43 (0.23)	1.36 (0.24)*	1.43 (0.22)	**.033**
Handgrip strength (kg)	30.24 (8.23)	27.62 (7.69)*	27.40 (8.19)	28.92 (8.12)	**.018**

Note. NLS-FI = Nagoya Longitudinal Study—Frailty Index; NEWS = Neighborhood Environment Walkability Scale; BMI = body mass index; ASM/h^2 = Appendicular Muscle Mass over height squared—evaluation of muscle mass. Bold values have p value <.05.
[a]Married: currently married opposed to single, widowed, or divorced. [b] At risk of social isolation: 12 or more points in the Lubben Social Network Scale–6. [c] Physical activity level: evaluated by Modified Baecke Physical Activity Scale.
*Robust (FI index: 0–0.10), Prefrail (FI index: 0.10–0.21), and Frail (FI index: >0.21); post hoc Tukey analysis with significant differences between robust and prefrail and robust and frail groups. **Post-hoc Tukey analysis with significant differences between robust and frail and prefrail and frail groups.

use mix access (p = .04), street connectivity (p = .03), walking and cycling facilities (p = .02), aesthetics (p = .03), and crime safety ($p < .01$), after adjustment for age, gender, marital status, educational level, risk of social isolation, economic situation, and physical activity level (Model 3).

In the multivariable linear regression model (Model 3), other socio-demographical and clinical covariates were also independently associated with neighborhood characteristics (Table 5). Being married was positively associated with residential density (p =.02) and street connectivity (p = .03). Attaining education level of high school or above was negatively associated with street connectivity (p = .03). Worse economic status was independently associated with the perception of worse street connectivity (p = .04) and worse perception of crime safety (p = .03), but better perceptions of walking and cycling facilities (p = .02).

Discussion

This study's key finding is that increasing levels of frailty were independently associated with poorer perceptions of the neighborhood environment. More specifically, after adjusting for age, gender, marital status, social isolation, economic situation, and physical activity, older adults with increasing FI scores were more likely to perceive their environment as having fewer destinations, worse street connectivity, poorer infrastructure for walking, poorer aesthetics and higher levels of crime than less frail older adults have. To the best of our knowledge, this is the first study showing the association between frailty status, determined by FI, and environmental perceptions where individual aspects of the environment are associated with FI scores.

Our results indicate that frail older adults have poorer perceptions of their local environment when compared to less

Table 3. Univariate Linear Regression Models With Dependent Variables: Composite NEWS, Residential Density, Land Use Mix Diversity, Land Use Mix Access, Street Connectivity, Walking and Cycling Facilities, Aesthetics, Traffic Safety, and Crime Safety.

NEWS		Composite index	Residential density	Land use mix diversity	Land use mix access	Street connectivity	Walking cycling facilities	Aesthetics	Traffic safety	Crime safety
Frailty index	*B**	−11.57	−96.83	−1.45	−1.05	−1.34	−1.01	−1.05	0.28	−1.10
	(95% CI)	(−16.73, −6.42)	(−249.89, 56.23)	(−22.20, −0.67)	(−1.65, −0.44)	(−2.30, −0.38)	(−1.89, −0.14)	(−1.92, −0.19)	(−0.17, 0.74)	(−1.70, −0.49)
	p value	**<.001**	**.214**	**<.001**	**<.001**	**.007**	**.024**	**.017**	**.223**	**<.001**
Gender: female	β	−0.26	3.66	−0.11	0.02	−0.05	0.04	0.07	−0.04	−0.07
	(95% CI)	(−1.11, 0.59)	(−20.96, 28.27)	(−0.24, 0.01)	(−0.08, 0.12)	(−0.20, 0.11)	(−0.10, 0.18)	(−0.07, 0.21)	(−0.12, 0.03)	(−0.17, 0.03)
	p value	.542	.771	**.082**	.647	.565	.584	.316	**.236**	**.180**
Age	β	−0.08	−1.11	−0.01	−0.02	−0.02	−0.01	0.00	0.01	0.00
	(95% CI)	(−0.18, 0.02)	(−3.95, 1.73)	(−0.03, 0.00)	(−0.03, 0.00)	(−0.04, 0.00)	(−0.02, 0.01)	(−0.01, 0.02)	(0.00, 0.01)	(−0.01, 0.01)
	p value	**.123**	.443	**.156**	**.009**	**.022**	.554	.822	**.208**	.831
Education level[a]	β	−0.94	−11.75	−0.14	−0.10	−0.23	−0.08	−0.11	0.06	0.01
	(95% CI)	(−1.78, −0.10)	(−36.20, 12.70)	(−0.27, −0.02)	(−0.20, 0.00)	(−0.38, −0.08)	(−0.22, 0.06)	(−0.25, 0.03)	(−0.02, 0.13)	(−0.09, 0.11)
	p value	**.028**	.346	**.026**	**.042**	**.003**	.245	**.124**	**.118**	.858
Married[b]	β	0.34	32.00	−0.14	−0.02	0.10	0.05	0.05	0.00	−0.01
	(95% CI)	(−0.60, 1.29)	(4.81, 59.19)	(−0.28, 0.00)	(−0.13, 0.09)	(−0.08, 0.27)	(−0.11, 0.21)	(−0.11, 0.21)	(−0.08, 0.08)	(−0.12, 0.10)
	p value	.475	**.02**	**.05**	.76	.27	.54	.54	.97	.92
At risk of social isolation[c]	β	−0.97	−18.27	−0.16	−0.09	−0.02	−0.13	−0.16	0.07	−0.06
	(95% CI)	(−2.04, 0.09)	(−49.12, 12.59)	(−0.32, 0.00)	(−0.21, 0.03)	(−0.22, 0.17)	(−0.30, 0.05)	(−0.33, 0.02)	(−0.02, 0.16)	(−0.18, 0.06)
	p value	**.073**	**.246**	**.047**	**.154**	.823	**.167**	**.073**	**.140**	.346
Economic situation—partial aid[d]	β	−0.65	65.11	−0.72	−0.16	−0.68	0.67	0.25	−0.01	−0.05
	(95% CI)	(−3.88, 2.56)	(−29.47, 158.6)	(1.20, −0.25)	(−0.53, 0.22)	(−1.27, −0.09)	(0.13, 1.21)	(−0.28, 0.79)	(−0.29, 0.27)	(−0.43, 0.32)
	p value	.695	**.173**	**.003**	.410	**.025**	**.015**	.349	.935	.782
Economic situation—not in trouble[d]	β	−1.16	−21.13	−0.02	−0.15	−0.20	−0.02	0.03	0.00	−0.18
	(95% CI)	(−2.32, 0.00)	(−54.63, 12.38)	(−0.19, 0.15)	(−0.29, −0.02)	(−0.41, 0.02)	(−0.21, 0.17)	(−0.16, 0.22)	(−0.10, 0.10)	(−0.32, −0.05)
	p value	**.049**	**.216**	.806	**.024**	**.070**	.825	.766	.964	**.008**
Physical activity level[e]	β	−0.12	−8.98	−0.01	0.01	0.01	−0.04	−0.01	0.01	−0.01
	(95% CI)	(−0.47, 0.23)	(−19.03, 1.07)	(−0.06, 0.04)	(−0.04, 0.05)	(−0.06, 0.07)	(−0.09, 0.02)	(−0.07, 0.05)	(−0.02, 0.04)	(−0.05, 0.03)
	p value	.486	**.080**	.735	.794	.775	**.246**	.679	.485	.653

