HEALTHY AGING AND THE COMMUNITY ENVIRONMENT

EDITED BY: Chanam Lee, Xuemei Zhu, Anna Patricia Lane and Erja Portegijs
PUBLISHED IN: Frontiers in Public Health

frontiers Research Topics

Frontiers eBook Copyright Statement

ISSN 1664-8714
ISBN 978-2-88971-714-9
DOI 10.3389/978-2-88971-714-9

About Frontiers

Frontiers is more than just an open-access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers Journal Series

The Frontiers Journal Series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the Frontiers Journal Series operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to Quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews.
Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the Frontiers Journals Series: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area! Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers Editorial Office: frontiersin.org/about/contact

HEALTHY AGING AND THE COMMUNITY ENVIRONMENT

Topic Editors:
Chanam Lee, Texas A&M University, United States
Xuemei Zhu, Texas A&M University, United States
Anna Patricia Lane, Singapore University of Technology and Design, Singapore
Erja Portegijs, University of Groningen, Netherlands

Citation: Lee, C., Zhu, X., Lane, A. P., Portegijs, E., eds. (2021). Healthy Aging and the Community Environment. Lausanne: Frontiers Media SA.
doi: 10.3389/978-2-88971-714-9

Table of Contents

frontiers in Public Health

EDITORIAL
published: 15 October 2021
doi: 10.3389/fpubh.2021.737955

Editorial: Healthy Aging and the Community Environment

Chanam Lee[1]*, Xuemei Zhu[2], Anna Patricia Lane[3] and Erja Portegijs[4]

[1] Department of Landscape Architecture and Urban Planning, Texas A&M University, College Station, TX, United States, [2] Department of Architecture, Texas A&M University, College Station, TX, United States, [3] Lee Kuan Yew Centre for Innovative Cities, Singapore University of Technology and Design, Singapore, Singapore, [4] Faculty of Sport and Health Sciences and Gerontology Research Center, University of Jyväskylä, Jyväskylä, Finland

Keywords: active aging, aging-friendly community, age-friendly community, aging in place, community environment, healthy aging

OPEN ACCESS

Edited and reviewed by:
Rebecca Hunter, University of North Carolina at Chapel Hill, United States

****Correspondence:***
Chanam Lee
chanam@tamu.edu

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *07 July 2021*
Accepted: *10 September 2021*
Published: *15 October 2021*

Citation:
Lee C, Zhu X, Lane AP and Portegijs E (2021) Editorial: Healthy Aging and the Community Environment. Front. Public Health 9:737955. doi: 10.3389/fpubh.2021.737955

Editorial on the Research Topic

Healthy Aging and the Community Environment

Population aging is a global issue that brings many challenges and opportunities to modern societies. Healthy aging and age-friendly communities are important public health priorities which rely heavily on having supportive community environments that meet the needs of older adults. Such environmental supports may include barrier-free home and neighborhood environments, daily destinations located within an easy walking distance from home, connected and well-maintained sidewalks, and benches and good lighting along streets/paths, among many others. Requirements and preferences for environmental supports vary by different groups and generations of older adults. Healthy aging also requires supportive social and technological environments. Technology is an increasingly important factor driving changes in senior living. It offers a variety of solutions to support older adults' independence and social connectedness, as well as strategies to improve measurement approaches to better understand spatio-behavioral patterns of older adults' daily living.

The 15 articles included in this Special Issue respond to some of the critical needs presented by the current generation of older populations living in diverse socio-cultural contexts. They address five main themes central to meeting these needs, including (a) active living/aging, (b) health-related outcomes linked with community environments, (c) housing environments, (d) technological innovations and novel applications, and (e) methodological approaches. Collectively, these articles illustrate the potential of using interventions in housing, community, and technology environments to create aging-friendly communities that can bring beneficial outcomes for healthy aging and aging in place in both the short-term and long-term, as illustrated through a logic model in **Figure 1** (1).

First, five articles in this Special Issue address active living/aging, and examine how community environments can help older adults adopt and maintain active lifestyles. Two articles address the link between neighborhood environments and physical activity. Keskinen et al. studied community-dwelling older adults in Finland and showed the importance of proximate environments (e.g., diverse natural/green areas, street intersection density, residential density) in supporting older adults' moderate-to-vigorous physical activity (MVPA). They also demonstrated that the environment-MVPA associations may vary depending on the days of the week (i.e., weekdays vs. weekends). Another Finnish study by Portegijs et al. demonstrated that barriers near (≤500 m) home were negatively associated with physical activity among community-dwelling older adults, while attractive destinations further away (>500 m) were positive correlates. He et al. conducted their study in a highly dense Chinese megacity, exploring the relationship between built environments and walking among older adults. Their results revealed limited roles of neighborhood walkability (street connectivity being the only significant factor) in leisure-time walking. This is somewhat different from another study in this issue (Herbolsheimer et al.) and the previous literature that reported significant

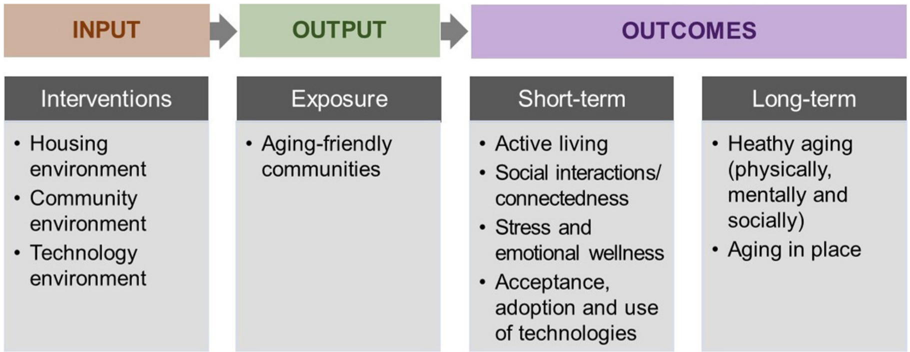


FIGURE 1 | Logic model for promoting healthy aging through environmental interventions, represented by the papers included in this Special Issue.

results for multiple walkability measures and strong relationships between built environments and transportation walking among seniors (2, 3). Two other studies under this theme were carried out in North American cities and identified specific features/elements of the neighborhood environment associated with transportation walking among older adults. Those features include density, crosswalks, and parks or outdoor fitness amenities in Herbolsheimer et al.; and crosswalks, pedestrian signals, unattended dogs, lighting at night, religious institutions, and slope in the study by Lee et al. These studies together highlighted diverse community factors associated with walking and overall physical activity among older adults.

The second theme in this Special Issue is represented by three articles linking older adults' health-related outcomes with walking and the community environment in the U.S. Zhong et al. reported that walkability-related features of the neighborhood, such as transportation infrastructure, land uses, land covers, population densities, and development activities, were associated with social interactions, including intergenerational activities, among older adults from Austin, Texas. Roe et al. found that walking in an urban green district (a quiet residential area with front gardens and street trees) brought positive changes in emotional well-being and stress physiology for senior residents. A national cohort study by Jones et al. detected a negative relationship between neighborhood Walk Score and the incident hypertension risk in black and white older adults. In addition to the behavioral outcomes discussed under the first theme of active living/aging, studies in this second theme add examples of physical, mental, and social health outcomes tied with community environments.

Third, three studies carried out in Australia, Finland, and Ghana address the roles of housing environments in diverse sociocultural contexts. The Australian study (Byles et al.) explored the relationship between housing types and the care needs among 12,432 women. Compared to those living in a house, older women living in an apartment and a retirement village/hostel had moved faster to a residential aged care facility. The Finnish study (Jolanki) used a qualitative approach to interview 36 residents of a communal senior housing complex. The results suggested that the design intention of providing accessible, safe, and affordable environments was met, while differences existed among the residents in terms of the specific environmental features and characteristics important to them. Another qualitative study (Alaazi et al.) involving older adults residing in slum and non-slum neighborhoods in Ghana found similar environmental barriers (e.g., poor drainage, lack of sidewalks, poor housing conditions, unsanitary conditions) to health in both types of neighborhoods. They also pointed out challenges in developing effective policy interventions to support living environments that are affordable, safe, and accessible for older adults. These studies on housing environments contribute to the discussions on the need to consider the community environment at multiple spatial scales, ranging from housing and immediate surroundings to the neighborhood and the larger city or socio-cultural contexts.

Fourth, this issue considered the emergence of technological innovations and novel applications to support healthy aging. Two articles address this topic. A U.S. study by Seo et al. introduced a novel art–technology intergenerational community program designed to support older adults' health, well-being, and intergenerational connectedness. The 18 participants of this program reported benefits in their relationships with student volunteers and with their own family members. den Haan et al. from the Netherlands and Australia presented a living lab approach to show how a social learning environment can be created to facilitate the acceptance, adoption, and sustainable use of smartphone technologies. They highlighted the promise of using super-users, who are previously trained peer users, to create supportive peer learning mechanisms and peer support environments. These articles on technologies offer valuable insights on the new or complementary approaches to empower older adults to remain engaged and age in place.

In addition, papers in this Special Issue employ a variety of measurement methods, ranging from the traditional self-report methods such as surveys, interviews, and focus groups, to objective measures using geographic information systems, accelerometers, street/environmental audits, noise and air quality sensors, and smartwatches. Two articles specifically focus on methodological approaches to facilitate healthy aging research. A literature review article by Zanwar et al. provided a synthesis of the growing body of interdisciplinary studies and methods on connected technologies such as wearable and embedded sensors and processors that connect people with their environments. Lin et al. validated the global self-rated health and happiness measures for use in community-dwelling older adults using a large sample in Taiwan, with the age- and gender-specific scoring systems. These studies point to the need for valid measurement methods tailored for older adults and the challenges in using technology-based methods in studies involving or about older adults due to reasons such as their health conditions and low acceptance levels.

In summary, articles in this Special Issue addressed the role of community environments in healthy aging, which encompassed diverse scales (e.g., homes, streets, neighborhoods) and domains of the built, social, and technological environment. They were carried out in multiple socio-cultural contexts from eight countries (Australia, Canada, China, Finland, Ghana, the Netherlands, Taiwan, and the U.S.) and five continents (Africa, Asia, Australia, Europe, and North America). Manuscript types are diverse, including one literature review article, four qualitative studies, one validation study, one pilot study, and eight quantitative studies. Most studies included in this issue are cross-sectional, and longitudinal and intervention studies are not well-represented. There is a need for continued work in this area addressing the full range of built, social, and technological environments and their causal impacts on healthy aging outcomes.

Collective findings from these studies offer valuable knowledge for future research and practice in terms of facilitating healthy aging and aging in place through supportive environments. This Special Issue highlights some of the promising efforts that interdisciplinary scholars have been making toward consolidating the link between community/technological environments and healthy aging.

AUTHOR CONTRIBUTIONS

CL drafted and finalized the editorial. XZ developed the figure and reviewed/edited the editorial. AL and EP reviewed/edited the editorial. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

We thank all the contributors to this Special Issue.

REFERENCES

1. Kaplan SA, Garrett KE. The use of logic models by community-based initiatives. *Evaluat Program Plann*. (2005) 28:167–72. doi: 10.1016/j.evalprogplan.2004.09.002
2. Cerin E, Nathan A, van Cauwenberg J, Barnett DW, Barnett A, Council on E, et al. The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act*. (2017) 14:15. doi: 10.1186/s12966-017-0471-5
3. Van Cauwenberg J, Nathan A, Barnett A, Barnett DW, Cerin E, Council on E, et al. Relationships between neighbourhood physical environmental attributes and older adults' leisure-time physical activity: a systematic review and meta-analysis. *Sports Med*. (2018) 48:1635–60. doi: 10.1007/s40279-018-0917-1

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 31 July 2020
doi: 10.3389/fpubh.2020.00346

Validation of Global Self-Rated Health and Happiness Measures Among Older People in the Yilan Study, Taiwan

Yen-Huai Lin[1,2], Hsi-Chung Chen[3], Nai-Wei Hsu[2,4,5,6]* and Pesus Chou[2]

[1] Department of Medical Imaging, Cheng Hsin General Hospital, Taipei, Taiwan, [2] Community Medicine Research Center, National Yang-Ming University, Taipei, Taiwan, [3] Department of Psychiatry and Center of Sleep Disorders, National Taiwan University Hospital, Taipei, Taiwan, [4] Division of Cardiology, Department of Internal Medicine, National Yang-Ming University Hospital, Yilan, Taiwan, [5] Department of Medicine, School of Medicine, National Yang-Ming University, Taipei, Taiwan, [6] Public Health Bureau, Yilan, Taiwan

OPEN ACCESS

Edited by:
Chanam Lee,
Texas A&M University, United States

Reviewed by:
Alexjandro C. Daviano,
EBSCO Health, United States
Angela M. Goins,
University of Houston–Downtown,
United States

***Correspondence:**
Nai-Wei Hsu
davidnwh@ms28.hinet.net

Specialty section:
This article was submitted to
Aging and Public Health,
a section of the journal
Frontiers in Public Health

Received: 21 December 2019
Accepted: 19 June 2020
Published: 31 July 2020

Citation:
Lin Y-H, Chen H-C, Hsu N-W and Chou P (2020) Validation of Global Self-Rated Health and Happiness Measures Among Older People in the Yilan Study, Taiwan. Front. Public Health 8:346. doi: 10.3389/fpubh.2020.00346

Background: Single-item measures of physical and mental health are feasible for older adults, but their validity for that age group is unclear. This study tested validity of a global self-rated health and a global self-rated happiness measure in a large sample of community-dwelling older adults in Taiwan.

Methods: A cross-sectional sample of 3,982 men and women aged 65 or older in Yilan, Taiwan, provided data on global self-rated health and happiness using 100-point numerical scales. The Physical Component Summary of the 12-Item Short Form Health Survey (version 2) and the Groningen Activity Restriction Scale were used to test the validity of the self-rated health item. The Mental Component of that 12-item scale and the Hospital Anxiety and Depression Scale were validators regarding the self-rated happiness item. Criterion validity was tested using the 12-Item Short Form Health Survey (version 2).

Results: The correlations between the self-rated health and happiness measures and the 12-Item Short Form Health Survey (version 2) validators were positive and statistically significant, supporting convergent validity. Sufficient divergent validity was demonstrated through the negative and significant relationship between the self-rated health item and the Groningen Activity Restriction Scale scores and the negative and significant relationship between the self-rated happiness item and the Hospital Anxiety and Depression Scale. Optimal cut-off scores for physical and mental health states depended on age and gender.

Conclusion: The global self-rated health and happiness measures were validated. Cut-off scores for evaluating older adults' physical and mental health should be age- and gender-specific.

Keywords: health-related quality of life, older adults, self-rated health, self-rated happiness, validation, Yilan study

INTRODUCTION

Population aging is dramatically increasing around the world, and evaluating and eliminating health problems for older adults in the community are important aspects of public health. Physical and mental health assessments are major components of comprehensive geriatric assessments (1). For these evaluations, the paper-and-pencil questionnaire remains the most feasible tool, but older adults' cognitive, functional and aging-related vision and hearing losses tend to increase the costs, decrease the validity and reduce older people's willingness to participate in these evaluations. Therefore, valid, simple, and easy ways to measure physical and mental health are important to community-based geriatric medicine. Asking a general or global question has the advantage of being a relatively low-cost way to easily collect, score and interpret these valuable data.