Note. NEWS = Neighborhood Environment Walkability Scale; CI = confidence interval.
[a]Education level: attaining at least high school degree. [b]Married: currently married opposed to single, widowed, or divorced. [c]At risk of social isolation: 12 or more points in the Lubben Social Network Scale–6. [d]Reference: participants who considered their economic situation as wealthy/comfortable. [e]Physical activity level: evaluated by Modified Baecke Physical Activity Scale.
*Unstandardized regression coefficient, or estimate; variables are bolded for p value < .250.

Table 4. Multivariable Linear Regression Models With Dependent Variables: Composite NEWS, Residential Density, Land Use Mix Diversity, Land Use Mix Access, Street Connectivity, Walking and Cycling Facilities, Aesthetics, Traffic Safety, and Crime Safety.

	Composite index	Residential density	Land use mix diversity	Land use mix access	Street connectivity	Walking and cycling facilities	Aesthetics	Traffic safety	Crime safety
NEWS	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
Model 1 FI	**−11.13 (−16.35, −5.90)***	−89.57 (−244.71, 65.57)	**−1.36 (−2.14, −0.57)***	**−0.93 (−1.54, −0.32)***	**−1.15 (−2.12, −0.18)****	**−1.01 (−1.90, −0.12)****	**−1.14 (−2.01, −0.27)****	0.25 (−0.21, 0.01)	**−1.11 (−1.72, −0.50)***
Model 2 FI	**−10.93 (−16.39, −5.46)***	−85.55 (−247.28, 76.18)	**−1.17 (−1.99, −0.36)***	**−0.88 (−1.51, −0.24)****	**−1.24 (−0.24, 5.89)****	**−1.06 (−1.99, −0.13)****	**−1.14 (−2.05, −0.22)****	0.20 (−0.29, 0.68)	**−1.07 (−1.71, −0.43)***
Model 3 FI	**−10.96 (−16.74, −5.18)***	−65.88 (−235.43, 103.68)	**−1.28 (−2.15, −0.40)***	**−0.70 (−1.38, −0.02)****	**−1.17 (−2.24, −0.10)****	**−1.17 (−2.16, −0.19)****	**−1.08 (−2.06, −0.09)****	0.27 (−0.22, 0.76)	**−1.37 (−2.05, −0.69)***

Note. Model 1: adjusted for age and gender, Model 2: Model 1 + educational level, marital status, at risk of social isolation, economic situation, Model 3: Model 2 + physical activity level. NEWS = Neighborhood Environment Walkability Scale; CI = confidence interval; FI = frailty index. Bolded variables for p value <.05.
*$p < .001$. **$p < .05$.

frail adults. It is possible that these perceptions could feed into the constriction of their life-space, defined as the spatial areas a person moves through his or her life (Xue et al., 2008). These perceptions influence physical and social activities and make it harder for the frailer person to break out of the frailty cycle of health decline. If the environment you live in is perceived to be challenging, then behavior modifications to adapt to those challenges emerge. Thus, if it is perceived that it is hard to cross a busy road, then it is less likely that the road will be crossed. Faced with these challenges, older people or their families may choose, for example, to get assistance with shopping, shop less often or even worse, eat less resulting in weight loss, increased risk of sarcopenia and worsening levels of frailty. In summary, these changing perceptions of environmental demand might create maladaptive behaviors to older frail adults, being detrimental to health, as theorized by Lawton's and Nahemow (1973) Environmental Press Theory.

Nonetheless, other factors must come into play in the associations between neighborhood environment and frailty. In Caldwell's study of socio, cultural, and physical aspects of the neighborhood environment and frailty in the United States, perceptions of worsening social cohesion were also associated with an increased incidence of frailty over 5 years (Caldwell et al., 2017). This poorer perception of social cohesion and belonging, allied with worse perceived personal safety, were also found to be determinants of increased frailty levels in Dutch communities (Cramm & Nieboer, 2013); with the hypothesis being that increasing frailty levels impact on levels of outdoor activity and restrict social interactions within the neighborhood, thus contributing negatively to frailty status.

Deriving from previous transportation and urban planning research, we investigated the specific components of the physical environment that were associated with frailty. Although it seems contradictory in a country with low objective crime rates, such as Japan (Organisation for Economic Co-operation and Development, 2014), crime safety perception was an important factor associated with frailty levels in our study. This might indicate that frail older adults feel more vulnerable to the threat of crime, explaining why similar findings were not found in Japanese studies conducted in a healthy cohort (S. Inoue et al., 2011). Regarding other factors analyzed, the findings that land use mix diversity and access, street connectivity, presence of walking and cycling facilities, and aesthetics were inversely associated with frailty are novel and previously unreported. Our findings build on previous research, showing that the same environmental factors are consistently associated with walking and physical activity levels (Tsunoda et al., 2012), influencing happiness and wellbeing (Yu et al., 2017), BMI (Mathis et al., 2017), cardiovascular risk (Y. Inoue et al., 2016), and disability (Beard et al., 2009) in older adults.

A major limitation of this study was that it was cross-sectional thus not allowing us to draw a causal effect between the two variables: frailty and negative perceptions of the neighborhood environment. The longitudinal nature of the NLS-HE study will allow us to investigate the effect of this negative perception on frailty status over time in future papers. In addition, due to confidentiality reasons, it was not possible to obtain participants' address or postal code which would have allowed us to obtain objective measurements of the neighborhood environment. These variables could be considered in future studies to evaluate whether individual perceptions match the observed objective environment.

This study had several strengths, however. One of the major strengths of this study was the use of a validated tool for the assessment of neighborhood perceptions, used in several countries (Cerin et al., 2013), adding to its generalizability. Furthermore, this was the first study in Japan to establish relationships between neighborhood characteristics and the FI, a multicomponent index that covers a range of health systems deficits.

To summarize, this study seeks to highlight that frailer older people perceive their neighborhoods more negatively than those who are less frail. While we cannot be certain that such perceptions impact on future frailty status, these

Table 5. Multivariable Linear Regression Models With Dependent Variables: Composite NEWS, Residential Density, Land Use Mix Diversity, Land Use Mix Access, Street Connectivity, Walking and Cycling Facilities, Aesthetics, Traffic Safety, and Crime Safety.

	Composite index	Residential density	Land use mix diversity	Land use mix access	Street connectivity	Walking and cycling facilities	Aesthetics	Traffic safety	Crime safety
NEWS	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)	β (95% CI)
FI	**−10.96** **(−16.74, −5.18)***	−65.88 (−235.43, 103.68)	**−1.28** **(−2.15, −0.40)***	**−0.70** **(−1.38, −0.02)***	**−1.17** **(−2.24, −0.10)***	**−1.17** **(−2.16, −0.19)***	**−1.08** **(−2.06, −0.09)***	0.27 (−0.22, 0.76)	**−1.37** **(−2.05, −0.69)***
Gender: female	0.54 (−0.47, 1.54)	11.32 (−18.18, 40.82)	0.08 (−0.08, 0.23)	−0.02 (−0.13, 0.1)	0.13 (−0.06, 0.31)	−0.07 (−0.24, 0.1)	−0.03 (−0.2, 0.14)	0.05 (−0.03, 0.14)	0.09 (−0.03, 0.21)
Age	−0.04 (−0.15, 0.06)	−0.64 (−3.67, 2.38)	0.0 (−0.02, 0.01)	−0.01 (−0.02, 0.0)	−0.02 (−0.04, 0.0)	0.0 (−0.02, 0.02)	0.0 (−0.2, 0.02)	0.0 (−0.01, 0.01)	0.0 (−0.01, 0.01)
Education level[a]	−0.8 (−1.68, 0.08)	−15.56 (−41.39, 10.27)	−0.1 (−0.23, 0.03)	−0.08 (−0.19, 0.02)	**−0.18** **(−0.34, −0.01)***	−0.09 (−0.24, 0.06)	−0.14 (−0.29, 0.01)	0.05 (−0.03, 0.12)	0.05 (−0.05, 0.15)
Married[b]	0.92 (−0.18, 2.02)	**39.11** **(6.79, 71.44)***	−0.03 (−0.2, 0.14)	0.03 (−0.1, 0.16)	**0.23** **(0.03, 0.44)***	0.03 (−0.16, 0.21)	0.13 (−0.06, 0.31)	0.0 (−0.1, 0.09)	0.03 (−0.1, 0.16)
Social network[c]	0.23 (−0.86, 1.32)	17.65 (−16.10, 51.41)	0.08 (−0.1, 0.25)	0.04 (−0.09, 0.18)	−0.08 (−0.29, 0.13)	0.03 (−0.16, 0.23)	0.09 (−0.11, 0.28)	−0.03 (−0.13, 0.07)	−0.06 (−0.2, 0.07)
Economic status (partial aid needed)[d]	1.55 (−2.19, 5.29)	89.93 (−19.72, 199.58)	−0.47 (−1.03, 0.1)	−0.05 (−0.49, 0.39)	**−0.72** **(−1.41, −0.03)***	**0.75** **(0.12, 1.39)***	0.46 (−0.18, 1.09)	0.28 (−0.04, 0.59)	0.03 (−0.41, 0.47)
Economic status (not in trouble)[d]	−0.61 (−1.82, 0.61)	−11.82 (−47.45, 23.81)	0.03 (−0.16, 0.21)	−0.11 (−0.25, 0.04)	−0.16 (−0.38, 0.07)	0.05 (−0.16, 0.26)	0.08 (−0.12, 0.29)	0.0 (−0.1, 0.11)	**−0.16** **(−0.3, 0.02)***
Physical activity[e]	−0.08 (−0.42, 0.26)	−8.57 (−18.57, 1.43)	−0.01 (−0.06, 0.04)	0.01 (−0.03, 0.05)	0.01 (−0.06, 0.07)	−0.03 (−0.08, 0.03)	−0.01 (−0.07, 0.05)	0.01 (−0.02, 0.04)	0.0 (−0.04, 0.04)

Note. NEWS = Neighborhood Environment Walkability Scale; CI = confidence interval; FI = frailty index.
[a]Education Level: attaining at least high school degree. [b]Married: currently married opposed to single, widowed, or divorced. [c]At risk of social isolation: 12 or more points in the Lubben Social Network Scale–6. [d]Reference: participants that considered their economic situation as wealthy/comfortable. [e]Physical activity level: evaluated by Modified Baecke Physical Activity Scale.
*Variables in bold have p value $< .05$.

findings raise the possibility that effective frailty interventions in those who are frailer or prefrail may need to focus on overcoming or adapting environmental perceptions to reduce frailty risk.

Appendix

Table 1. Baseline Participants' Characteristics in 2014—Comparison Between Current Participants and Lost to Follow-Up.

	Participants lost to follow-up (N = 356)	2017 participants (N = 415)	Complete sample (N = 771)	
	M (*SD*)/*n* (%)	*M* (*SD*)/*n* (%)	*M* (*SD*)/*n* (%)	*p* value
Frailty index (n = 673)	0.12 (0.08)	0.12 (0.08)	0.12 (0.08)	.167
Gender—female (n = 712)	174 (56.9)	234 (57.6)	408 (57.3)	.878
Age (years) in 2014 (n = 712)	69.8 (4.6)	69.4 (4.4)	69.5 (4.5)	.231
Education (>13 years—college, university degree or higher) (n = 673)	130 (45.8)	193 (49.6)	323 (48)	.349
House ownership—(n = 673)	257 (90.5)	354 (91)	611 (90.8)	.893
Living alone (n = 673)	55 (19.4)	76 (19.5)	131 (19.5)	1.000
Marital status—married[a] (n = 639)	208 (78.2)	282 (75.6)	490 (76.7)	.507
At risk of social isolation[b] (n = 668)	73 (26.1)	77 (19.8)	150 (22.5)	.061
Economic situation—(n = 673)				
Governmental aid needed	5 (1.8)	7 (1.8)	12 (1.8)	1.000
Physical activity level[c] (range: 3–15)	8.38 (1.26)	8.27 (1.23)	8.32 (1.24)	.303
Waist circumference (cm)—(n = 711)	83.66 (8.72)	83.84 (7.99)	83.76 (8.31)	.771
BMI (kg/m^2)—(n = 710)	22.71 (2.95)	22.47 (2.59)	22.57 (2.75)	.239
ASM/h^2, kg/m^2—(n = 710)	6.67 (1.00)	6.69 (0.99)	6.68 (0.99)	.607
Walking speed (m/s)—(n = 707)	1.38 (0.23)	1.39 (0.23)	1.38 (0.22)	.569
Handgrip strength (kg)—(n = 712)	28.43 (8.16)	29.04 (8.21)	28.77 (8.19)	.323

Note. BMI = body mass index; ASM/h^2 = Appendicular Muscle Mass over height squared—evaluation of muscle mass.
[a]Married: currently married opposed to single, widowed or divorced. [b]At risk of social isolation: 12 or more points in the Lubben Social Network Scale–6.
[c]Physical activity level: evaluated by Modified Baecke Physical Activity Scale.