Global self-rated health measures have been widely applied in general populations, developing countries, militaries, and many societies, and they have been found to adequately and objectively indicate physical health, mental health, chronic diseases, unhealthy behaviors and physical functioning (2–5). Despite the potential value of global measures, they are not widely used for older adults, partly because their validity has not been established for that age group. It is suspected that global self-ratings might not be sensitive enough to distinguish among subtle individual differences because of older adults' declining physical functionality. However, most of the global self-rated health measures' response options are ordinal scales, which tend to be relatively insensitive to skewed distributions and might compromise validity (6). It has been suggested that a numerical rating scale in response to a global question might be more accurate for measuring older adults' health status (7). To the best of our knowledge, no previous study has investigated the validity of global self-rated health measures with numerical scales for older adults in Asia.

Regarding mental health, global self-rated happiness measures have been developed. Happiness is a combination of positive hedonic, cognitive, and affective states, and individual assessments of personal happiness are influenced by individual, cultural and societal factors (8). Similar to self-rated physical health, the instruments use ordinal response scales (9–11). Moreover, although comprehensive verifications of construct validity should evaluate divergent as well as convergent validity, most global self-rated happiness measures have been assessed for convergent validity using constructs that measure emotions or attitudes, such as life satisfaction (12), or happiness (13). The 12-Item Short Form Health Survey (version 2) [SF-12v2] is a multi-dimensional instrument that comprises physical, mental, emotional, and social health dimensions to evaluate health-related quality of life, which is reasonable as an external validator for self-rated health and happiness. Although the physical component summary (PCS) of the SF-12v2 has previously been used to validate global self-rated health (14), no previous study has used its mental component summary (MCS) as an external validator of global self-rated happiness. Besides, we know of just one multi-item self-rated happiness scale of which the divergent validity was assessed using depression and anxiety (15). Further, similar to measures of self-rated health, no global self-rated happiness measure with numerical scales has been assessed regarding its construct validity in older adults.

Therefore, the present study investigated validity of a global self-rated health measure and of a global self-rated happiness measure. The sample was a large cohort of community-dwelling older adults. A comprehensive set of external validators, including SF-12v2 was used to evaluate construct validity and the criterion validity of the two self-rated measures.

METHODS

Participants

The data used for this study were derived from the Yilan Study, a community health survey conducted by the Community Medicine Research Center of National Yang-Ming University and National Yang-Ming University Hospital in Taiwan. The data were collected between January 2012 and November 2016. The household registration lists were protected under the personal data protection law of Taiwan and, therefore, a sample was randomly selected from all city residents aged 65 years or older living in Yilan City. Trained interviewers went to the participants' homes for face-to-face interviews. The final sample comprised 3,982 individuals. The details of the sampling methods have been previously reported (16, 17). The institutional review board of National Yang-Ming University Hospital (IRB No. 2011A016) approved the study. Informed written consent was obtained from all the participants, and all methods were performed according to the relevant guidelines and regulations.

Instruments

Verifying Convergent and Divergent Validity of the Global Self-Rated Health Measure

The participants were asked to self-rate their general health status on a scale of zero to 100 where higher scores indicated better health. They answered the following question: "How would you rate your present health status?" The PCS of the SF-12v2 was used to assess the convergent validity of the global self-rated health measure. The Chinese translation of the SF-12v2 previously was found to be a valid instrument (18). The Groningen Activity Restriction Scale (GARS) was used to assess the divergent validity of the global self-rated health measure. The GARS is considered a valid measure for assessing disability in activities of daily living (ADLs) and instrumental activities of daily living (IADLs) in older people (19).

Verifying Convergent and Divergent Validity of the Global Self-Rated Happiness Measure

The participants evaluated their happiness by responding to the question: "In general, how would you rate your current state of happiness?" They rated themselves on a scale of zero to 100 and higher scores indicated more happiness. To assess the convergent validity of global self-rated happiness, the Mental Component Summary (MCS) of the SF-12v2 was used. The Chinese translation of this part of the SF-12v2 is considered valid (18). The Hospital Anxiety and Depression Scale (HADS) was used to determine the divergent validity of the global self-rated health measure. The HADS is a reliable instrument used to measure clinical and subclinical anxiety and depression in the general population (20, 21), and the Chinese translation of the HADS is considered valid (22).

Criterion Validity of the Global Self-Rated Health and Happiness Measures

Previous studies that investigated the cut-off scores for PCS or MCS for predicting physical or mental health outcomes (23–25) implied the inclusiveness of the SF-12v2 regarding overall health status. Thus, the two components' scores were effective options for assessing optimal physical and mental health scores with respect to global questions. A previous study has used the SF-12v2 as a validation instrument for global self-rated health (14). The PCS and the MCS use norm-based scoring in which scores higher (or lower) than 50 indicate better (or worse) physical (or mental) health relative to that of a given sample's population (26). In addition, previous studies have found that cut-off values on the PCS and MCS below 50 points were related to poor physical and mental health, respectively (23–25, 27). Accordingly, the present study used a score of 50 or higher on the PCS and MCS as the cut-off scores to indicate the optimal self-rated health and happiness scores in the self-rated measures, respectively. Regarding criterion validity, the receiver operating characteristics (ROC) curve was used to determine the cut-off scores on global self-rated health and happiness based on a score of 50 in the PCS and MCS.

Statistical Analysis

The Chi-Square goodness-of-fit test was used to compare the demographic characteristics of the sample to those of the Yilan city population. Pearson's correlation coefficients were calculated to investigate the relationships among the two global measures, PCS, MCS, GARS, and HADS. The size of the correlation is defined as high, moderate, and low by scores of: 0.70–0.89, 0.40–0.69, and 0.10–0.39, respectively (28). A stepwise multivariable linear regression analysis estimated the associations between the PCS and self-rated health and between the MCS and self-rated happiness. A general linear model was used to compare the between-group differences in self-rated health and in self-rated happiness with and without controlling for the effects of gender and age. The Youden's index was calculated from the ROC curve to determine the optimal cut-off scores for self-rated health and happiness based on cut-off scores of 50 on the PCS and MCS, respectively. All statistical tests were two-tailed, and $p < 0.05$ was considered statistically significant. The statistical software package SPSS for Windows, Version 19.0 (SPSS Inc., Chicago, IL, USA) was used to perform all the analyses.

RESULTS

Sample Characteristics

Table 1 presents the sample's demographic characteristics. About 57% of the sample was female, and compared to the registered residents of Yilan who were aged ≥ 65 in 2012 (29), the sample was significantly older ($\chi^2 = 99.2$, df = 1, $p < 0.001$) and more likely to be female ($\chi^2 = 21.1$, df = 1, $p < 0.001$). The PCS mean was 46.7, and the MCS mean was 57.9. The self-rated health mean was 69, and the self-rated happiness mean was 74.

TABLE 1 | Descriptive statistics (n = 3,982).

Variable	Number of cases *(n)*	Percentage (%)	Mean	Standard deviation
Age (in years)				
65–74	1,841	46.2		
75 or older	2,141	53.8		
Gender				
Male	1,711	43.0		
Female	2,271	57.0		
Self-rated measures				
Self-rated health (range: 0–100)			69.0	12.5
Self-rated happiness (range: 0–100)			74.0	14.5
Short Form-12v2				
Physical Component Summary (PCS) (range: 11.6–71.1)			46.7	10.0
Mental Component Summary (MCS) (range: 10.4–77.8)			57.9	8.3
Groningen activity restriction scale (GARS) (range: 18–72)			23.7	12.3
Hospital Anxiety And Depression Scale (HADS) (range: 0–36)			4.6	5.0

TABLE 2 | Bivariate correlation matrix among the six measures of health and happiness[a] (n = 3,982).

Measure	1	2	3	4	5	6
1. PCS	1					
2. MCS	0.038*	1				
3. HADS	−0.264***	−0.583***	1			
4. GARS	−0.766***	−0.355***	0.319***	1		
5. Global self-rated health	0.471***	0.249***	−0.318***	−0.316***	1	
6. Global self-rated happiness	0.310***	0.357***	−0.423***	−0.264***	0.600***	1

*$p < 0.05$, ***$p < 0.001$.
[a]*PCS, physical component summary; MCS, mental component summary; HADS, hospital anxiety and depression scale; GARS, groningen activity restriction scale.*

Convergent and Divergent Validity

Table 2 shows the bivariate correlation coefficients among the self-rated health, self-rated happiness, PCS, MCS, GARS, and HADS variables. Regarding global self-rated health, the convergent validity was tested by the correlation between global self-rated health and PCS ($r = 0.471$, $p < 0.001$) and divergent validity was indicated by the correlation between global self-rated health and GARS ($r = -0.316$, $p < 0.001$). Regarding global self-rated happiness, the correlation between global self-rated happiness and MCS assessed convergent validity ($r = 0.357$, $p < 0.001$) and the correlation between global self-rated health and HADS assessed divergent validity ($r = -0.423$, $p < 0.001$). The overall sizes of correlations between global self-rated health and happiness with external validators were low to moderate. In addition, the correlation between self-rated health and self-rated happiness was high ($r = 0.600$, $p < 0.001$).

TABLE 3 | Stepwise multivariable linear regressions for the associations of global self-rated health and happiness with the Physical Component Summary (PCS, Model 1[a]) and Mental Component Summary (MCS, Model 2[a]).

Model 1: PCS				Model 2: MCS			
Variable	**B**	**95% CI**	**Cum R^2**	**Variable**	**B**	**95% CI**	**Cum R^2**
Global self-rated health	0.351	0.330, 0.373	0.221	Global self-rated happiness	0.179	0.159, 0.200	0.127
Gender (ref.: female)				Gender (ref.: female)			
Male	0.564	0.027, 1.101	0.248	Male	0.917	0.434, 1.400	0.130
Age (in years; ref.: 75+)				Age (in years; ref.: 75+)			
65–74	3.128	2.596, 3.661	0.247	65–74 years	0.555	0.076, 1.034	0.133
Global self-rated happiness	–	–	–	Global self-rated health	0.029	0.005, 0.053	0.131

[a]*Final models are shown; unstandardized coefficients (B), 95% Confidence Intervals (CI), and cumulative R^2 (Cum R^2).*

TABLE 4 | Mean differences in global self-rated health and global self-rated happiness among the participants with PCS scores at or above the mid-score and MCS scores at or above the mid-score by age group and gender[a].

Variable	Global self-rated health						Global self-rated happiness					
	PCS ≥ 50			MCS ≥ 50			PCS ≥ 50			MCS ≥ 50		
	Mean	**SD**	***p***	**Mean**	**SD**	***p***	**Mean**	**SD**	***p***	**Mean**	**SD**	***p***
Age												
65–74	73.6	10.7	0.018	70.6	11.6	0.015	78.0	13.4	0.966	76.7	13.4	<0.001
75+	74.7	10.8		69.6	12.4		78.0	12.2		74.8	13.1	
Gender												
Male	74.6	10.8	0.04	70.9	12.0	0.001	78.1	12.5	0.549	76.2	13.0	0.076
Female	73.6	10.7		69.5	12.0		77.8	13.1		75.3	13.5	
	EMM	**95% CI**	***p***	**EMM**	**95% CI**	***p***	**EMM**	**95% CI**	***p***	**EMM**	**95% CI**	***p***
Age[b]												
65–74	73.7	73.0, 74.3	0.034	70.8	70.1, 71.4	0.006	78.0	77.2, 78.8	0.970	76.8	76.2, 77.5	<0.001
75+	74.7	74.0, 75.4		69.6	69.0, 70.2		78.0	77.1, 78.8		74.8	74.2, 75.4	
Gender[c]												
Male	74.6	73.9, 75.3	0.086	70.9	70.3, 71.6	<0.001	78.1	77.3, 79.0	0.567	76.3	75.7, 77.0	0.026
Female	73.8	73.1, 74.4		69.4	68.9, 70.0		77.8	77.0, 78.6		75.3	74.7, 75.9	

[a]*PCS, physical component summary; MCS, mental component summary; EMM, estimated marginal mean.*
[b]*Estimates are gender adjusted.*
[c]*Estimates are age adjusted.*

To examine the relationships between the PCS and the MCS and the two global self-rated measures, stepwise multivariable linear regression analysis was performed. The goal was to determine the strengths of the associations. **Table 3** shows the results. Model 1 shows that, net of the effects of age and gender, global self-rated health was related to PCS ($R^2 = 0.221$). With every unit increase in the global self-rated health, the PCS increased by 0.351. In Model 2, global self-rated health and global self-rated happiness related to MCS, and the relationship of global self-rated happiness was stronger than that of global self-rated health ($R^2 = 0.127$). With every unit increase in the global self-rated happiness, the MCS increased by 0.179.

Criterion Validity

The mean global self-rated health scores were significantly different by age and gender among the participants with PCS scores of 50 or higher (**Table 4**). Controlling for gender differences, the mean PCS score was still significantly higher among those aged 75 years or older compared to the younger participants. Among the participants with MCS scores of 50 or higher, the mean global self-rated happiness score was significantly different by age (those younger than 75 had a higher mean score) and gender (the males' mean was higher than the females' mean) even after controlling for the effects of gender or age (**Table 4**). Therefore, because of the gender and age differences, we calculated optimal scores for global self-rated health and global self-rated happiness separately by age and gender.

At a score of 50 on the PCS, the global self-rated health measure's cut-off scores were calculated as 68.5 overall, 68.5 for males, 67.0 for females, 67.0 for those aged 65–74 years, and 69.0 for those aged 75 or older (**Table 5**). At a score of 50 on the MCS, the cut-off scores on the global self-rated happiness measure were calculated as 69.5 overall, 69.5 for males, 62.5 for females, 69.5 for

TABLE 5 | Optimal cut-off scores on global self-rated health and global self-rated happiness when the PCS and MCS cut-offs are scores of '50'; n = 3,982.

Group	Physical component summary (PCS)	Mental component summary (MCS)
	Optimal cut-off scores on global self-rated health	Optimal cut-off scores on global self-rated happiness
Total sample	68.5	69.5
Gender		
Male	68.5	69.5
Female	67.0	62.5
Age (in years)		
65–74	67.0	69.5
75+	69.0	62.5

those younger than 75 years, and 62.5 for those aged 75 years or older (**Table 5**). **Figures 1**, **2** illustrate ROC curves among total participants and subgroups. The sensitivity, specificity and area under curve are shown in the **Table S1**.

DISCUSSION

Using a large number of elderly participants in Taiwan and various measurements as external validators, this study verified global measures of self-rated health and happiness, which differentially represent physical and mental dimensions of elders' health, respectively. In addition, cut-off scores for evaluating elderly adults' physical and mental health should be determined depending on age and gender.

Although the present study found global self-rated health and happiness were correlated with each other, the global self-rated health measure had a stronger relationship to the PCS, supporting the results of a previous study (14). That previous study also examined the relationship between global self-rated health and MCS (14). Although the present study found that global self-rated health significantly related to MCS, it was not a stronger association than that of global self-rated happiness with MCS. Our findings suggest that the PCS was a relatively better validator of global self-rated health and MCS was a relatively better validator of global self-rated happiness.

Gender related to the measures of self-rated health and happiness. Many previous studies have found that women rate their health lower than men rate their health (30–32). We found a similar gender difference, which might be because men generally compare their health to other men, whereas women tend to rate their health based on their family members' opinions (33). However, the gender difference regarding global self-rated happiness was inconsistent with previous results. One previous study found that women reported higher happiness than men in the past, but men had higher happiness than women at present (34). We found that men had higher self-rated happiness than women. Therefore, it is important to understand gender differences in self-rated health and happiness among older adults.

Self-rated health is believed to decrease with age (35, 36), but whether the influence of age continues into old age is unclear. Several previous studies found better self-rated health among older than younger old people (37, 38). Our results support these findings. A previous study on age-related changes in self-rated health among older men considered age, time and cohort effects and found that self-rated health was influenced by time, but there were no age or cohort effects (39). The researchers explained the absence of an age effect first by evoking the reference-group hypothesis, which contends that, among older people who perceive poor health and disability as their age-related norm, those who are relatively healthy rate their health positively. Another explanation was the health survivor effect, which proposes that people who do not have serious health problems are more likely to survive to older ages, so their assessments are objectively accurate.

Age also has been positively associated with happiness, and older people have been found to self-rated happiness higher than younger people (40, 41). The socio-emotional selectivity theory proposes that older people accumulate emotional wisdom that helps them to select emotionally satisfying activities and experiences (40); however, similar to self-rated health, it is not clear whether the influence of age on self-rated happiness continues into old age. Indeed, the age-happiness relationship among older people is often not discussed (40, 41). However, a recent study reported that happiness declined among very old people in Europe (42).

We found that the participants aged 75 or older with MCS scores of 50 or higher were less happy than their younger counterparts, which contradicts the socio-emotional selectivity theory. One previous study reported that older Chinese people had a high prevalence of mental disorders (43), which might contribute to low self-rated happiness. Moreover, our sample was drawn from the population of Yilan, which is an agricultural suburb. If they compared themselves to younger old people, the older old people in our sample might have thought they had fewer resources and less social support and rated themselves as less happy (42).

The present study argued the 100-point numerical rating scale is better than other scales to measure self-rated health and happiness. First, scores can be obtained in written or oral form, and it is simple to administer and score. It is reasonable for older adults who might be illiterate or have vision or hearing problems. In contrast, the visual analog scale can be administered only in writing. Second, regarding the psychometric criteria of reliability and predictive validity, there is the advantage of having 101 response options (44–46), which is likely to appeal to researchers concerned with the limited response options offered by ordinal scales (7). Third, it has the advantage over ordinal scales of being able to assess criterion validity.

This study had several strengths. First, the sample size of participants was large. Second, face-to-face interviews at the participants' homes reduced information bias. Third, it was the first study to determine the corresponding cut-off scores on global self-rated health and global self-rated happiness relative to the PCS and MCS separately by gender and age group. However, it had some limitations. First, the sample's demographic characteristics differed from that of the registered elderly residents of Yilan city. However, because this study was not an epidemiological survey, the sociodemographic representativeness of this sample is not

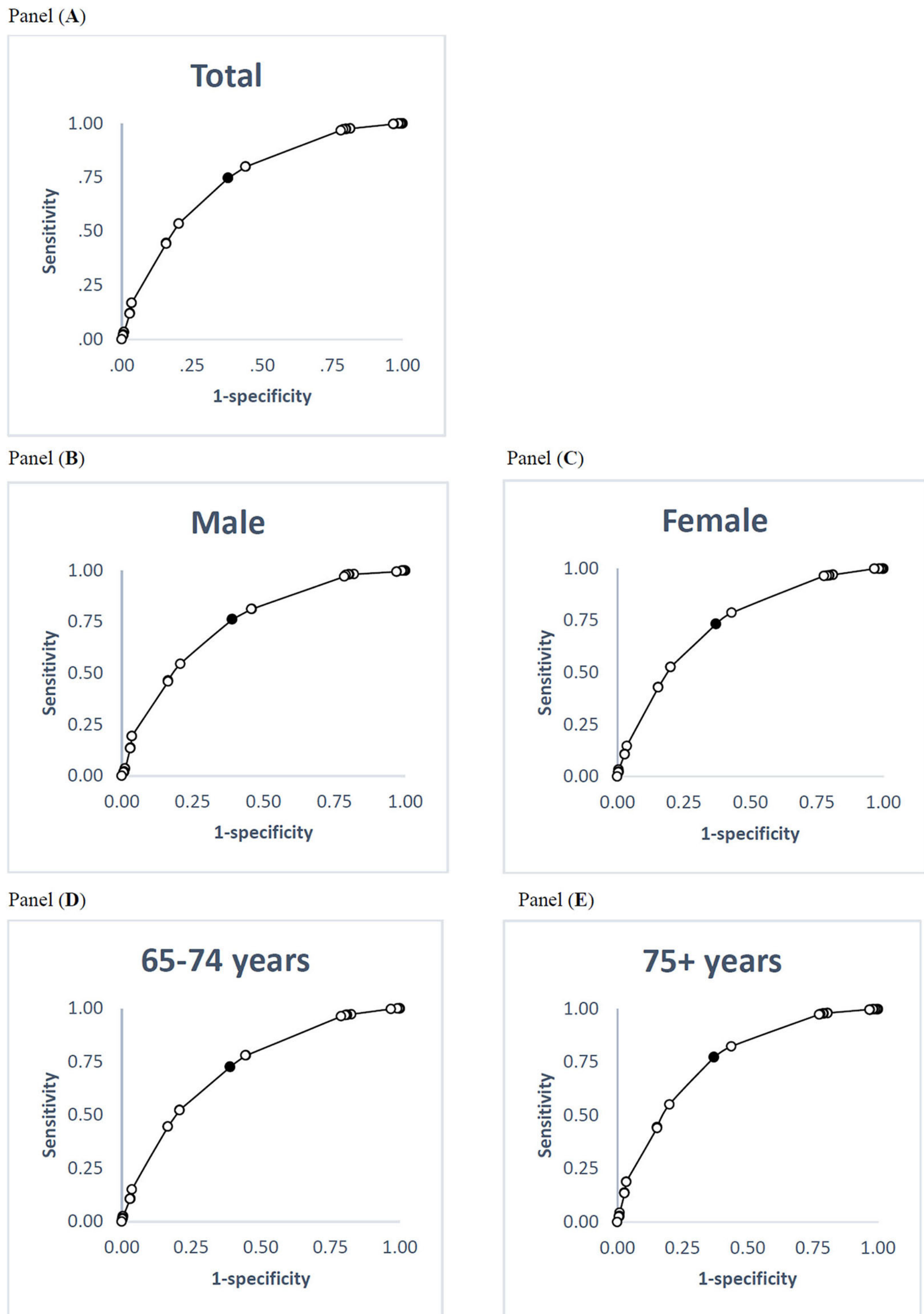


FIGURE 1 | ROC curves for global self-rated health relative to the PCS cut-off scores of 50. **(A)** Total participants; **(B)** male; **(C)** female; **(D)** 65–74 years; **(E)** 75+ years. Black point indicates the optimal cut-off point. ROC, receiver operating characteristics; PCS, physical component summary.

expected to compromise the generalizability of our findings. In contrast, the physical and cognitive demanding nature of our interview protocol suggests that the generalizability of our findings is limited to community-dwelling older adults with no serious physical and cognitive disability. The generalizability of our findings in additional populations

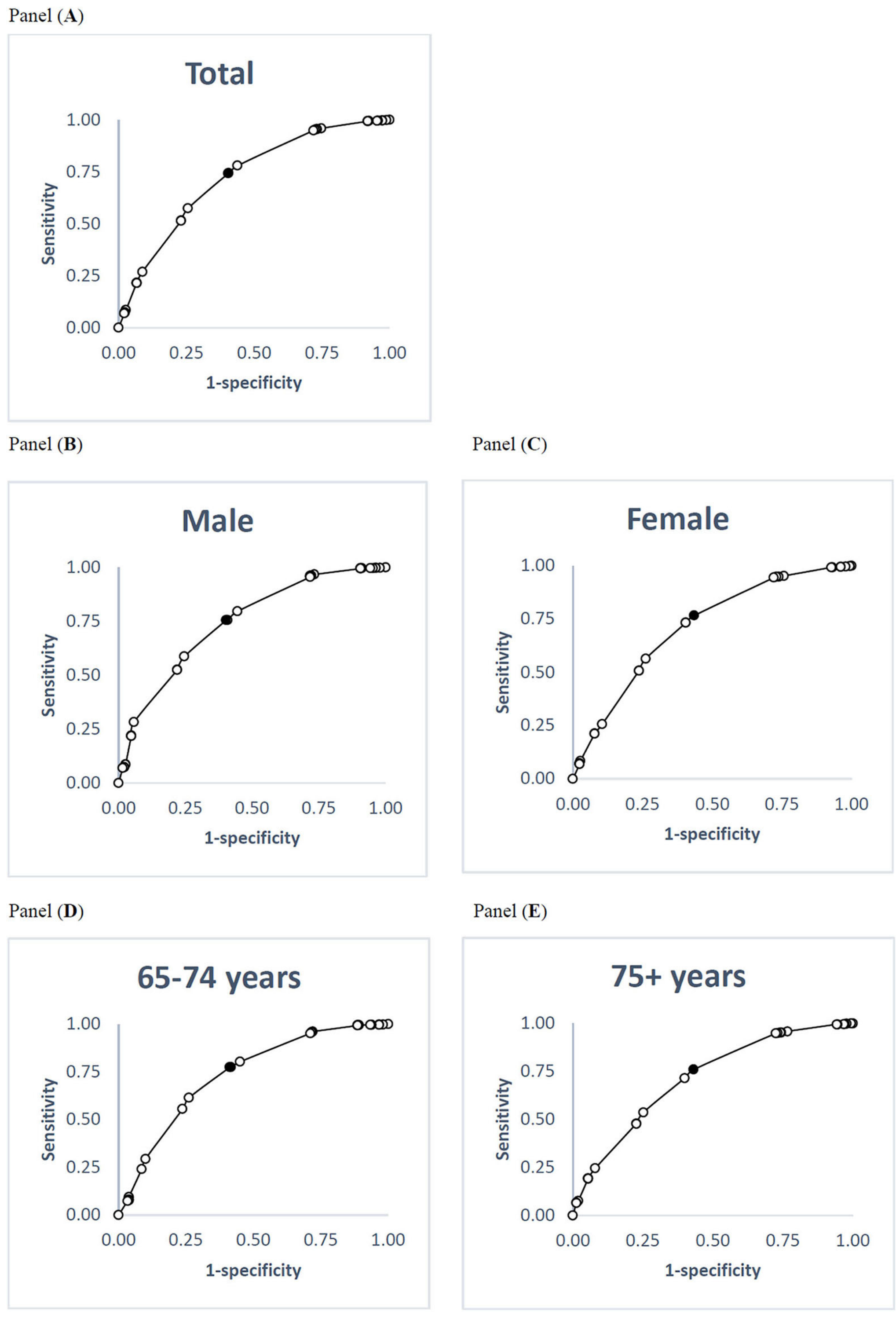


FIGURE 2 | ROC curves for global self-rated happiness relative to the MCS cut-off scores of 50. **(A)** Total participants; **(B)** male; **(C)** female; **(D)** 65–74 years; **(E)** 75+ years. Black point indicates the optimal cut-off point. ROC, receiver operating characteristics; MCS, mental component summary.

such as those institutionalized and with severe disabilities should be further examined in the future. Second, it was not clear that the SF-12v2 was the most appropriate instrument for older people because health-related quality of life among older people might be focused on physical aspects at the expense of other quality-of-life dimensions (47).

However, targeted measures have not yet been developed for older adults.

CONCLUSION

This study's results suggest that global measures of self-rated health and self-rated happiness are valid instruments for quick assessments of the physical and mental health states of Chinese older adults, who reside in the community, remain socially active, and do not have any serious disability. Further, the cut-off scores we calculated to indicate optimal physical and mental health scores seemed to be age- and gender-specific, and the reasons for age and gender differences in global self-rated health and self-rated happiness among older adults should be investigated.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board of National Yang-Ming University Hospital (IRB No. 2011A016). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

Y-HL and N-WH initiated the study. Y-HL, N-WH, and H-CC managed the data collection, performed the data analysis, and wrote the first draft of the manuscript. Y-HL, N-WH, H-CC, and PC are collectively responsible for interpreting the results and reviewed critically subsequent drafts of the manuscript. All authors contributed to its design read and approved the final manuscript.

FUNDING

This work was supported by the National Yang-Ming University Hospital, Taiwan under Grant (RD2019-008).

ACKNOWLEDGMENTS

The authors would also like to thank Yang-Ming Crusaders, Mr. Da-Wei Lin, Ms. Yu-Hui Lin, Mr. Chia-Hsiang Lin and Ms. Tzu-Chun Lo for their help with data collection.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.00346/full#supplementary-material

REFERENCES

1. Devons CA. Comprehensive geriatric assessment: making the most of the aging years. *Curr Opin Clin Nutr Metab Care.* (2002) 5:19–24. doi: 10.1097/00075197-200201000-00004
2. Wu S, Wang R, Zhao Y, Ma X, Wu M, Yan X, et al. The relationship between self-rated health and objective health status: a population-based study. *BMC Public Health.* (2013) 13:320. doi: 10.1186/1471-2458-13-320
3. Cullati S, Mukhopadhyay S, Sieber S, Chakraborty A, Burton-Jeangros C. Is the single self-rated health item reliable in India? A construct validity study. *BMJ Glob Health.* (2018) 3:e000856. doi: 10.1136/bmjgh-2018-000856
4. Haddock CK, Poston WS, Pyle SA, Klesges RC, Vander Weg MW, Peterson A, et al. The validity of self-rated health as a measure of health status among young military personnel: evidence from a cross-sectional survey. *Health Qual Life Outcomes.* (2006) 4:57. doi: 10.1186/1477-7525-4-57
5. Perez-Zepeda MU, Belanger E, Zunzunegui MV, Phillips S, Ylli A, Guralnik J. Assessing the validity of self-rated health with the short physical performance battery: a cross-sectional analysis of the international mobility in aging study. *PLoS ONE.* (2016) 11:e0153855. doi: 10.1371/journal.pone.0153855
6. Preston CC, Colman AM. Optimal number of response categories in rating scales: reliability, validity, discriminating power, and respondent preferences. *Acta Psychol.* (2000) 104:1–15. doi: 10.1016/S0001-6918(99)00050-5
7. Jensen MP, Karoly P, Braver S. The measurement of clinical pain intensity: a comparison of six methods. *Pain.* (1986) 27:117–26. doi: 10.1016/0304-3959(86)90228-9
8. Weech-Maldonado R, Miller MJ, Lord JC. The Relationships among socio-demographics, perceived health, and happiness. *Appl Res Qual Life.* (2017) 12:289–302. doi: 10.1007/s11482-017-9517-8
9. Parker MG, Thorslund M, Nordstrom ML. Predictors of mortality for the oldest old. A 4-year follow-up of community-based elderly in Sweden. *Arch Gerontol Geriatr.* (1992) 14:227–37. doi: 10.1016/0167-4943(92)90023-W
10. Ryuichi Kawamoto TD. Self-reported functional ability predicts three-year mobility and mortality in community-dwelling older persons. *Geriatr Gerontol Int.* (2002) 2:68–74. doi: 10.1046/j.1444-1586.2002.00024.x
11. Jo HS, Moon JY, Kim BG, Nam EW. Analysis of socio-demographics, self-rated health, social capital, and happiness in a medium-sized healthy city, Republic of Korea. *J Lifestyle Med.* (2015) 5:68–75. doi: 10.15280/jlm.2015.5.2.68
12. Cheung F, Lucas RE. Assessing the validity of single-item life satisfaction measures: results from three large samples. *Qual Life Res.* (2014) 23:2809–18. doi: 10.1007/s11136-014-0726-4
13. Abdel-Khalek AM. Measuring happiness with a single-item scale. *Soc Behav Pers.* (2006) 34:139–50. doi: 10.2224/sbp.2006.34.2.139
14. DeSalvo KB, Fisher WP, Tran K, Bloser N, Merrill W, Peabody J. Assessing measurement properties of two single-item general health measures. *Qual Life Res.* (2006) 15:191–201. doi: 10.1007/s11136-005-0887-2
15. Malone C, Wachholtz A. The relationship of anxiety and depression to subjective well-being in a mainland chinese sample. *J Relig Health.* (2018) 57:266–78. doi: 10.1007/s10943-017-0447-4
16. Hsu NW, Tsao HM, Chen HC, Chou P. Anxiety and depression mediate the health-related quality of life differently in patients with cardiovascular disease and stroke-preliminary report of the Yilan study: a population-based community health survey. *PLoS oNE.* (2014) 9:e107609. doi: 10.1371/journal.pone.0107609
17. Hsu NW, Tsao HM, Chen HC, Lo SS, Chen SA, Chou P. Different impacts of atrial fibrillation and cardiac premature contractions on the health-related quality of life in elderly people: the Yilan study. *Tohoku J Exp Med.* (2016) 238:75–83. doi: 10.1620/tjem.238.75
18. Tseng HM LJ, Tsai YJ. Assessment of health-related quality of life in Taiwan (II): norming and validation of SF-36 Taiwan version. *Taiwan J Public Health.* (2003) 22:512–8. doi: 10.6288/TJPH2003-22-06-10
19. Kempen GI, Miedema I, Ormel J, Molenaar W. The assessment of disability with the groningen activity restriction scale. conceptual