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Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval

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

'Objective and subjective measures of the neighbourhood environment: associations with frailty levels' was submitted for publication and is under review in the *Archives of Geriatrics and Gerontology* .

The statement of authorship and paper (.pdf) follow over the page. Additional tables are available in the Supplementary material for Chapter 7.

8.1 Summary

Following the investigations undertaken in Japan into the relationship between frailty and the perceptions of older Japanese of their neighbourhoods, a study of the relationship between frailty and perceptions of the neighbourhood environment (NE) compared with objective geographical information system (GIS) measures of the same environment was undertaken with older adults from Adelaide, Australia.

A sample population of 115 community-dwelling adults aged ≥60 years, living in the Adelaide urban centre and was invited to participate. Respondents' perceptions of their NEs were assessed using the Neighbourhood Environment Walkability Scale (NEWS). An objective assessment of these same NEWS survey questions was then conducted using seven GIS-derived variables: residential density, land use mix diversity, street connectivity, accessibility (MetroARIA), seasonal persistent green cover, road crashes and crime rate. Frailty was evaluated using the FRAIL (fatigue, resistance, ambulation, illnesses and loss of weight) scale. Multivariable linear regression analyses were then employed to assess the associations between the data from the NEWS and frailty, adjusting for age, gender, other socio-demographic variables, and the respective objective variables. Multivariable linear regression was also used to assess objective neighbourhood variables associated with frailty.

It was found that frail and pre-frail older adults were more likely to live in areas with lower residential density (p value = 0.002), lower density of road crashes (p value = 0.004), and higher accessibility (MetroARIA) (p value = 0.02) than robust participants. Additionally, the poorer the perception of the overall environment (p value =0.003), the greater the association with frailty and pre-frailty after adjustment of covariates and objective GIS variables.

The results indicate that 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, as well as the older person's perception of the NE.

8.2 Statement of authorship

Statement of Authorship

Title of Paper	Objective and subjective measures of neighbourhood environment are associated with frailty levels
Publication Status	☐ Published ☐ Accepted for Publication ☒ Submitted for Publication ☐ Unpublished and Unsubmitted work written in manuscript style
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Principal Author

Name of Principal Author (Candidate)	Beatriz Arakawa Martins		
Contribution to the Paper	Study concept and design, data analysis and database creation, collected data, performed statistical analysis, manuscript writing, corresponding article		
Overall percentage (%)	75%		
Certification:	This paper reports on original research I conducted during the period of my Higher Degree by Research candidature and is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in this thesis. I am the primary author of this paper.		
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iii. the sum of all co-author contributions is equal to 100% less the candidate's stated contribution.

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8.3 Submission to *Archives of Geriatrics and Gerontology*

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, 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.

Methods

Study population

A convenience sample of community-dwelling older adults (age ≥60 years) was recruited from two associated health studies. We acknowledge the potential risk of frail participants not taking part in medical research, and the effect on the investigated associations, so a population of participants that had been hospitalized (SMART-MOVE) as well as participants living on the community (Adelaide Walkability and Frailty Study) were assessed 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.

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.

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 metres, 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).

Data collection and analysis

Dependent variables

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.

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-metre 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.

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 30m 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 100m precision of its location was used to create a density of road crashes index. A kernel density model with bandwidth of 250m 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*

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 to 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].

Independent variables

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, Malmstrom and Miller 2012). Upon assessment, participants were categorised as either frail (3-5 points); pre-frail (1-2 points); or robust (0 points).

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 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).

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).

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					0.016
<65 years old	4(3.4)	2(6.9)	1(2.6)	1(2.1)	
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					0.815
female	66(56.9)	11(37.9)	17(43.6)	22(45.8)	
male	50 (43.1)	18(62.1)	22(56.4)	26(54.2)	
Education					0.001
primary school	9(7.8)	0(0)	5(13.2)	4(8.3)	
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					
married	56(48.7)	15(51.7)	18(47.4)	23(47.9)	0.943
Living with					0.646
alone	55(47.8)	16(55.2)	17(44.7)	22(45.8)	
with partner/family	60(52.2)	13(44.8)	21(55.3)	26(54.2)	
IRSAD[b]					0.005
most disadvantaged					
intermediate	25(21.7)	1(3.4)	7(18.4)	17(35.4)	
most advantaged	75(65.2)	21(72.4)	26(68.4)	28(58.3)	
	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)

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.

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.

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)

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

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

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.

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

NEWS	Residential density β (95%CI)	Land use mix diversity β (95%CI)	MetroARIA accessibility index β (95%CI)	Street connectivity β (95%CI)	Persistent green cover β (95%CI)	Density of road crashes β (95%CI)	Crime safety β (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

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.

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 β (95%CI)	Residential density β (95%CI)	Land use mix diversity β (95%CI)	Land use mix access β (95%CI)	Street connectivity β (95%CI)	Aesthetics and greenery β (95%CI)	Traffic safety β (95%CI)	Traffic load β (95%CI)	Crime safety β (95%CI)
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									
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									
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

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 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(E. Dent et al., 2017; Elsa Dent et al., 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.

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8.4 Supplementary materials for Chapter 8

Supplementary Table 1 Neighbourhood Environment Walkability Scale – Australian version

Neighbourhood Environment Walkability Scale		
Subscale	Scoring	Description
Residential density	score 5-805, sum of responses, with different weights for each type of dwelling	Perceived number of residential dwellings in the neighbourhood, ranging from single-family detached houses to high-rise buildings
Land use mix diversity	score 1-5, mean of 23 different destinations	Perceived distances to a mixture of different land uses (residential, commercial and public spaces), evaluated by the time taken to walk to that destination
Land use mix access	score 1-4, mean of 4-point Likert scale	Perceived accessibility to different services and transportation
Street connectivity	score 1-4, mean of 4-point Likert scale	Perceived connectivity of streets and roads
Walking/cycling facilities	score 1-4, mean of 4-point Likert scale	Perceived infrastructure and safety for walking and cycling
Aesthetics	score 1-4, mean of 4-point Likert scale	Perceived attractiveness of landscape and buildings
Traffic safety	score 1-4, mean of 4-point Likert scale	Perceived safety from traffic hazards
Traffic load	score 1-4, mean of 4-point Likert scale	Perceived load of traffic in your neighbourhood
Crime safety	score 1-4, mean of 4-point Likert scale	Perceived safety from crime

Supplementary Table 2 Univariate linear associations between covariates, frailty and neighbourhood environment perceptions