framework and psychometric properties. *Soc Sci Med.* (1996) 43:1601–10. doi: 10.1016/S0277-9536(96)00057-3
20. Bjelland I, Dahl AA, Haug TT, Neckelmann D. The validity of the hospital anxiety and depression scale. an updated literature review. *J Psychosom Res.* (2002) 52:69–77. doi: 10.1016/S0022-3999(01)00296-3
21. Zigmond AS Snaith RP. The hospital anxiety and depression scale. *Acta Psychiatr Scand.* (1983) 67:361–70. doi: 10.1111/j.1600-0447.1983.tb09716.x
22. Leung CM, Ho S, Kan CS, Hung CH, Chen CN. Evaluation of the Chinese version of the hospital anxiety and depression scale. a cross-cultural perspective. *Int J Psychosom.* (1993) 40:29–34. doi: 10.1037/t05677-000
23. Goh GS, Liow MHL, Yeo W, Ling ZM, Guo CM, Yue WM, et al. Poor baseline mental health does not influence improvement in patient-reported outcomes, satisfaction, and return to work two years after single-level anterior cervical discectomy and fusion. *Spine (Phila Pa).* (2019) 44:839–47. doi: 10.1097/BRS.0000000000002960
24. Kusleikaite N, Bumblyte IA, Kuzminskis V, Vaiciuniene R. The association between health-related quality of life and mortality among hemodialysis patients. *Medicina.* (2010) 46:531–7. doi: 10.3390/medicina46080076
25. Vilagut G, Forero CG, Pinto-Meza A, Haro JM, de Graaf R, Bruffaerts R, et al. The mental component of the short-form 12 health survey (SF-12) as a measure of depressive disorders in the general population: results with three alternative scoring methods. *Value Health.* (2013) 16:564–73. doi: 10.1016/j.jval.2013.01.006
26. Maruish ME, DeRosa MA. *A Guide to the Integration of Certified Short Form Survey Scoring and Data Quality Evaluation Capabilities*. Lincoln, RI: QualityMetric, Incorporated (2009).
27. DiBonaventura M, Andrews LM, Yadao AM, Kahler KH. The effect of gout on health-related quality of life, work productivity, resource use and clinical outcomes among patients with hypertension. *Expert Rev Pharmacoecon Outcomes Res.* (2012) 12:821–9. doi: 10.1586/erp.12.60
28. Schober P, Boer C, Schwarte LA. Correlation coefficients: appropriate use and interpretation. *Anesth Analg.* (2018) 126:1763–8. doi: 10.1213/ANE.0000000000002864
29. Office YCHR. *Household Registration Statistics Data.* (2019). Retrieved from: https://ilhhr.e-land.gov.tw/cp.aspx?n=2B3911AF933DF44D (accessed March 15, 2018).
30. Chang HT, Hsu NW, Chen HC, Tsao HM, Lo SS, Chou P. Associations between body mass index and subjective health outcomes among older adults: findings from the Yilan Study, Taiwan. *Int J Environ Res Public Health.* (2018) 15:ijerph15122645. doi: 10.3390/ijerph15122645
31. Dong W, Wan J, Xu Y, Chen C, Bai G, Fang L, et al. Determinants of self-rated health among shanghai elders: a cross-sectional study. *BMC Public Health.* (2017) 17:807. doi: 10.1186/s12889-017-4718-5
32. Eriksson I, Unden AL, Elofsson S. Self-rated health. Comparisons between three different measures. Results from a population study. *Int J Epidemiol.* (2001) 30:326–33. doi: 10.1093/ije/30.2.326
33. af Sillen U, Nilsson JA, Mansson NO, Nilsson PM. Self-rated health in relation to age and gender: influence on mortality risk in the Malmo Preventive Project. *Scand J Public Health.* (2005) 33:183–9. doi: 10.1080/14034940410019235
34. Stevenson B, Wolfers J. Happiness Inequality in the United States. *J Legal Stud.* (2008) 37:S33–79. doi: 10.1086/592004
35. Moum T. Self-assessed health among Norwegian adults. *Soc Sci Med.* (1992) 35:935–47. doi: 10.1016/0277-9536(92)90108-3
36. Goldstein MS, Siegel JM, Boyer R. Predicting changes in perceived health status. *Am J Public Health.* (1984) 74:611–4. doi: 10.2105/AJPH.74.6.611
37. Hays JC, Schoenfeld DE, Blazer DG. Determinants of poor self-rated health in late life. *Am J Geriatr Psychiatry.* (1996) 4:188–96. doi: 10.1097/00019442-199622430-00002
38. Idler EL. Age differences in self-assessments of health: age changes, cohort differences, or survivorship? *J Gerontol.* (1993) 48:S289–300. doi: 10.1093/geronj/48.6.S289
39. Hoeymans N, Feskens EJ, van den Bos GA, Kromhout D. Age, time, and cohort effects on functional status and self-rated health in elderly men. *Am J Public Health.* (1997) 87:1620–5. doi: 10.2105/AJPH.87.10.1620
40. Steptoe A, Deaton A, Stone AA. Subjective wellbeing, health, and ageing. *Lancet.* (2015) 385:640–8. doi: 10.1016/S0140-6736(13)61489-0
41. Blanchflower DG, Oswald AJ. Is well-being U-shaped over the life cycle? *Soc Sci Med.* (2008) 66:1733–49. doi: 10.1016/j.socscimed.2008.01.030
42. Morgan J, Robinson O, Thompson T. Happiness and age in European adults: the moderating role of gross domestic product per capita. *Psychol Aging.* (2015) 30:544–51. doi: 10.1037/pag0000034
43. Xu G, Chen G, Zhou Q, Li N, Zheng X. Prevalence of mental disorders among older chinese people in Tianjin city. *Can J Psychiatry.* (2017) 62:778–86. doi: 10.1177/0706743717727241
44. Lozano Luis M. García-Cueto E, Muñiz J. Effect of the number of response categories on the reliability and validity of rating scales. *Methodology.* (2008) 4:73–9. doi: 10.1027/1614-2241.4.2.73
45. Maydeu-Olivares A, Kramp U, Garcia-Forero C, Gallardo-Pujol D, Coffman D. The effect of varying the number of response alternatives in rating scales: experimental evidence from intra-individual effects. *Behav Res Methods.* (2009) 41:295–308. doi: 10.3758/BRM.41.2.295
46. Revilla M, Saris W, Krosnick J. Choosing the number of categories in agree-disagree scales. *Sociol Methods Res.* (2014) 43:73–97. doi: 10.1177/0049124113509605
47. Netuveli G, Blane D. Quality of life in older ages. *Br Med Bull.* (2008) 85:113–26. doi: 10.1093/bmb/ldn003

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 07 August 2020
doi: 10.3389/fpubh.2020.00335

Check for updates

Older Adults' Physical Activity and the Relevance of Distances to Neighborhood Destinations and Barriers to Outdoor Mobility

Erja Portegijs[1]*, **Kirsi E. Keskinen**[1], **Johanna Eronen**[1], **Milla Saajanaho**[1], **Merja Rantakokko**[2] and **Taina Rantanen**[1]

[1] Faculty of Sport and Health Sciences and Gerontology Research Center, University of Jyvaskyla, Jyväskylä, Finland,
[2] School of Health and Social Studies, JAMK University of Applied Sciences, Jyväskylä, Finland

Aim: To determine the relevance of features located close to home and further away, our aim was to study associations between older adults' physical activity and self-reported neighborhood destinations and barriers to outdoor mobility categorized by presence and maximal distance from home.

Methods: Cross-sectional analyses comprising men and women 79–94 years old (57%) living independently in Central Finland ($n = 185$). Self-reported physical activity was categorized into lower (≤3 h moderate activity a week) and higher (≥4 h moderate or intense activity a week) activity. Assisted by interviewers, participants located on an interactive map destinations perceived to facilitate and barriers perceived to hinder outdoor mobility in their neighborhood. Participants' home addresses were geolocated. Euclidean distances between home and reported locations were computed, and the maximal distance from home to neighborhood destinations and barriers, respectively, was categorized based using four common buffer distances, i.e., 250 m, 500 m, 750 m, and 1 km. Participants reporting destinations or barriers within and beyond the respective distance were compared with those reporting none.

Results: About 80% of participants reported neighborhood destinations and 55% neighborhood barriers to outdoor mobility. Barriers were generally located closer to home than destinations [median 166 m (range 25 m−6.10 km) vs. 492 m (5 m−2.7 km)]. Logistic regression analyses adjusted for age, sex, and physical performance showed that neighborhood destinations increased the odds for higher physical activity when located beyond 500 m from home [OR 2.95, 95% confidence interval (CI) 1.02–8.54], but not when located solely within 500 m (OR 1.70, 95% CI 0.30–9.61), in comparison with when reporting no destinations. In contrast, neighborhood barriers decreased the odds for higher physical activity when solely located within 500 m (OR 0.31, 95% CI 0.14–0.72), but not when any barrier was located beyond 500 m (OR 0.96, 95% CI 0.23–3.99), compared with when reporting no barriers. Associations were similar for 250-m buffer distances, but not robust for 750-m and 1,000-m buffers because of lower prevalence.

OPEN ACCESS

Edited by:
Louise Lafortune,
University of Cambridge,
United Kingdom

Reviewed by:
Hélio José Coelho Júnior,
Catholic University of the Sacred Heart, Italy
Angela M. Goins,
University of Houston–Downtown,
United States

***Correspondence:**
Erja Portegijs
erja.portegijs@jyu.fi

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *30 March 2020*
Accepted: *16 June 2020*
Published: *07 August 2020*

Citation:
Portegijs E, Keskinen KE, Eronen J, Saajanaho M, Rantakokko M and Rantanen T (2020) Older Adults' Physical Activity and the Relevance of Distances to Neighborhood Destinations and Barriers to Outdoor Mobility. Front. Public Health 8:335. doi: 10.3389/fpubh.2020.00335

Conclusion: Neighborhood barriers to outdoor mobility located close to home were associated with lower physical activity of older adults, whereas barriers further away were not. Attractive destinations for outdoor mobility located further away from home correlated with higher physical activity, potentially by motivating one to go out and be physically active. Temporal relationships warrant further study.

Keywords: mobility limitation, physical exercise, built environment, aging, walking, active aging, age-friendly community

INTRODUCTION

With the globally aging population, healthy, and active aging is an important policy goal endorsed by WHO and the European Union (1, 2). Physical activity is an essential aspect of active aging through its role in maintaining health and function into high age (3), and also because it constitutes a vital element of many social, communal, and even cognitive activities (4). Physical activity is defined as any bodily movement actuated by skeletal muscle and requiring energy expenditure. With age, the amount of physical exercise typically declines, whereas lighter physical activities such as walking for transport or recreation become more popular (5). Providing suitable circumstances for older adults' physical activities is important because the health benefits of even light intensity activities and activity breaks in periods of inactivity are acknowledged in current physical activity guidelines (3).

According to the socioecological model of aging (6), declines in physical and cognitive capacity make older adults more vulnerable to barriers in the physical environment, and thus, may lead to lower physical activity levels (7, 8). Walking typically starts from the home and has a limited range, hence also policies of age-friendly environments and communities acknowledge the link between the immediate neighborhood environment and physical activity. Design of age-friendly environments has been advocated by organizations such as WHO and the European Union (9). They are frequently interpreted as barrier-free environments, but clear guidelines and measures for implementation of age-friendly features are not available (10, 11). Qualitative studies especially show that features such as poor walkway quality and inadequate lighting may encumber older adults' mobility (12). Conversely, an attractive environment may positively affect older adults' out-of-home mobility, for example, by providing incentives to go out (13–15). Reporting interesting destinations in the neighborhood, such as shops and parks or green areas, is associated with higher levels of physical activity (16), and reporting multiple environmental facilitators for outdoor mobility may even protect against the development of walking difficulty years later (17, 18).

Overall, the associations between environmental factors hindering or facilitating outdoor mobility and physical activity have been demonstrated, especially in the immediate home neighborhood (12, 16). However, the relevance of the geographical areas representing the neighborhood in research has been questioned (19). Moreover, definitions of access to destinations and their operationalization, prevalence, and correlates vary hugely in different studies (20). For example, presence of certain environmental features may affect outdoor mobility of older adults differently depending on whether they are self-reported or assessed more objectively using geographical resources or environmental audits (21, 22). This is because individuals often report features that are meaningful to them and do not mention personally irrelevant features, whereas more objective methods do not distinguish these.

Self-reports and more objective measures of environment complement each other. For example, self-reported long distance to services has been reported as a barrier to outdoor mobility (20) and as a predictor of long-term detrimental changes in outdoor walking ability and frequency of walking (23, 24). However, without actual spatial references, such self-reports are difficult to translate to concrete distances and may lead to misinterpretations. Studies on active means of transportation, i.e., walking and cycling, employing GPS trackers, and map-based questionnaires have shown that older adults visit services beyond common operationalization of neighborhood, i.e., 500 m and 1 km distance from home (25, 26). Therefore, it is possible that attractive environmental destinations, also when located further away, may contribute to an individual's total physical activity.

To our knowledge, few studies have considered spatial locations of participant-reported neighborhood destinations and barriers to outdoor mobility relative to the homes. Therefore, the aim of this paper is to study associations between older adults' physical activity and self-reported neighborhood destinations and neighborhood barriers to outdoor mobility categorized according to their presence and maximal distance from home. We determined whether neighborhood destinations and barriers close to home, that is, within commonly used buffer distances of 250 m, 500 m, 750 m, and 1 km, are of equal importance as those located further away, in comparison with reporting no neighborhood destinations or barriers, respectively.

MATERIALS AND METHODS

Study Design and Participants

We report cross-sectional analyses of the Mobility and Active Aging (MIIA) study comprising older adults aged 79–93 years living independently in Jyväskylä and Muurame municipality in Central Finland (27). Data were collected by computer-assisted face-to-face home interviews in spring 2016. Participants were part of a randomly selected sample ($N = 298$) of the population-based "Life-space mobility in old age" (LISPE) cohort, which was composed 4 years earlier (28). Of those invited, 15 were not reached and 77 declined to participate. Those living independently in the recruitment area, willing to participate, and able to communicate were eligible for participation. Compared with non-participants ($n = 642$) from the original LISPE cohort, MIIA participants ($n = 206$) did not differ in terms of sex, number of chronic conditions, or years of education, but they were somewhat younger, and had slightly better cognition and physical performance than the others as reported earlier (27). Participants' home addresses were derived from the national population register and geocoded in the Geographic Information System (GIS) (29) [Digiroad dataset 2013 (30)] using ArcMap 10.3.1 (Esri, Redlands, CA, USA). This study was carried out in accordance with Finnish National Board on Research Integrity guidelines and recommendations of the European Union. The MIIA study protocol was approved by The Ethical Committee of the University of Jyväskylä. All participants gave written informed consent before the assessments in accordance with the Declaration of Helsinki.

Main Variables

Level of *habitual physical activity* was self-reported using a validated seven-category question combining frequency and intensity of common physical activities (31). The question takes into account physical exercise as well as physical activity related to transport and household activities. Participants were asked to choose the description that best captured their level of physical activity in the previous 6 months. Response options were (0) mostly resting, hardly any activity, (1) mostly sitting, (2) light physical activity, (3) moderate physical activity about 3 h a week, (4) moderate physical activity at least 4 h a week or heavier physical activity up to 2 h a week, (5) Engaging in active sports several times a week making you sweat and breathless or doing heavy gardening or leisure-time activities (at least 3 h a week), and (6) Practicing competitive sports. For category 1 to 4, additional examples of eligible activities were provided. In line with earlier studies, participants were categorized into lower (≤3 h moderate activity a week; category 0–3) and higher (≥4 h moderate or intensive activity a week; category 4–6) (31).

The PENFOM and PENBOM checklists were used to collect participant perceptions of environmental destinations and barriers to outdoor mobility in the neighborhood, respectively (13). For each item, participants were asked to indicate whether they perceived that the respective feature facilitated or hindered their outdoor mobility (yes vs. no). If an item was reported, the participant was subsequently asked to locate it on an online interactive map using the Maptionnaire tool (Mapita, Espoo, Finland). Considering the prevalence of computer illiteracy in this age group, an interviewer assisted participants technically with orientation on the map and navigation to desired locations. For this study, we selected from the PENFOM questionnaire 5 items considered as *neighborhood destinations*; that is, park or other green space, walking trail or skiing track, nature or lakeside, appealing scenery, and services such as shops, markets, or events nearby. From the PENBOM questionnaire, all locatable *neighborhood barriers* to outdoor mobility, 14 items in total, were used for the analyses; that is, poor street conditions, high curbs, lack of sidewalks, hills in nearby environment, lack of benches, poor lighting, noisy environment, busy traffic, dangerous cross-roads, vehicles on walkways, cyclists on walkways, insecurity caused by other pedestrians, snow and ice, and lack of benches in winter. Participants were allowed to provide more than one location for each item. For each participant, we computed Euclidean distances from home to all reported locations (visualized in **Figure 1**; expressed in units of 100 m) and used the distance to the most distantly located neighborhood destination and barrier, respectively, for further analyses (*maximal distance*). Furthermore, overall presence of destinations or barriers was determined (none reported vs. reported), thus, also including reporting destinations and barriers with unknown location owing to technical problems or participants' inability to locate features.

Covariates

Participants' *age* and *sex* were derived from the population register. The number of self-reported physician-diagnosed *chronic conditions* was computed based on a 22-item checklist and an additional open question (33). The number of chronic conditions is a commonly used and recommended indicator of total disease burden and recommended when information on severity of diseases is lacking (34). *Physical performance* was measured using Short Physical Performance Battery (SPPB), comprising a balance, a 2.44-m walking, and a 5-time sit-to-stand test (33, 35). Each test was scored from zero to four using age- and sex-specific cut-off points and a sum score was computed (range 0–12). For five participants, the test was not conducted (e.g., because of wheelchair use or temporary restriction), and for one participant, one missing subscore for reasons unrelated to mobility was replaced by average score of the two remaining tests. *Cognitive function* was assessed using the Mini-Mental State Examination (MMSE) (36). For four participants, missing item scores for reasons unrelated to cognition were imputed using the average of available items. The MMSE score ranges from 0 to 30, and higher scores indicate better performance. In addition, *social support* was assessed using self-report questions of having a friend with whom to walk or run errands (yes vs. no) and living arrangement (lives alone vs. lives together with spouse, relative, or others).

Statistical Analyses

Descriptive characteristics were compared between those categorized as having higher vs. lower levels of physical activity using Mann–Whitney U-tests or χ^2-tests depending on the variable distribution. Characteristics are reported as medians and interquartile ranges or percentages.

Logistic regression analyses were used to test associations between physical activity and neighborhood destinations, and associations between physical activity and neighborhood barriers to outdoor mobility. First, the analyses were run including the variable overall presence, and then maximal distance from home was added to the model. All analyses were adjusted for age and sex (method enter), and subsequently, using forward conditional selection, adjusted for statistically significant covariates number of chronic conditions, SPPB score, MMSE score, and two dichotomous variables of social support. SPPB score was the sole

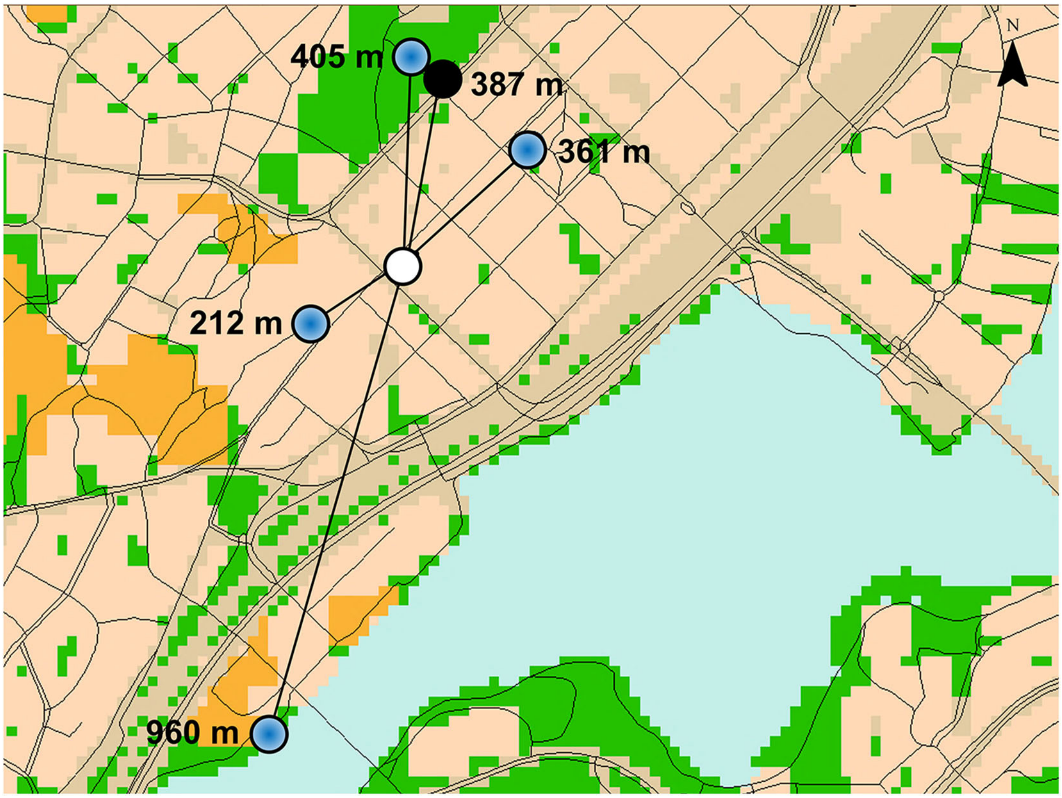


FIGURE 1 | Visualization of the Euclidean distance from the home (white open circle) of a fictive participant to reported destinations (blue dot) and barriers (black dot) for outdoor mobility located on a map [geographical datasets used (30, 32)].

covariate that statistically significantly contributed to all models and was thus reported as part of the final models.

In addition, we conducted the logistic regression models described before with categorized variables as independent variables. For this, we categorized participants based on presence and maximal distance to reported neighborhood destinations or barriers, respectively, as follows for 250, 500, 750, and 1,000 m buffer distances from home: (1) none reported (reference category); (2) reported, all within the respective buffer distance; (3) reported, at least one beyond the respective buffer distance; and (4) reported, but location unknown. Finally, we conducted sensitivity analyses comparing those reporting destinations or barriers beyond each buffer distance with those reporting them within the respective distance, i.e., category 3 vs. 2, thus excluding category 1 and 4 from the analyses.

Because of low numbers of reported barriers especially, it was not possible to study potential interaction effects between the neighborhood destinations and barriers to outdoor mobility. However, we did add to models of neighborhood destinations the variable indicating overall presence of perceived barriers (yes vs. no), but this did not markedly change the results (thus, not reported).

SPPS version 24 (IBM SPPS Statistics version 24, Armonk, NY, USA) was used for all statistical analyses and $p < 0.050$ was considered statistically significant.

RESULTS

Of the 206 participants in the MIIA study, 196 participants completed the map-based questionnaire on neighborhood destinations and barriers to outdoor mobility, four participants had ended the interview before the assessment, one was unable to respond, and in five cases technical problems related to the PC or server prevented data collection. Physical activity was assessed successfully in 194 participants, which left 185 participants with data on both the neighborhood environment and physical activity for the current analyses. Those who dropped out from the analyses did not differ from participants analyzed for any of the descriptive variables (data not shown).

Table 1 shows characteristics of participants. Participants who were more physically active were on average younger, they had lower SPPB scores and lower MMSE scores, and they were less frequently living alone.

Reporting of Neighborhood Destinations and Barriers to Outdoor Mobility

About 80% of participants reported at least one neighborhood destination for outdoor mobility, and for 93% of these reported destinations, a location was reported (**Table 2**). Neighborhood destinations were located at a median distance of 492 m from home (range 25 m–6.10 km), and the distance was longer

TABLE 1 | Descriptive characteristics of participants with lower and higher physical activity levels.

	Lower physical activity (n = 103) Median (IQR)	Higher physical activity (n = 82) Median (IQR)	*P*-value
Age (years)	85.3 (8.3)	81.4 (5.5)	<0.001[a]
Chronic conditions (*n*)	4.0 (3.0)	4.0 (4.0)	Unable to compute[a]
SPPB score (p)	8.0 (4.0)	11.0 (1.0)	<0.001[a]
MMSE score (p)	26.0 (4.0)	27.5 (3.3)	0.002[a]
Sex (female, %)	62.1	50.0	0.132[b]
Friend for walking (yes, %)	50.5	59.8	0.208[b]
Living alone (yes, %)	68.0	48.8	0.013[b]

IQR, interquartile range; SPPB, Short Physical Performance Battery.
[a]*Mann–Whitney U-test.*
[b]*χ^2-test.*

for those reporting higher (median = 704 m, IQR = 634 m) than lower (median = 349 m, IQR = 458 m; $p < 0.001$) physical activity. Participants with higher physical activity more frequently reported neighborhood destinations in general (89%) and especially at longer distances from home (e.g., ≥500 m 55%) than those with lower activity (70 and 22%, respectively).

About half of participants reported at least one neighborhood barrier to outdoor mobility, and for 84% of these reported barriers, a location was reported (**Table 2**). Barriers were located at a median distance of 166 m from home (range 5 m−2.7 km), and the distance was similar regardless of physical activity (higher median = 193 m, IQR = 509 m; vs. lower median = 155 m, IQR = 218 m; $p = 0.684$). Participants with lower physical activity more frequently reported barriers to outdoor mobility in general (66%) and especially within 250 m from home (37%) than those with higher activity (43 and 20%, respectively).

Logistic Regression Analyses—Neighborhood Destinations for Outdoor Mobility

Table 3 shows that only when not accounting for distance, reporting any neighborhood destination perceived to facilitate one's outdoor mobility increased the odds for higher physical activity [OR 3.22, 95% confidence interval (CI) 1.33–7.76] compared with reporting no destinations at all. Adjusting for SPPB score attenuated the association so that it was no longer statistically significant. Among those reporting neighborhood destinations, each 100-m distance between home and the most distant neighborhood destination increased the odds for higher physical activity by at least 11%, also when adjusted for SPPB score.

Table 4 shows that those reporting at least one neighborhood destination beyond 250 m had four times and those reporting at least one neighborhood destination beyond 500 m had six times the odds for higher physical activity than those reporting no destinations at all in the age- and sex adjusted model. Adjusting for SPPB score attenuated the associations to three times the odds for the 500-m distance, and it was no longer statistically significant for the 250-m distance. Reporting all destinations within 250 or 500 m from home was not associated with physical activity when compared with reporting no destinations. Sensitivity analyses showed that compared with those reporting all destinations within 500 m, those reporting at least one destination further away more than tripled the odds to report higher physical activity (age- and sex-adjusted model OR 3.98, 95% CI 1.15–6.81; fully adjusted model OR 3.73, 95% CI 1.56–8.93).

Those reporting neighborhood destinations beyond 750 or 1,000 m had increased odds for higher physical activity (OR 6–11), but confidence intervals were wide and group sizes relatively small.

Logistic Regression Analyses—Neighborhood Barriers to Outdoor Mobility

Compared with reporting none, reporting any neighborhood barrier to outdoor mobility (regardless of distance) was associated with lower odds to report higher physical activity (OR 0.36, 95% CI 0.19–0.69; **Table 3**). Among those reporting barriers, each 100-m distance between the home and the most distant mobility barrier increased the odds to report higher physical activity by at least 16%.

Table 4 shows that those reporting neighborhood barriers within 250 or 500 m from home only (OR 0.31, 95% CI 0.14–0.69 and OR 0.30, 95% CI 0.14–0.62, respectively), but not those reporting barriers also further away, had markedly lower odds for higher physical activity than those reporting no neighborhood barriers at all. Further adjustment of the models for SPPB score did not markedly change the described associations. Sensitivity analyses showed that those reporting at least one barrier at or beyond 500 m from home tended to report higher physical activity than those reporting barriers solely within 500 m, although statistical significance was not reached (age- and sex-adjusted OR 3.23, 95% CI 0.91–11.44, and fully adjusted OR 3.03, 95% CI 0.79–11.62, respectively).

Because of a small number of participants reporting neighborhood barriers to outdoor mobility beyond 750 and 1,000 m (2.7%), it was not meaningful to conduct regression analyses using these buffer sizes.

DISCUSSION

A common assumption in research of older adults' physical activity behavior is that they move close to the home and, thus, that the environment close to home may motivate or hinder older adults' mobility and physical activity (12, 16, 20). This study using an interactive map-based questionnaire provides new information about spatial relations between neighborhood destinations and barriers to outdoor mobility relative to older adults' homes. The distance from home to neighborhood destinations facilitating outdoor mobility, rather

TABLE 2 | Neighborhood destinations and barriers to outdoor mobility reported and their distance to home.

	Distance	All (n = 185)		Lower physical activity (n = 103)		Higher physical activity (n = 82)		*P*-value
	From home	***N***	**%**	***N***	**%**	***N***	**%**	
Destinations								<0.001
None reported		40	21.6	31	30.1	9	11.0	
Reported	<250 m	39	21.1	27	26.2	12	14.6	
	250–499 m	29	15.7	17	16.5	12	14.6	
	500–749 m	28	15.1	13	12.6	15	18.3	
	750–999 m	14	7.6	2	1.9	12	14.6	
	≥1,000 m	26	14.1	8	7.8	18	22.0	
	Location unknown	9	4.9	5	4.9	4	4.9	
Barriers								<0.001
None reported		82	44.3	35	34.0	47	57.3	
Reported	<250 m	54	29.2	38	36.9	16	19.5	
	250–499 m	19	10.3	14	13.6	5	6.1	
	500–749 m	8	4.3	4	3.9	4	4.9	
	750–999 m	2	1.1	1	1.0	1	1.2	
	≥1,000 m	3	1.6	0	0.0	3	3.7	
	Location unknown	17	9.2	11	10.7	6	7.3	

TABLE 3 | Logistic regression models of overall presence and maximal distance from home to neighborhood destinations and barriers to outdoor mobility and odds ratios (OR) for higher physical activity (n = 185).