		NEWS								
Objective		**Residential density**	**Land use mix diversity**	**Access to services**	**Road connectivity**	**Aesthetics and greenery**	**Traffic safety**	**Traffic load**	**Crime safety**	**Overall NEWS**
Frailty	β (95%CI) P value	-5.3 (-18.4,7.8) 0.428	-0.6 (-1.0,-0.3) <0.001	-0.5 (-0.6,-0.3) <0.001	-0.1(-0.3,0.1) 0.298	-0.6 (-0.8,-0.3) <0.001	0.0 (-0.2,0.2) 0.967	-0.3 (-0.6,-0.0) 0.023	-0.4 (-0.6,-0.2) <0.001	-5.6 (-7.8,-3.5) <0.001
Pre-frailty	β(95%CI) P value	3.7 (-9.9,17.5) 0.591	-0.6 (-0.9,-0.2) 0.002	-0.3 (-0.5,0.2) <0.001	-0.08 (-0.3,0.1) 0.391	-0.3 (-0.6,-0.1) 0.015	0.0(-0.2,0.2) 0.723	-0.2(-0.5,0.1) 0.235	-0.4(-0.6,-0.2) <0.001	-4.4(-6.6,-2.2) <0.001
Gender (female)	B (95%CI) P value	-1.1(-11.7,9.5) 0.839	-0.1(-0.4,0.2) 0.342	0.1(-0.1,0.2) 0.225	0.1(-0.1,0.3) 0.061	0.4(0.2,0.6) 0.001	0.2(0.0,0.3) 0.02	0.4(0.1,0.6) 0.002	0.2(0.0,0.4) 0.018	2.1(0.3,4.0) 0.022
Age	B (95%CI) P value	-0.1(-0.8,0.6) 0.798	0.0(0.00,0.0) 0.009	0.0(0.0,0.0) 0.001	0.0(0.0,0.0) 0.513	0.0(0.0,0.0) 0.011	0.0(0.0,0.0) 0.765	0.0(0.0,0.0) 0.258	0.0(0.0,0.0) 0.047	-0.2(-0.3,-0.1) 0.005
Education (tertiary)	β (95%CI) P value	-33.3(-52.8,-13.6) 0.001	0.2(-0.3,0.8) 0.365	0.1(-0.1,0.4) 0.352	-0.1(-0.4,0.1) 0.277	0.3(-0.1,0.7) 0.163	-0.1(-0.3,0.2) 0.686	0.1(-0.3,0.6) 0.618	0.2(-0.1,0.5) 0.123	0.9(-2.3,4.1) 0.572
Education (secondary)	β (95%CI) P value	-27.1(-46.3,-7.8) 0.006	-0.3(-0.8,0.2) 0.272	-0.2(-0.4,0.1) 0.155	-0.3(-0.5,-0.1) 0.05	-0.3(-0.7,0.1) 0.152	-0.1(-0.4,0.2) 0.544	-0.1(-0.5,0.4) 0.671	-0.2(-0.5,0.1) 0.160	-4.0(-7.2,-0.9) 0.013
Married	β (95%CI) P value	-2.9(-13.4,7.5) 0.585	-0.1(-0.4,0.2) 0.516	0.0(-0.1,0.2) 0.857	0.1(-0.1,0.2) 0.103	0.00(-0.2,0.2) 0.933	0.0(-0.1,0.2) 0.875	-0.1(-0.3,0.2) 0.645	-0.1(-.2,0.1) 0.432	0.1(-1.8,2.0) 0.891
Living alone	β(95%CI) P value	-6.9(-17.36,3.6) 0.197	0.2(-0.1,0.5) 0.178	0.0(-0.1,0.2) 0.646	-0.1(-0.2,0.1) 0.219	0.1(-0.1,0.4) 0.198	0.1(-0.1,0.2) 0.234	0.1(-0.1,0.4) 0.255	0.2(0.1,0.3) 0.013	1.0(-0.9,2.9) 0.300
IRSAD (high)	β(95%CI) P value	12.4(-5.6,30.5) 0.1789	0.0(-0.5,0.5) 0.971	0.4(0.2,0.6) 0.002	0.1(-0.1,0.3) 0.373	1.0(0.6,1.4) <0.001	0.1(-0.1,0.4) 0.328	0.5(0.1,0.9) 0.013	0.4(0.4,0.9) <0.001	7.2(4.2,10.1) <0.001
IRSAD (medium)	β(95%CI) P value	12.5(-0.3,25.3) 0.056	0.1(-0.3,0.4) 0.698	0.2(0.0,0.4) 0.042	0.1(-0.1,0.7) 0.237	0.4(0.1,0.6) 0.004	0.0(-0.1,0.2) 0.736	0.2(-0.1,0.5) 0.124	0.4(0.2,0.6) <0.001	3.9(1.8,5.9) <0.001
Sports index	β(95%CI) P value	1.2(-5.7,8.2) 0.726	0.3(0.1,0.4) 0.012	0.1(0.0,0.2) 0.238	-0.1(-0.2,0.0) 0.091	-0.0(-0.2,0.1) 0.689	0.0(-0.1,0.1) 0.579	0.2(0.0,0.3) 0.029	0.0(-0.1,0.1) 0.504	0.4(-0.9,1.7) 0.540
Step count	β(95%CI) P value	0.0(0.0,0.0) 0.856	0.0(0.0,0.0) 0.008	0.0(0.0,0.0) <0.001	0.0(0.0,0.0) 0.006	0.0(0.0,0.0) <0.001	0.0(0.0,0.0) 0.084	0.0(0.0,0.0) 0.001	0.0(0.0,0.0) <0.001	0.0(0.0,0.0) <0.001

Discussion, future directions and conclusions

9.1 Discussion

The study of frailty has gained increased relevance in gerontological research as a method of explaining individual heterogeneity of the ageing process and as an accurate predictor of adverse health outcomes among ageing individuals (Kojima, Liljas, & Iliffe, 2019). However, very little insight exists into the risk factors for frailty and, critically, how these factors interact with each other (Hoogendijk et al., 2019), to guide public health and therapeutic efforts.

Furthermore, the study of frailty is contributing to the move of medical knowledge away from a single-organ focus on disease to multidimensional concepts of health (Tinetti & Fried, 2004). Holistic ways of looking at health focus on multiple intrinsic and extrinsic factors to determine how to achieve the ultimate goals of healthy ageing: independence and well-being. The extent to which this new knowledge and holistic approach are being transferred to medical training is still unknown.

In the field of frailty, there have been inconsistent investigations of neighbourhood environmental risk factors, often evaluating only one or two factors, only in a few countries, and considering only area-level or individual characteristics. The Active Ageing Framework established by the WHO in 2002 (*Active Ageing: A Policy Framework*, 2002), has brought new attention to two major concomitant demographic transitions occurring worldwide – ageing and urbanization – and robust evidence has demonstrated the association between older adults' health and the physical and social environment in which they live (Beard & Petitot, 2010).