	Overall presence				Presence and maximal distance			
	Age and sex adjusted		Fully adjusted		Age and sex adjusted		Fully adjusted	
	OR	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Destinations								
None reported	1.00		1.00		1.00		1.00	
Reported	**3.22**	**1.33–7.76**	1.64	0.62–4.32	1.52	0.55–4.19	0.83	0.27–2.49
Maximal distance	–	–	–	–	**1.12**	**1.04–1.22**	**1.11**	**1.02–1.21**
Age	0.81	0.75–0.89	0.84	0.76–0.93	0.81	0.74–0.89	0.84	0.76–0.93
Sex	1.06	0.55–2.05	1.75	0.83–3.72	1.13	0.56–2.28	1.70	0.78–3.71
SPPB score	–	–	1.72	1.38–2.15	–	–	1.66	1.31–2.09
Barriers								
None reported	1.00		1.00		1.00		1.00	
Reported	**0.36**	**0.19–0.69**	**0.40**	**0.19–0.85**	**0.23**	**0.10–0.53**	**0.22**	**0.09–0.55**
Maximal distance	–	–	–	–	**1.16**	**1.01–1.32**	**1.21**	**1.04–1.40**
Age	0.81	0.74–0.89	0.84	0.76–0.93	0.80	0.73–0.88	0.84	0.76–0.93
Sex	1.12	0.58–2.18	1.63	0.76–3.49	1.36	0.66–2.78	1.80	0.80–4.07
SPPB score	–	–	1.73	1.39–2.16	–	–	1.72	1.36–2.19

Statistically significant associations of main variables are bolded (p < 0.050).
SPPB, Short Physical Performance Battery; 95% CI, 95% confidence interval.

than their presence *per se*, was associated with physical activity. Neighborhood destinations facilitating outdoor mobility, such as nature, parks, and services, were associated with higher physical activity especially when located further away from home, i.e., beyond 500 m. In contrast, outdoor mobility barriers, such as street quality and difficult terrain, were associated with markedly lower levels of physical activity, especially when located close to the home, i.e., within 250 or 500 m.

In line with previous research (25), distances of 500 m from home may not be sufficient to capture all destinations for outdoor mobility of an older person. The current study showed that reporting locations beyond 500 m from home especially correlated with higher physical activity. Correspondingly, research has shown that older adults moving further away from home generally are more physically active (37). A previous study based on traditional questionnaire data showed that reporting

TABLE 4 | Logistic regression models of neighborhood destinations and barriers to outdoor mobility categorized by distance from home and odds ratios (OR) for higher physical activity ($n = 185$).

		Age and sex adjusted		Fully adjusted	
		OR	95% CI	OR	95% CI
Destinations 250 m	None reported	1.00		1.00	
	All within	1.51	0.50–4.57	0.90	0.26–3.13
	≥1 beyond	**4.22**	**1.69–10.50**	1.95	0.71–5.33
	Location unknown	2.25	0.43–11.62	1.77	0.32–9.91
	Age	0.82	0.75–0.89	0.84	0.76–0.93
	Sex	1.16	0.59–2.31	1.78	0.83–3.81
	SPPB score	–	–	1.70	1.36–2.14
Destinations 500 m	None reported	1.00		1.00	
	All within	1.61	0.60–4.31	0.78	0.26–2.35
	≥1 beyond	**6.19**	**2.34–16.41**	**2.95**	**1.02–8.54**
	Location unknown	2.17	0.41–11.37	1.70	0.30–9.61
	Age	0.81	0.74–0.89	0.83	0.75–0.92
	Sex	1.27	0.63–2.55	2.01	0.92–4.41
	SPPB score	–	–	1.73	1.37–2.18
Destinations 750 m	None reported	1.00		1.00	
	All within	2.03	0.80–5.15	1.07	0.38–2.97
	≥1 beyond	**11.21**	**3.60–34.97**	**4.99**	**1.44–17.26**
	Location unknown	2.32	0.44–12.27	1.82	0.32–10.28
	Age	0.79	0.72–0.87	0.82	0.74–0.91
	Sex	1.08	0.54–2.18	1.62	0.75–3.54
	SPPB score	–	–	1.69	1.34–2.12
Destinations 1 km	None reported	1.00		1.00	
	All within	2.77	1.12–6.82	1.41	0.52–3.82
	≥1 beyond	**6.94**	**2.09–23.09**	3.07	0.82–11.49
	Location unknown	2.35	0.45–12.16	1.83	0.33–10.22
	Age	0.81	0.74–0.89	0.84	0.76–0.93
	Sex	1.05	0.53–2.05	1.67	0.78–3.58
	SPPB score	–	–	1.72	1.37–2.15
Barriers 250 m	None reported	1.00		1.00	
	All within	**0.31**	**0.14–0.69**	**0.30**	**0.12–0.74**
	≥1 beyond	0.48	0.19–1.19	0.56	0.20–1.55
	Location unknown	0.33	0.10–1.04	0.51	0.14–1.79
	Age	0.81	0.74–0.89	0.84	0.76–0.93
	Sex	1.14	0.58–2.25	1.65	0.76–3.59
	SPPB score	–	–	1.75	1.40–2.18
Barriers 500 m	None reported	1.00		1.00	
	All within	**0.30**	**0.14–0.62**	**0.31**	**0.14–0.72**
	≥1 beyond	0.96	0.26–3.45	0.96	0.23–3.99
	Location unknown	0.33	0.10–1.04	0.51	0.14–1.79
	Age	0.81	0.74–0.89	0.84	0.76–0.93
	Sex	1.14	0.58–2.5	1.61	0.74–3.49
	SPPB score	–	–	1.74	1.39–2.18

Barrier reporting beyond 750 or 1,000 m was too rare to compute valid regression models. Statistically significant associations of main variables are bolded ($p < 0.050$). SPPB, Short Physical Performance Battery; 95% CI, 95% confidence interval.

destinations within 10- to 20-min walk distance from home in a lower density city was associated with higher physical activity in adults aged 65 and over, thus suggesting that destinations are optimally located when within easy reach, but not too close to home (38). Although walking speeds vary in old age (39), it is likely that destinations located beyond 500 m from home, as reported in the current study, are situated within a 10- to 20-min walk time frame. However, other studies have shown that shorter distances to destinations may be beneficial on the long term, as reporting utilitarian destinations within 10 min from home was associated with better maintenance of walking for transportation 4 years later in adults 50–64 years old (18). In addition, objectively assessed proximity to services based on home and service locations was also associated with better maintenance of walking activity 3 years later in adults 67–84 years old (23). Differences between cross-sectional and longitudinal findings warrant further study.

In contrast to neighborhood destinations, neighborhood barriers to outdoor mobility were more commonly identified at relatively close distance from home. In line with previous research (7, 8), the current study shows that those reporting at least one barrier in the neighborhood more likely reported lower physical activity. When further looking at locations of reported barriers, we found that this association was true only when barriers were located within 250 or 500 m from home and not when barriers were located further away from home. Moreover, as a continuous variable, longer distances from home to reported barriers increased the odds for higher physical activity. This finding may be explained in several ways. Older adults with a restricted life space are known to report outdoor mobility barriers in the neighborhood more frequently than those moving further away from home (13). Outdoor mobility barriers located closer to home, including those related to poor walking conditions, may be related to avoidance of activities for example as a result of fear of falls (40). In the current study, only those moving further away from the home—and consequently more physically active (37)—were likely reporting barriers located further away from home. To perceive an outdoor mobility barrier, it needs to be relevant to one's outdoor mobility and one needs to be aware of it (41), thus, located in the area used by an individual. Moreover, barriers located further away from the home may be less limiting for physical activity and more easy to avoid, i.e., by taking alternative routes than those located closer to home. Taking a closer look at specific barriers revealed that especially lack of benches was reported at longer distances from home. Possibly, this suggests that older adults may need environmental support when moving further away from home. Considering that barriers are typically perceived only when the demands of the environment challenge the capacities of an individual (6), it is possible that any barrier reporting, including perceived barriers at long distances from home, point to early declines in functioning. It is unclear whether reporting perceived barriers located further away from home may potentially lead to avoidance of activity or whether individuals are able to modify their behaviors to overcome the challenge and maintain their activity regardless (42, 43).

The sample of the current study was on average well-over 80 years, an age where physical and cognitive limitations typically manifest. Previous studies have shown that associations between environmental features and physical activity differ for those with and without limitations in walking or physical function (29, 44). Adjusting the current analyses for an early indicator of functional decline, i.e., the SPPB score, clearly attenuated associations between neighborhood destinations and physical activity. Thus, in line with previous studies (24, 29), it seems that those with better function more frequently report neighborhood destinations and higher physical activity. Yet, the association found between neighborhood barriers to outdoor mobility and physical activity was virtually unaffected by adjustment for SPPB score. This contradicts the assumptions of the socioecological model (6), where declines in physical capacity are expected to increase the vulnerability to environmental demands, and thus, as a logical consequence, would affect barrier reporting. However, considering the fact that barrier perception also depends on use and awareness of the environment (41), it is possible that those with poorer function, and thus, less physically active, may not report neighborhood barriers to outdoor mobility as a result of infrequent moving through the neighborhood.

Cognitive function, chronic conditions, and social support were not associated with physical activity in any of the current regression models, and they did not affect associations between neighborhood destinations and barriers for outdoor mobility and physical activity. Partly the lack of associations may be related to the use of rather crude measures in the current study. Executive function, one domain of cognitive function involved in task planning and coordination, may be more proximal to motoric tasks and physical activity than general cognitive function, such as assessed with the MMSE (45). Furthermore, one single chronic condition with large debilitating effects on mobility, e.g., painful musculoskeletal or neurological conditions, may be more meaningful than overall chronic diseases burden (46). However, considering the difficulty to assess disease severity and impact in large epidemiological studies, general indicators of chronic disease burden are frequently used and recommended (34). In addition to the physical environment, aspects of the social environment may play an important role in physical activity (19). Social activities, such as visiting friends, may provide a reason to go out and having a companion to walk with may make it more enjoyable to leave home, and, as a consequence, facilitate physically active lifestyle (7, 37, 47). In the current study, participants with lower physical activity more frequently lived alone, and also, they were older and more often female, possibly related to widowhood. However, the other indicator of social support in the current study, that is, having a friend to walk or run errands with, did not differ according to physical activity level. Furthermore, based on these two indicators, social support was not associated with physical activity. Yet considering loneliness being a common problem in aging populations, relations of the social and physical environment and physical activity warrant further study.

Until recently, relations between perceived distance or proximity to services and physical activity were mainly based on questionnaire data without reference to the actual environment (20). Technological innovations led to the development of map-based questionnaires, but spatial measures of the perceived environment have rarely been used in research (48) and, to our knowledge, previously only in adults up to the age of 75 years (49). Our participants were markedly older (79–94 years) and were able to determine locations for most of the features hindering and facilitating their outdoor mobility on a map when provided with technical assistance by an interviewer. Independent completion of map-based questionnaires will be possible in the near future, as younger generations are more familiar with the use of digital devices. Map-based questionnaires seem a feasible alternative for collecting place-based data from participants, as GPS data collection currently burdens both researchers (data cleaning and analyses) and participants (e.g., continuous charging of device) (50). GPS and map-based self-report data do not fully coincide, but still provide reasonable estimates of distances traveled by older adults (50, 51).

Strengths of the current study are the population-based sample of adults above 75 years. There were relatively few missing data and characteristics of participants and non-respondents were studied and did not markedly differ. We used a novel method to collect data from older adults using map-based questionnaires and thereby provide new insights in spatial relations in physical activity research.

Limitations of the study were the rather limited sample size, which did not enable us to look at subgroups of age, sex, or function or to thoroughly adjust for potential confounders. This study comprised a culturally relatively homogenous sample; therefore, generalizability of these results to cultural settings beyond Finland needs to be established. Only self-reported measures for the neighborhood environment and for physical activity were available for analyses. Physical activity derived from self-report questionnaires is typically overestimated, but the use of accelerometers poses higher commitment of study participants and staff, and its accurateness may be challenged by slow movement patterns typical for older adults (52). The measure of physical activity was non-specific, covering both utilitarian and recreational walking as well as other physical activities, but different environmental features may be associated with such types of physical activity (16, 53). Perceived neighborhood features may not accurately reflect the actual environment (22, 29), but may be more proximal to physical activity behavior of the individual than more objectively assessed measures of the environment (21). Ideally, studies should include both objective and perceived measures of the environment and physical activity to provide a comprehensive picture. The current study does not account for residential self-selection, which may theoretically bias the results (54). However, with half of participants already living in the same home for 23 years and with marked urbanization of the study area in the past decennia, choices made at the time of moving to the current home may no longer be relevant. Distances from home to neighborhood destinations and barriers were measured over a straight line (Euclidean distance), thus likely underestimating actual distances along the road network, which are more complicated to compute (55). Regardless, distances of 250 and 500 m from home, as used in the current study, are likely within walkable distance along the road network as well. Yet it is possible that distances are perceived differently by each person depending on function and habits, thus associations with perceived distances require further study.

CONCLUSIONS

The current study shows that Finnish older adults move at distances beyond 500 m from home, and that those reporting neighborhood destinations and barriers to outdoor mobility beyond such distances are likely more physically active. Outdoor mobility barriers seem to limit physical activity only when located closer to the home, that is, within 250 or 500 m from home. Based on the current study, collecting spatial data using map-based questionnaires seems feasible even in older populations. Utilizing such data expands the possibilities for scientific research on person–environment interactions and may help to inform urban planning about designing environments conducive of active aging. Comprehensive measures including perceptions and objective measures of environmental features and distances are needed to capture the full picture of spatial relations and person–environment interactions in physical activity relative to older adults' homes. Future research should broaden the scope to also cover activities beyond physical activity, i.e., investigating active aging more in general and in more diverse settings.

DATA AVAILABILITY STATEMENT

Due to ethical restrictions pseudonymized datasets are available only upon request from Professor Taina Rantanen (taina.rantanen@jyu.fi). External collaborators may use data upon agreement on the terms of data use and publication of results.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Committee of the University of Jyväskylä. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

EP, JE, and TR: acquisition of data. KK: spatial analyses. EP: statistical analyses and drafting the manuscript. KK, JE, MS, MR, and TR: critically revising the manuscript and substantially contributing to its contents. All authors: concept and design of study and interpretation of results.

FUNDING

This research was financially supported by the Ministry of Education and Culture (to TR and EP), the Academy of Finland (Grant No. 255403 to TR). The writing of the manuscript was supported by the Foundation for Municipal Development (to KK), the Finnish Cultural Foundation (to KK), the Academy of Finland (Grant No. 323541; contribution of MS), and the European Research Council (Grant No. 693045; Advanced Grant to TR).

ACKNOWLEDGMENTS

We thank participants of the MIIA study for their time and effort. Gerontology Research Center is a joint effort between the University of Jyväskylä and the University of Tampere.