9.1.1 Educating medical students

Given the significance of frailty and the shift to multidimensional concepts of health, one of the preliminary goals of this PhD was to investigate the extent of medical students' current perceptions of the importance of the topic of frailty and their competence in assessing, diagnosing and managing frailty. Given the changing demographics, caring for older patients is going to increasingly be a reality for medical doctors, irrespective of their field of expertise.

Understanding geriatric principles, including frailty, the implications of frailty assessment to risk management, and to the medical decision process is essential for better medical care (Nanda et al., 2013). This observation was pursued in Chapter 3, which reported on significant changes in medical students' perceived importance of, and competence in, understanding frailty after a dedicated 4.5-week teaching block in Geriatric Medicine during the fifth year of medical training. More than merely assessing knowledge, competence refers to acquiring, skills, attitudes and interpersonal abilities (Gruppen et al., 2016).

The improvements seen in competence can possibly be explained by the topic being embedded in multiple tutorials, administered by a multidisciplinary team, with different views being provided on these complex and unfamiliar topics. The increased competence among the students, and their positive perception of the topic indicated that the medical students had begun to appreciate the complexities of frailty and how it could affect their practice in the future. Changing students' attitudes towards geriatric medicine and older adults has been an important goal among medical education researchers (Meiboom, de Vries, Hertogh, & Scheele, 2015). The research reported in Chapter 3 recommends that students receive more training in topics, such as treating and reversing frailty, in which they had the lowest competence scores. The research also emphasised the inclusion of competence evaluation in the undergraduate medical assessment.

Involving medical students in research projects. While the demand for doctors trained in the care of older adults increases worldwide, the number of trainees choosing geriatric medicine as a speciality is failing to keep pace with the growth of the aged population (Petriceks, Olivas, & Srivastava, 2018). To develop research projects that involve medical students could be an interesting strategy by which to attract them to the study of geriatrics, and strengthen the development of academic geriatric medicine (Bragg et al., 2012).

Medical students were, in fact, involved in the research project and contributed to the refinement of the research methods and data collection used to prepare the research article contained in Chapter 4, 'Older adults' perceptions of the built environment and associations with frailty: a feasibility and acceptability study'. The fourth- and fifth-year students were enrolled in the elective Medical Scientific Attachment (MSA), University of Adelaide (GTRAC), and used their experiences in the study to deliver both oral and written reports reflecting on what they had learned about frailty and frailty care. Formal feedback about their placement experiences was quite positive in previous assessments of this elective course, as shown by the national evaluation of the Teaching and Research Aged Care Service (TRACS) (Barbett, Moretti, & Howards, 2015). Their involvement in the data collection for Chapter 4, alongside other initiatives developed by the Adelaide Geriatric Training & Research with Aged Care (Adelaide G-TRAC) department, was responsible for significantly increasing students' interest in working in aged care in the future.

9.1.2 Assessing multiple geriatric domains

The journal article in Chapter 4 reported on the feasibility and acceptability of a comprehensive survey to assess multiple geriatric domains, including frailty and perceptions of their local neighbourhoods. The recruitment and retention of older adults in research programs have been persistently challenging. Recruitment requires timely screening and identification, while retention depends on the perceived personal benefit of the research compared to the burden of participating. Research has examined strategies to retain participants, including continuity of care of older adults (Mody et al., 2008).

In addition to what has been reported previously, our study findings suggest that geriatric assessment tools need to be customised to the setting and populations of interest, and consideration should be given to the length of surveys and improved support to the respondents in order to produce a higher quality of response. One of key findings reported in Chapter 4 is that some tools, although targeted at older adults, were nevertheless difficult to comprehend and complete, especially when self-administered. Surveys developed for research reported in journal articles later during the PhD were adjusted to accommodate lessons from the research reported in Chapter 4.

9.1.3 Public spaces in hospitals

Chapter 5 was produced under a University of Adelaide Interdisciplinary Funding Scheme with the aim of developing and testing an interdisciplinary methodology (combining geography, computer sciences, architecture and medicine) to investigate whether the planning and design of public spaces in Adelaide support ageing well. We chose the public spaces of a hospital for a detailed qualitative and quantitative investigation of the influence of the built environment on the experiences and health of older adults.

In this mixed-method approach, a comprehensive geriatric survey (tested during research for Chapter 4 for its feasibility), a walking observation experience, semi-structured interview and independent architectural audit were developed in order to evaluate whether the hospital's public spaces were age-friendly, using the older adults' perspectives as the starting point of the research.

A convenience sample of 16 older adult outpatients of the Aged Care Extended Services Department was recruited, the majority of whom (n=14) were pre-frail or frail. From their responses to surveys and interviews, several themes emerged that revealed the major features of the hospital spaces that affected the participants in various ways. These were the:

- lighting
- noise
- temperature
- design
- seating
- wayfinding
- access/transportation.

Several issues raised by the participants related to reductions in physical capacities, with frailty being one of the areas of weakness. Some issues, such as seating and wayfinding in the hospital, were noted more frequently in the data from the frail older adults' interviews than in responses from non-frail participants.

Other themes, such as aesthetics and design, wayfinding and person-to-person assistance, were relevant for the entire sample of older adults and consistently correlated with the architectural audit of the space. It became clear that the public spaces of the hospital could directly influence the experience of older adults exhibiting reduced intrinsic capacity, and that their opinions should be considered in the design and planning of such spaces.

9.1.4 The Nagoya Longitudinal Study

Chapter 6 reports on the analysis of data from the Nagoya Longitudinal Study begun in 2014. Using a frailty index (FI) developed for this database of participants, we obtained a prevalence of frailty of 13.5%. Frailty was associated with age, polypharmacy, low physical activity levels, lower walking speed and lower handgrip strength. Our FI showed similar mean scores and skewed distribution as other studies using frailty indices, and consistent, moderate to low agreement with the frailty phenotype and the Kihon checklist. Many of the associated factors captured are amenable to intervention, such as polypharmacy and physical activity levels. Additionally, improvements in walking speed and handgrip strength are seen in targeted interventions for frailty (Dent et al., 2017).

Frailty prevalence rates (FI: 13.5%, FP: 1.5%, KCL: 4%) were lower than previous meta-analyses of Japanese community-dwelling older adults (Kojima et al., 2017) and other international meta-analyses (Shamliyan, Talley, Ramakrishnan, & Kane, 2013). One possible explanation for these results could be the personal characteristics of the convenience sample of older adults. All were attending a college for the Third Age, and were younger (mean age 69.5 ±4.5 years) and healthier than those involved in earlier meta-analyses of Japanese cohort studies (mean age 73.3-74.3 years old) (Kojima et al., 2017).

It is important to acknowledge that a limitation of the present Nagoya Longitudinal Study was the exclusion of patients with the diagnosis of dementia in the initial recruitment of the cohort. This criterion could have created selection bias that led to lower frailty prevalence. Frail older adults have often been under-represented in medical research in the past, and purposeful recruiting strategies are often necessary. Although it was not possible to change recruiting criteria in this cohort, we have attempted to recruit more frail older adults, by recruiting from a residential aged care facility (in Chapter 4) and including patients discharged from a tertiary hospital (Chapter 8) were strategies to try to overcome this issue.

The profiles obtained using our frailty index identified more frail people than the other two frailty tools (Frailty Phenotype and Kihon Checklist) and the index was able to determine those individuals in the low to middle range of frailty (Blodgett, Theou, Kirkland, Andreou, & Rockwood, 2015; Theou, Brothers, Mitnitski, & Rockwood, 2013), which is of interest when considering the generally healthier cohort of the Nagoya Longitudinal Study. The frailty index created for the research reported in Chapter 6 was used in Chapter 7 and led to a collaboration with other researchers at the Department of Geriatric Medicine, School of Medicine, University of Nagoya. A similar index for the use with a database of home care patients was created. This led to the publication of the article by Watanabe et al, which I co-authored (Watanabe et al., 2019).

Another analysis using the cohort of the Nagoya Longitudinal Study of Healthy Elderly (NLS-HE), investigating the associations between nutrition and frailty, also used our original frailty index. The article entitled 'A 3-year prospective cohort study of dietary patterns and frailty risk among community-dwelling Japanese elderly' was submitted in December 2019 to the journal *Clinical Nutrition* (Impact Factor 4.77), by Huang et al, and myself as one of the co-authors.

9.1.5 Physical environment and its influence on frailty

Chapters 7 and 8 focused on the main goals of this doctoral thesis, investigating the association of the physical environment with frailty in older adults. The research reported in Chapter 7 investigated the association between perceptions of the neighbourhood environment and the levels of frailty among older adults living in the community in Nagoya, Japan, using univariate and multivariable linear regression models. Analysis of the 2017 wave of the Nagoya Longitudinal Study found a linear association between frailty index and neighbourhood perceptions captured using the Neighbourhood Environment Walkability Score (NEWS) (Cerin et al., 2013). This NEWS captures overall neighbourhood environment walkability, that is, ease of movement around the neighbourhood in terms of the physical effort and the desire to get out and walk. The eight subscales used to investigate walkability were:

- residential density
- land use mix diversity
- land use access
- street connectivity
- walking and cycling facilities
- aesthetics
- traffic safety
- crime safety.

After adjustments to several covariates, frailer older adults were recorded as more likely to perceive their environment as a location with fewer destinations, worse street connectivity, poorer infrastructure for walking, poorer aesthetics and higher levels of crime than less frail older adults.

In Chapter 8, perceptions of the neighbourhood environment among older adults living in Adelaide, South Australia were compared to objective measures of the same environment. The same NEWS (Australian version) (Cerin et al., 2008) as in Chapter 7 was used to develop a multivariable model that adjusted each subscale to its correspondent GIS objective variable, as well as other covariates. A poor neighbourhood environment, poor diversity of land use, poor land use access and poor perceptions of crime safety were independently associated with frailty and pre-frailty.

The combined findings from the two studies reported in Chapters 7 and 8 corroborate our initial hypothesis that neighbourhood environment is independently associated with frailty in community-dwelling older adults in Japan and Australia, and several individual aspects of the neighbourhood environment were found to be associated with frailty. Analysis of the data indicated that the effect of neighbourhood environments on frailty risk related to the behavioural adaptations seen in challenging environments, which have been described previously as ‘constriction to life-space’ by Xue et al (Xue et al., 2008). The influence of life-space constriction on physical activity is especially related to the availability of green spaces, as described by Yu et al (Yu et al., 2018).

Although the Xue (2008) and Yu (2018) studies are very relevant longitudinal analyses, they reflect the reality of the specific environments they analysed – Maryland, USA and Hong Kong, China – and different elements of the environment might be associated with frailty, depending on the nature of the population and the context (Koohsari et al., 2018). Differences were seen in the associations found for Nagoya (Chapter 7) and Adelaide (Chapter 8).

Another important finding from Chapter 8 was the different findings obtained using objective and perceived neighbourhood variables. The use of perceived or objective neighbourhood environment variables has received considerable debate in the environmental literature, and research studies have often focused on a single variable to assess the characteristics of the physical environment.

Our research found a poor agreement between objective and subjective environmental variables, which is consistent with previous literature (Lin & Moudon, 2010; McGinn, Evenson, Herring, Huston, & Rodriguez, 2007). Poor agreement probably indicates that a single subjective variable cannot fully represent the respective objective variable and vice-versa. It is more likely that the variables complement one another in the information they provide about the characteristics of the built environment (Nyunt et al., 2015). As mentioned in Chapter 8, our research might indicate that subjective evaluations of space might yield stronger relationships with behaviour, which is the ultimate goal when inducing health-enhancing habits, although some researchers argue that the use of objective measures of the environment can produce stronger associations with certain health outcomes, such as walking (Lin & Moudon, 2010).

9.2 Significance and contribution

This PhD has generated new knowledge and contributed significantly to research in the area of the neighbourhood environment and frailty in older adults.

9.2.1 Perceptions of the environment

A major contribution arising from this PhD is the demonstration that perceptions of the neighbourhood environment are associated with frailty status in two different populations, with different socioeconomic and cultural backgrounds, as noted particularly in Chapters 7 and 8.

An overall worse perception of the neighbourhood environment was consistently associated with frailty in Nagoya and Adelaide, meaning that an environment that is less conducive to walking and physical activities is associated with increased frailty. Based on the findings of this research, it appears that the elements in the environment that negatively affect the perceptions of older residents vary according to the nature of the residents. It was found that in Nagoya there were significant associations between frailty and:

- diversity of land use
- land use access
- street connectivity
- walking and cycling facilities
- aesthetics
- crime safety.

In Adelaide, frailty was associated with:

- the diversity of the mix of land use
- access to land use
- crime safety.

after adjustment to objective assessments of the physical environment. The broad evaluation of different elements of the neighbourhood environment in relation to frailty is a novel investigation and has not been described in Japan or Australia. Understanding which factors influence older adults' physical and social activities might be important to the effective implementation of interventions targeting frail older adults and public health efforts to prevent or reduce frailty risk in the community.