REFERENCES

1. World Health Organization. *Active Ageing. A Policy Framework. Geneva*. Geneva: World Health Organization (2002)
2. EU. *European Innovation Partnership on Active and Healthy Ageing*. Available online at: https://ec.europa.eu/eip/ageing/home_en (accessed February 06, 2018).
3. Piercy KL, Troiano RP, Ballard RM, Carlson SA, Fulton JE, Galuska DA, et al. The Physical activity guidelines for Americans. *JAMA*. (2018) 320:2020–8. doi: 10.1001/jama.2018.14854
4. Rantanen T, Portegijs E, Kokko K, Rantakokko M, Tormakangas T, Saajanaho M. Developing an assessment method of active aging: university of Jyvaskyla active aging scale. *J Aging Health*. (2019) 31:1002–24. doi: 10.1177/0898264317750449
5. Fishman E, Bocker L, Helbich M. Adult active transport in the Netherlands: an analysis of its contribution to physical activity requirements. *PLoS ONE*. (2015) 10:e0121871. doi: 10.1371/journal.pone.0121871
6. Lawton MP, Nahemow L. Ecology and aging process. In: Eisdorfer C, Lawton MP, editors. *The Psychology of Adult Development and Aging*. Washington DC: American Psychology Association (1973). p. 619–74. doi: 10.1037/10044-020
7. Tsai LT, Rantakokko M, Portegijs E, Viljanen A, Saajanaho M, Eronen J, et al. Environmental mobility barriers and walking for errands among older people who live alone vs. with others. *BMC Public Health*. (2013) 13:1054. doi: 10.1186/1471-2458-13-1054
8. Portegijs E, Rantakokko M, Viljanen A, Rantanen T, Iwarsson S. Perceived and objective entrance-related environmental barriers and daily out-of-home mobility in community-dwelling older people. *Arch Gerontol Geriatr*. (2017) 69:69–76. doi: 10.1016/j.archger.2016.11.011
9. WHO. *Global Network of Age-Friendly Cities and Communities*. Available online at: http://www.who.int/ageing/age_friendly_cities_network/en/ (accessed January 07, 2015).

10. *Global Age-Friendly Cities: A Guide.* France: World Health Organization (2007).
11. Buffel T, Phillipson C. A manifesto for the age-friendly movement: developing a new urban agenda. *J Aging Soc Policy.* (2018) 30:173–92. doi: 10.1080/08959420.2018.1430414
12. Moran M, Van Cauwenberg J, Hercky-Linnewiel R, Cerin E, Deforche B, Plaut P. Understanding the relationships between the physical environment and physical activity in older adults: a systematic review of qualitative studies. *Int J Behav Nutr Phys Act.* (2014) 11:79. doi: 10.1186/1479-5868-11-79
13. Rantakokko M, Iwarsson S, Portegijs E, Viljanen A, Rantanen T. Associations between environmental characteristics and life-space mobility in community-dwelling older people. *J Aging Health.* (2015) 27:606–21. doi: 10.1177/0898264314555328
14. Winters M, Voss C, Ashe MC, Gutteridge K, McKay H, Sims-Gould J. Where do they go and how do they get there? Older adults' travel behaviour in a highly walkable environment. *Soc Sci Med.* (2015) 133:304–12. doi: 10.1016/j.socscimed.2014.07.006
15. Davis MG, Fox KR, Hillsdon M, Coulson JC, Sharp DJ, Stathi A, et al. Getting out and about in older adults: the nature of daily trips and their association with objectively assessed physical activity. *Int J Behav Nutr Phys Act.* (2011) 8:116. doi: 10.1186/1479-5868-8-116
16. Barnett DW, Barnett A, Nathan A, Van Cauwenberg J, Cerin E. Council on Environment and Physical Activity (CEPA) - Older Adults working group. Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act.* (2017) 14:103. doi: 10.1186/s12966-017-0558-z
17. Eronen J, von Bonsdorff M, Rantakokko M, Rantanen T. Environmental facilitators for outdoor walking and development of walking difficulty in community-dwelling older adults. *Eur J Aging.* (2014) 11:67–75. doi: 10.1007/s10433-013-0283-7
18. Sugiyama T, Cerin E, Mridha M, Koohsari MJ, Owen N. Prospective associations of local destinations and routes with middle-to-older aged adults' walking. *Gerontologist.* (2018) 58:121–9. doi: 10.1093/geront/gnx088
19. Kestens Y, Wasfi R, Naud A, Chaix B. "Contextualizing Context": reconciling environmental exposures, social networks, and location preferences in health research. *Curr Environ Health Rep.* (2017) 4:51–60. doi: 10.1007/s40572-017-0121-8
20. Sugiyama T, Neuhaus M, Cole R, Giles-Corti B, Owen N. Destination and route attributes associated with adults' walking: a review. *Med Sci Sports Exerc.* (2012) 44:1275–86. doi: 10.1249/MSS.0b013e318247d286
21. Weden MM, Carpiano RM, Robert SA. Subjective and objective neighborhood characteristics and adult health. *Soc Sci Med.* (2008) 66:1256–70. doi: 10.1016/j.socscimed.2007.11.041
22. Gebel K, Bauman A, Owen N. Correlates of non-concordance between perceived and objective measures of walkability. *Ann Behav Med.* (2009) 37:228–38. doi: 10.1007/s12160-009-9098-3
23. Gauvin L, Richard L, Kestens Y, Shatenstein B, Daniel M, Moore SD, et al. Living in a well-serviced urban area is associated with maintenance of frequent walking among seniors in the VoisiNuAge study. *J Gerontol B Psychol Sci Soc Sci.* (2012) 67:76–88. doi: 10.1093/geronb/gbr134
24. Rantakokko M, Iwarsson S, Manty M, Leinonen R, Rantanen T. Perceived barriers in the outdoor environment and development of walking difficulties in older people. *Age Ageing.* (2012) 41:118–21. doi: 10.1093/ageing/afr136
25. Prins RG, Pierik F, Etman A, Sterkenburg RP, Kamphuis CB, van Lenthe FJ. How many walking and cycling trips made by elderly are beyond commonly used buffer sizes: results from a GPS Study. *Health Place.* (2014) 27C:127–33. doi: 10.1016/j.healthplace.2014.01.012
26. Hinrichs T, Keskinen KE, Pavelka B, Eronen J, Schmidt-Trucksass A, Rantanen T, et al. Perception of parks and trails as mobility facilitators and transportation walking in older adults: a study using digital geographical maps. *Aging Clin Exp Res.* (2019) 31:673–83. doi: 10.1007/s40520-018-01115-0
27. Siltanen S, Rantanen T, Portegijs E, Tourunen A, Poranen-Clark T, Eronen J, et al. Association of tenacious goal pursuit and flexible goal adjustment with out-of-home mobility among community-dwelling older people. *Aging Clin Exp Res.* (2019) 31:1249–56. doi: 10.1007/s40520-018-1074-y
28. Rantanen T, Portegijs E, Viljanen A, Eronen J, Saajanaho M, Tsai LT, et al. Individual and environmental factors underlying life space of older people - study protocol and design of a cohort study on life-space mobility in old age (LISPE). *BMC Public Health.* (2012) 12:1018. doi: 10.1186/1471-2458-12-1018
29. Portegijs E, Keskinen KE, Tsai LT, Rantanen T, Rantakokko M. Physical limitations, walkability, perceived environmental facilitators and physical activity of older adults in Finland. *Int J Environ Res Public Health.* (2017) 14:333. doi: 10.3390/ijerph14030333
30. Finnish Transport Agency. *Digiroad Road and Street Database, R-Format 2013.* Helsinki: CSC—IT Center for Science Ltd., & Finnish Transport Agency (2013).
31. Portegijs E, Sipila S, Viljanen A, Rantakokko M, Rantanen T. Validity of a single question to assess habitual physical activity of community-dwelling older people. *Scand J Med Sci Sports.* (2017) 27:1423–30. doi: 10.1111/sms.12782
32. Finnish Environment Institute SYKE (partly Metla, Mavi, LIVI, VRK, MML Topographic Database (2012, May)). *Corine Land Cover (CLC) 2012 and Finnish National Dataset (20 m).* Helsinki: CSC—IT Center for Science Ltd., & Finnish Environment Institute SYKE (2012).
33. Portegijs E, Rantakokko M, Mikkola TM, Viljanen A, Rantanen T. Association between physical performance and sense of autonomy in outdoor activities and life-space mobility in community-dwelling older people. *J Am Geriatr Soc.* (2014) 62:615–21. doi: 10.1111/jgs.12763
34. Nosikov A, Gudex G, editors. *EUROHIS: Developing Common Instruments for Health Surveys.* Amsterdam: WHO Regional Office for Europe; IOS Press (2003).
35. Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol.* (1994) 49:M85–94. doi: 10.1093/geronj/49.2.M85
36. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state." A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res.* (1975) 12:189–98. doi: 10.1016/0022-3956(75)90026-6
37. Portegijs E, Tsai LT, Rantanen T, Rantakokko M. Moving through greater life-space areas and objectively measured physical activity of older people. *PLoS ONE.* (2015) 10:e0135308. doi: 10.1371/journal.pone.0135308
38. Boakye-Dankwa E, Barnett A, Pachana NA, Turrell G, Cerin E. Associations between latent classes of perceived neighborhood destination accessibility and walking behaviors in older adults of a low-density and a high-density city. *J Aging Phys Act.* (2019) 27:553–64. doi: 10.1123/japa.2018-0297
39. Bohannon RW, Williams Andrews A. Normal walking speed: a descriptive meta-analysis. *Physiotherapy.* (2011) 97:182–9. doi: 10.1016/j.physio.2010.12.004
40. Lee S, Lee C, Ory MG, Won J, Towne SD Jr., Wang S, et al. Fear of outdoor falling among community-dwelling middle-aged and older adults: the role of neighborhood environments. *Gerontologist.* (2018) 58:1065–74. doi: 10.1093/geront/gnx123
41. Portegijs E, Rantakokko M, Edgren J, Salpakoski A, Heinonen A, Arkela M, et al. Effects of a rehabilitation program on perceived environmental barriers in older patients recovering from hip fracture: a randomized controlled trial. *Biomed Res Int.* (2013) 2013:769645. doi: 10.1155/2013/769645
42. Rantakokko M, Portegijs E, Viljanen A, Iwarsson S, Rantanen T. Mobility modification alleviates environmental influence on incident mobility difficulty among community-dwelling older people: a two-year follow-up study. *PLoS ONE.* (2016) 11:e0154396. doi: 10.1371/journal.pone.0154396
43. Baltes PB, Baltes MM. Psychological perspectives on successful aging: the model of selective optimization with compensation. In: Baltes PB, Baltes MM, editors. *Successful Aging: Perspectives From the Behavioral Sciences.* Cambridge: Cambridge University Press (1990) p. 1–34. doi: 10.1017/CBO9780511665684.003
44. Keskinen KE, Rantakokko M, Suomi K, Rantanen T, Portegijs E. Nature as a facilitator for physical activity: defining relationships between the objective and perceived environment and physical activity among community-dwelling older people. *Health Place.* (2018) 49:111–9. doi: 10.1016/j.healthplace.2017.12.003
45. Eggermont LH, Milberg WP, Lipsitz LA, Scherder EJ, Leveille SG. Physical activity and executive function in aging: the MOBILIZE Boston

study. *J Am Geriatr Soc.* (2009) 57:1750–6. doi: 10.1111/j.1532-5415.2009.02441.x

46. Vancampfort D, Koyanagi A, Ward PB, Rosenbaum S, Schuch FB, Mugisha J, et al. Chronic physical conditions, multimorbidity and physical activity across 46 low- and middle-income countries. *Int J Behav Nutr Phys Act.* (2017) 14:6. doi: 10.1186/s12966-017-0463-5
47. Tsai LT, Rantakokko M, Viljanen A, Saajanaho M, Eronen J, Rantanen T, et al. Associations between reasons to go outdoors and objectively-measured walking activity in various life-space areas among older people. *J Aging Phys Act.* (2016) 24:85–91. doi: 10.1123/japa.2014-0292
48. Perchoux C, Chaix B, Cummins S, Kestens Y. Conceptualization and measurement of environmental exposure in epidemiology: accounting for activity space related to daily mobility. *Health Place.* (2013) 21:86–93. doi: 10.1016/j.healthplace.2013.01.005
49. Laatikainen TE, Hasanzadeh K, Kytta M. Capturing exposure in environmental health research: challenges and opportunities of different activity space models. *Int J Health Geogr.* (2018) 17:29. doi: 10.1186/s12942-018-0149-5
50. Schmidt T, Kerr J, Kestens Y, Schipperijn J. Challenges in using wearable GPS devices in low-income older adults: can map-based interviews help with assessments of mobility? *Transl Behav Med.* (2019) 9:99–109. doi: 10.1093/tbm/iby009
51. Hinrichs T, Zanda A, Fillekes MP, Bereuter P, Portegijs E, Rantanen T, et al. (in review). Map-based assessment of older adults' life- space: validity and reliability (2020).
52. Schrack JA, Cooper R, Koster A, Shiroma EJ, Murabito JM, Rejeski WJ, et al. Assessing daily physical activity in older adults: unraveling the complexity of monitors, measures, and methods. *J Gerontol A Biol Sci Med Sci.* (2016) 71:1039–48. doi: 10.1093/gerona/glw026
53. Cerin E, Nathan A, van Cauwenberg J, Barnett DW, Barnett A. Council on Environment and Physical Activity (CEPA) - Older Adults working group. The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act*. (2017) 14:15. doi: 10.1186/s12966-017-0471-5
54. Cao X. Residential self-selection in the relationships between the built environment and travel behavior: introduction to the special issue. *J Transport Land Use.* (2014) 7:1–3. doi: 10.5198/jtlu.v7i3.726
55. Shahid R, Bertazzon S, Knudtson ML, Ghali WA. Comparison of distance measures in spatial analytical modeling for health service planning. *BMC Health Serv Res.* (2009) 9:200. doi: 10.1186/1472-6963-9-200

Disclaimer: The funders had no role in the design of the study and data collection, analysis, and interpretation of data, and in writing the manuscript. The content of this article does not reflect the official opinion of the European Union. Responsibility for the information and views expressed in the article lies entirely with the author(s).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 23 September 2020
doi: 10.3389/fpubh.2020.575946

Check for updates

The Urban Built Environment, Walking and Mental Health Outcomes Among Older Adults: A Pilot Study

Jenny Roe[1], Andrew Mondschein[2], Chris Neale[1], Laura Barnes[3], Medhi Boukhechba[3] and Stephanie Lopez[2]*

[1] Center for Design & Health, School of Architecture, University of Virginia, Charlottesville, VA, United States, [2] Department of Urban and Environmental Planning, School of Architecture, University of Virginia, Charlottesville, VA, United States, [3] Engineering Systems and Environment Department, School of Engineering, University of Virginia, Charlottesville, VA, United States

OPEN ACCESS

Edited by:
Erja Portegijs,
University of Jyväskylä, Finland

Reviewed by:
Patricia M. Alt,
Towson University, United States
Kenneth Chui,
Tufts University, United States

****Correspondence:***
Jenny Roe
jjr4b@virginia.edu

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *24 June 2020*
Accepted: *13 August 2020*
Published: *23 September 2020*

Citation:
Roe J, Mondschein A, Neale C, Barnes L, Boukhechba M and Lopez S (2020) The Urban Built Environment, Walking and Mental Health Outcomes Among Older Adults: A Pilot Study. Front. Public Health 8:575946. doi: 10.3389/fpubh.2020.575946

The benefits of walking in older age include improved cognitive health (e.g., mental alertness, improved memory functioning) and a reduced risk of stress, depression and dementia. However, research capturing the benefits of walking among older people in real-time as they navigate their world is currently very limited. This study explores cognitive health and well-being outcomes in older people as they walk in their local neighborhood environment. Residents from an independent living facility for older people (mean age 65, $n = 11$) walked from their home in two dichotomous settings, selected on the basis of significantly different infrastructure, varying levels of noise, traffic and percentage of green space. Employing a repeated-measures, cross over design, participants were randomly allocated to one of two groups, and walked on different days in an urban busy "gray" district (a busy, built up commercial street) vs. an urban quiet "green" district (a quiet residential area with front gardens and street trees). Our study captured real-time air quality and noise data using hand-held Airbeam sensors and physiologic health data using a smart watch to capture heart rate variability (a biomarker of stress). Cognitive health outcome measures were a pre- and post-walk short cognitive reaction time (SRT) test and memory recall of the route walked (captured via a drawn mental map). Emotional well-being outcomes were a pre- and post-walk mood scale capturing perceived stress, happiness and arousal levels. Findings showed significant positive health benefits from walking in the urban green district on emotional well-being (happiness levels) and stress physiology ($p < 0.05$), accompanied by faster cognitive reaction times post-walk, albeit not statistically significant in this small sample. Cognitive recall of the route varied between urban gray and urban green conditions, as participants were more likely to rely on natural features to define their routes when present. The environmental and physiologic data sets were converged to show a significant effect of ambient noise and urban conditions on stress activation as measured by heart rate variability. Findings are discussed in relation to the complexity of combining real-time environmental and physiologic data and the implications for follow-on studies. Overall, our study demonstrates the viability of using older people as citizen scientists in the capture of environmental and physiologic stress data and establishes a new protocol for exploring relationships between the built environment and cognitive health in older people.