There is a need to broaden the investigations into the development of frailty and include more complex evaluations of the neighbourhood environmental influences on frailty. As proposed by ecological models of aging, the environment can act as a stressor or barrier to vulnerable older individuals, but as mentioned in Chapter 1, if competence far surpasses the environmental press, boredom and atrophy can occur, suggesting that enriching environments can also promote active and healthy behaviours, thus deferring or delaying the occurrence of frailty. Physical activity and nutritional interventions remain the most common strategies used to treat frailty (Dent et al., 2017). But initial evidence suggests that neighbourhood environmental factors can influence the effectiveness of trials promoting physical activity in the community (Perez et al., 2018).

9.2.2 Development of a frailty index tool for a Japanese context

Another contribution to the frailty literature was the development of a frailty index tool for the NLS-HE, and the comparison with other frailty tools in the Japanese context. This is discussed in Chapter 6. A brief review of the Japanese literature revealed that a frailty index had rarely been used with the Japanese population, with much more focus on the frailty phenotype (Kojima et al., 2017) or the use of an abbreviated version in the surgical context (Gomibuchi et al., 2018; Mori et al., 2017; Morisaki, Yamaoka, Iwasa, & Ohmine, 2017; Yagi et al., 2018; Yoshida et al.,

2012) that does not incorporate the multidimensional character of the frailty index proposed by Mitnitski (Mitnitski et al., 2001).

Our use of the frailty index in a Japanese population of older adults receiving home medical care (Watanabe et al., 2019), and in the Nagoya Longitudinal Study – Healthy Elderly – to investigate the associations of frailty with dietary patterns (Huang et al) generated increased interest in using the index more often for research in Japan. It is anticipated that the frailty index will be used in the longitudinal analysis of frailty transitions obtained in the Nagoya cohort. We also introduced to this cohort the use of the Neighbourhood Environment Walkability Scale in 2017 and 2018, allowing for the analysis of the perception of the neighbourhood environment among this cohort, with a possible longitudinal analysis of changes in neighbourhood perceptions.

9.2.3 Training health professionals to identify and manage frailty

Finally, the research reported in this thesis has raised the awareness of the topic of frailty and the training of health professionals to correctly identify and manage frailty, which are priorities in the frailty agenda (Cesari, Prince, et al., 2016). We also addressed these priorities by investigating medical students' perceptions of the importance and competence in diagnosing frailty, bringing attention to this topic in the medical curricula, as presented in Chapter 3.

9.3 Future directions and policy implications

9.3.1 Future research

Future research possibilities have been identified based on the findings from this PhD:

- There is a need for more longitudinal examinations of the effects of neighbourhood characteristics on frailty, both objective features and perceived attributes, as well as investigating the determinants of perceived environment among frail subjects. Considering that frailty can change over time, for better or worse, more evaluation of the causal relationships between frailty and neighbourhood environment over time is required, as proposed by Yu et al. (2018), in a study of green spaces and frailty. Time spans of over 12 months might be important to ascertain meaningful changes, as seen for the effect of neighbourhood environment characteristics over other similar outcomes, such as BMI and walking habits (Gebel, Bauman, Sugiyama, & Owen, 2011). The evaluation of the ongoing cohort of the Nagoya Longitudinal Study with yearly re-evaluations can be considered for this purpose.
- In Japan (as noted in Chapter 7), evaluation of objective neighbourhood characteristics and their relationship to frailty, as well as a comparison of the perceptions of the neighbourhood environment with the objective variables, would improve our knowledge of the effects of the neighbourhood environment on vulnerable older adults for Japanese older adults, as discussed in older adults from Adelaide in Chapter 8.
- The findings discussed in Chapter 5 indicate that the evaluation of physiological markers of stress, such as heart rate variability and electrodermal activity, during older adults' use of the public spaces of a hospital would allow for a more accurate correlation of the effect of space on their health. Some evidence from Japan has shown that certain architectural elements, such as a garden placed inside ward areas, can produce physiological changes in patients with dementia (Goto et al., 2017); but the physiological effects of experiences in a public space of the hospital (such as waiting rooms, corridors etc) have not been assessed. And evaluation of their physiological reactions could ultimately confirm our findings from qualitative interviews about the effects of environmental features in a hospital.
- The review of the literature reported in Chapter 3 demonstrated a lack of available training on the topic of frailty for health professionals. It is important to assess whether and how well the training of young physicians prepares these future medical professionals for the management of frail patients, evaluating the competence levels of trained medical students longitudinally, over internship and residency training. The development of assessment tools that evaluate competence, as well as the objective knowledge that changes during training, is necessary to pursue this important line of research.

9.3.2 Policy implications

From the findings from this PhD, a few policy implications were identified.

- Although the *Global age-friendly cities guide* (WHO, 2007) notes that outdoor spaces and public buildings have a major impact on the independence and quality of life of older adults, very few specific local governmental policies exist to guide the design of the built environment to ensure that it meets the needs of older adults with increasing frailty. As observed in Chapter 4, significant challenges exist for older adults with frailty and/or reduced mobility, and few architectural audits take place after public building renovations or expansions occur. Seating, aesthetically pleasing effect, wayfinding systems and accessibility should receive special focus in designing for frail older adults.
- The planning and design of local neighbourhood environments should take into account the challenges faced by frail older adults. The importance of neighbourhood walkability in an age-friendly city can be seen in WHO's core indicators of age-friendliness (WHO, 2015a), which focus on pedestrian walkability, the accessibility of buildings and general safety. These points agree with our findings, outlined in Chapters 7 and 8, as neighbourhood features associated with frailty. We emphasise, as well, the importance of street connectivity and land use diversity, also associated with frailty. Including these elements creates a more 'walkable' environment and accounts for more careful city planning.
- Finally, changing older adults' perceptions of their local environment might be an interesting strategy for improving their physical and social participation in their neighbourhood. As discussed in Chapter 8, subjective perceptions of neighbourhood environment might be more relevant to the behaviour of older adults than objective variables. In a longitudinal study conducted in Australia (Gebel et al., 2011), the misperception of highly walkable neighbourhoods as low in walkability has been found to significantly decrease walking time among older adults. Furthermore, negative neighbourhood perceptions might even affect the effectiveness of interventions aimed at increasing physical activity in the community (Perez et al., 2018). Understanding local perceptions of the neighbourhood and addressing the mismatches between perceptions and reality might be a good strategy to improve older adults' participation, and even long-term health.

9.4 Conclusion

The research for this PhD explored how frailty can be influenced by the physical environment of the neighbourhood. Research participants were community-dwelling older adults from Adelaide, Australia and Nagoya, Japan. The determinants of healthy ageing depend on extrinsic, as well as intrinsic factors, and understanding how these factors interact with one another is one of the challenges in the management of frailty. There is a clear need for public health and therapeutic strategies to consider how individual perceptions of a neighbourhood environment might affect health. Additionally, adequate assessment and training of health professionals on the topic of frailty are essential to improve the management of frailty in the community.

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