Keywords: cognitive health, stress, air pollution, noise pollution, urban green space, wearable sensors

INTRODUCTION

Exercise is extremely important to healthy aging, reducing the risk of cardio-vascular disease, susceptibly to stress and depression, and improving cognitive functioning. Physical activity is an important modifiable risk factor for reducing the risk of dementia and cognitive decline in older age (1, 2). Exercise also has a direct role in brain health; even light exercise in older adults (55–80 years) can increase the volume of the anterior hippocampus (3), a key part of the brain network that supports spatial memory (our memories of place and spatial relations). In the same age group, research has shown 30 min of exercise may increase neural processes underlying semantic memory activation (our recall of objective knowledge) in healthy older adults (4). All of these types of memories facilitate our experience of space but with aging, this memory network – particularly semantic memory – can diminish and become disrupted with older age, as well as with certain forms of dementia. But, regular physical activity can help maintain memory performance by increasing neural efficiency (5) and is associated with increased white-matter volume in older people (which allows for communication between different brain regions) and brain plasticity (the brain's ability to adapt to changes in the environment or new situations) [reported in Macpherson et al. (6)].

Exercise also plays a role in supporting social interrelations. Older people have a heightened risk of social isolation and loneliness; walkable neighborhoods and using different modes of transport (bicycle, public transport) can significantly reduce loneliness in older people (7) offering impromptu opportunities for social interaction. But only between 6 and 29.8 per cent of older adults aged 65 plus attain the US recommended activity guidelines (i.e., $\geq$150 min of moderate-intensity equivalent minutes of activity per week in bouts of at least 10 min) (8) for "lifestyle" and "ambulatory" activities, respectively (9).

Older people are often hampered from walking in their local neighborhood owing to traffic, noise, air pollution and poorly maintained sidewalks. In addition, people living in lower income neighborhoods are less likely to encounter features that encourage walking, including street trees and parks. Being physically active in older age is now identified as one simple, low cost strategy that can help reduce the burden of dementia, the greatest global challenge for health and social care in the 21st century (10). How we design the environment to promote walkability therefore has an important role to play in healthy aging.

Improving walkability includes regulating for and reducing air and noise pollution. A systematic review of longitudinal cohort studies ($n = 13$) identified an association between greater exposure to airborne pollutants and an increased risk of dementia and cognitive decline (11). Increases in dementia risk were found for fine particulate ($PM_{2.5}$), nitrogen oxides (NO_2/NO_x) and carbon monoxide (CO). One study showed people aged 50 plus living with high levels of air pollutants have a 40 percent greater risk of developing dementia as compared to those living with lower air pollution (12). Because traffic is a large source of many different pollutants, concentrations of air pollutants are often elevated near roadways (13, 14) with residential proximity to roadways linked to a variety of adverse health effects [e.g., (15, 16)]. The contribution of noise to this association has rarely been examined and findings to date are inconclusive. However, excessive noise is associated with physical and mental illness and with higher levels of heart disease, stress, poor sleep quality and cognitive impairment (17). Despite the evidence that excessive urban noise can contribute to negative health outcomes, governments rarely regulate average or ambient street noise (18). Instead, local governments primarily regulate noise with regard to individual instances, such as a single vehicle's engine or horn noise. Using our pilot study's location as an example, Richmond, Virginia sets the maximum allowable dBA of a vehicle, measured at a distance of at least 50 feet (15 m) at 86dBA on streets with a speed limit of 35 MPH (56 kph) or less (19). However, this regulatory standard would have little effect on average street noise levels. While not available for Richmond, a 2015 study of NYC street noise found a mean street noise level of 73.4dBA, with the busiest streets ranging up to 95.0 dBA on a typical day (18).

Decades of research have shown that exposure to natural environments, or green space, can act as an equalizer in health inequities, such as cardiovascular disease (CVD), obesity, psychological well-being, stress regulation and social health across the lifespan (20). Low-income neighborhoods with a high proportion of older residents are disproportionately healthier if their neighborhoods contain good quality, publicly accessible green space (21). Living in areas with walkable green space is associated with increased life longevity in older urban citizens (22, 23). Furthermore, walking in urban green space ("green exercise") - as compared to urban busy districts - is associated with improved emotional well-being and mental alertness (24, 25).

Theoretically, it's postulated that one of the mechanisms by which green space delivers these health benefits is through the air pollution pathway (i.e., trees and other greenery filter pollutants such as $PM_{2.5}$ improving respiratory health and reducing the risk of heart disease); other postulated pathways include the effect of green space on stress regulatory mechanisms (e.g., reduced allostatic load, the neuroendocrine system), the increased likelihood of exercising in green spaces (owing to improved place aesthetics) as well as the social benefits that accrue from meeting people in green spaces (either on an impromptu or organized basis) (26). It is posited that relationships between urban green space and health outcomes are stronger in older people because they spend more time in their residential environment owing to retirement or limited mobility.

But green space is not distributed equitably; economically deprived areas often contain both lower quantity and poorer quality of green space resulting in less opportunity for green exercise and recreation (27), and in turn, fewer opportunities for public health.

Recently, the evidence of positive health effects has grown through the application of biologic indicators to capture immediate physiologic changes that occur in response to exposure to the outdoors, aided by the advancement in mobile technologies (e.g., smart phones). This has resulted in captures of biologic responses to the outdoors including heart rate variability (HRV), blood pressure, saliva, actigraph, urine, and electroencephalography. These studies generally have small sample sizes, are mostly carried out in healthy (student) populations, are rarely carried out in older populations and have generated mixed results [see (28) for a systematic review].

Additionally, the effect of urban environments on individuals can be measured through its effects on spatial knowledge and cognitive maps. Cognitive mapping exercises, such as sketch mapping of traveled routes, can highlight the elements of the environment that are most salient to a traveler (29). Salient elements vary not just by route or environment, but also by socio-cultural factors, such as ethnicity (30). Older adults, in particular, may have difficulty forming cognitive maps after travel (31). However, the elements of the built environment that are most salient to older adults as they travel through urban environments remains little examined.

Aims and Rationale

We recruited a sample of retired older people on lower-incomes ($n = 11$) to examine the feasibility of (a) integrating real-time physiological data with real-time environmental data; and (b) establish a new study protocol integrating cognitive health measures with real-time stress measures to explore outdoor exposure effects in an aging population.

Given the evidence above, we developed two hypotheses:

(1) Older people, on a low income, will experience mental health benefits from walking in local neighborhoods that include urban street stress, and other urban natural features such as domestic gardens and nearby parks. Benefits will extend to subjective well-being, cognitive functioning (reaction times and spatial memory), and physiological indicators of stress.
(2) Lower levels of air and noise pollution will result in improvements across the outcome measures described in Hypothesis 1.

We tested the above hypotheses using the mechanism of a walk in two distinctly dichotomous environmental settings with different spatial and environmental characteristics: an urban "gray" walk in a busy, trafficked urban district vs. an urban "green" walk in a quieter residential district with front gardens, street trees and a pocket park. Using a walk as the outdoor exposure mechanism replicates tried and tested protocol in environment-health research (24, 25, 32, 33).

METHODS

Subjects

Participants were healthy adults ($n = 11$, mean age 64.8, 6 male: 5 female) living in an independent residential facility in Richmond, Virginia. Participants were recruited by purposive sampling methods to ensure they met the required inclusion criteria. We carried out a baseline health survey in a larger sample prior to identify fit, healthy adults capable of walking at ease (unassisted) for 15–20 min. Exclusion criteria for study participation included visual impairment, chronic mental illness and a history of epileptic or psychiatric disorders. All participants were required to be able to walk, unassisted by another person, for at least 15 min. Ethical approval for the study was provided by the University of Virginia Institutional Review Board for Health Sciences Research (IRB-HSR) with informed and signed consent a condition of taking part in the study.

TABLE 1 | Percentage landcover for "gray" and "green" walks.

Landcover areas	Urban gray (%)	Urban green (%)
Non-building impervious	74%	48%
Non-tree vegetation	2%	16%
Tree canopy	9%	25%
Building impervious	15%	11%

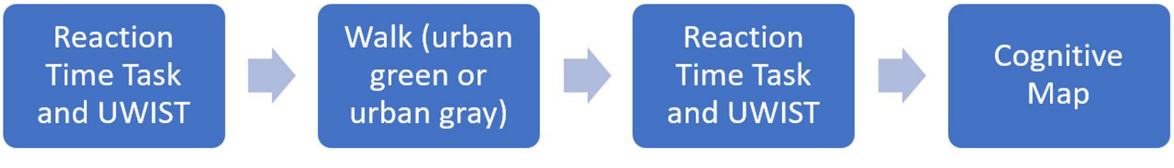


FIGURE 1 | Experimental protocol for each testing day. Note: participants walk condition was counterbalanced between days.

Study Design

We employed a repeated-measures, cross over design, ensuring participants act as their own control. Participants were randomly allocated to one of two groups, each of 5–6 participants: Group 1 walked the urban "gray" route on Day 1, followed by the urban "green" route on Day 2, and Group 2 vice versa, with a 1-day intervening period between walks (see **Figure 1**). The two dichotomous walk routes are described above.

Walking Routes

The two walk routes were located nearby to participants' residential home and were selected on the basis of significantly different levels of green space and gray infrastructure ($z = -18.578$, $p < 0.00001$): the urban "gray" walk comprised 89% gray infrastructure and 11% green infrastructure, compared to the urban "green" walk which comprised 59% gray and 41% green infrastructure. See **Table 1** for further breakdown by land use cover (and supplemental data for maps of the spatial data for each route). From hereon we refer to the walk routes as "urban gray" and "urban green."

The urban gray walk was characterized by a wide road system (4-lanes) with heavy traffic (including trucks and buses), a wide sidewalk with shops and restaurants fronting onto it, a flat gradient, and incorporated some minor road crossings enroute. It was linear in spatial composition (see **Figure 2** below). The urban green walk was characterized by a narrower road system (two lanes), street trees, residential with front gardens, and included a small park, some historic buildings, and some road crossings. It was circular in spatial composition. See **Figure 2** below for the two routes walked, and **Figures 3**, **4** for the visual context of the two settings. Participants walked at either 8:30 A.M. or 9:30 A.M. on Day 1 and 2 in small groups of 5-6. The walk routes were orientated in order to allow for safe road crossings. Participants were instructed not to eat, smoke, talk to each other or chat on their mobile phones. The weather condition on Day 1 was warm (temp 73F) and sunny; Day 2 was warm (temp 70F) and overcast with some occasional spots of rain.

Participant information about the study was provided prior to fieldwork, with signed consent checked by researchers prior to data collection. Data collection took place in a public meeting room at the residential facility on the day of the walk. Participants (living on-site) were asked to arrive 10 min prior to the walk-start time and completed a series of mental health tests and were fitted with a smart watch capturing heart rate (described below). They were asked to follow a walk leader and instructed not to eat, smoke, talk to each other or chat on their mobile phones during the walk. One of the research team led the walk, whilst another researcher walked at the tail-end to ensure participants did not encounter any difficulty. On returning to the residency, participants repeated the mental health tests (described below) and the smart watch was removed, with the data immediately backed up on a computer.

Outcome Measures

Measures of Psychological Well-Being

We used the following psychological scales, previously used in senior populations.

FIGURE 2 | Aerial view of the two walking routes.

FIGURE 3 | The urban busy "gray" walk.

FIGURE 4 | The urban quiet "green" walk.

(1) **Mood** was measured using the short version of the University of Wales Institute of Science and Technology (UWIST) Mood Adjective Check List (MACL) (34, 35), giving acute measures of hedonic tone (valence), stress and (physical) arousal, shown as three individual scores. The hedonic tone scale measures overall pleasantness of mood, and is associated with feelings of somatic comfort and well-being, the stress scale measures feelings of subjective tension and the arousal scale measures feelings of subjective energy. Scores are obtained from summation of individual item scores pertaining to each of the three mood components.

(2) **Subjective well-being** was measured using the short version of the Warwick and Edinburgh Mental Well-being Scale (SWEMWBS), a 7-item scale which measures how people have felt over a 2-week time scale (e.g., feeling relaxed, feeling useful), with responses rated on a 5-point Likert scale from "none of the time" to "all of the time." Scores can range from 7 (indicating very low well-being) to 35 (very high well-being). This scale captures a longer-term subjective well-being and was employed to determine if participants' well-being was stable during the period of the experiment.

Measures of Cognitive Functioning

(1) Reaction time was measured using the Deary-Liewald computer-based simple reaction time test (SRT) (36). In the SRT, participants press a key in response to a single stimulus (the appearance of a diagonal cross within a square) displayed on a computer screen (see **Figure 5** below). Each time the cross appears, participants respond by pressing the response key as quickly as possible. Each cross remained on the screen until the key was pressed, after which it disappears, and another cross appeared some seconds later. The inter-stimulus interval (the time interval between each response and when the next cross appeared) ranged between 1 and 3 s and was randomized within these boundaries. Participants' mean reaction time across all trials is calculated and presented as a millisecond value which is used in subsequent analyses.

(2) Cognitive memory recall of the route as measured by a drawn map, post walk.

In order to capture participants' cognitive route recall, they were asked to draw sketch maps of each respective walk, completed immediately post walk. Following an unconstrained, route-based sketch mapping modality (29, 37), participants were given a blank page (no base map) with limited instructions, stating, "*Imagine you have a visitor who wants to undertake the route you just completed. Please draw the route you undertook so that the visitor could repeat this route.*" The cognitive sketch maps were reviewed by a member of the research team in order to assess five aspects of the maps: Usability, Accuracy, Network Quality, Waypoints, and Natural Features. These aspects of the map were selected based on prior literature establishing methods for assessing overall map quality (Usability, Accuracy, and Network Quality) as well as objective counts of specific map features (Waypoints and Natural Features) (38–40).

Nine participants completed sketch maps for each urban condition.

Physiological Measures

Real-time stress was captured during the walk using an android smart watch (Huawei Watch2) capturing heart rate and walking speed. We used an in-house built app to collect 100 HZ Photoplethysmogram (PPG), 60 Hz accelerometer, 1 HZ sound amplitude, and 1/60 HZ GPS data (41). The PPG signal used to estimate HRV was processed using bandpass filters to reduce motion artifacts. Heart rate is a bio indicator of the stress biologic system, and of SAM (sympathetic-adrenomedullary) system and HPA (hypothalamic-pituitary-adrenocortical) system activation, which work together to achieve allostasis, the body's ability to maintain stability through exposure to change and stressors. Heart rate variability captures the beat-to-beat interval variability

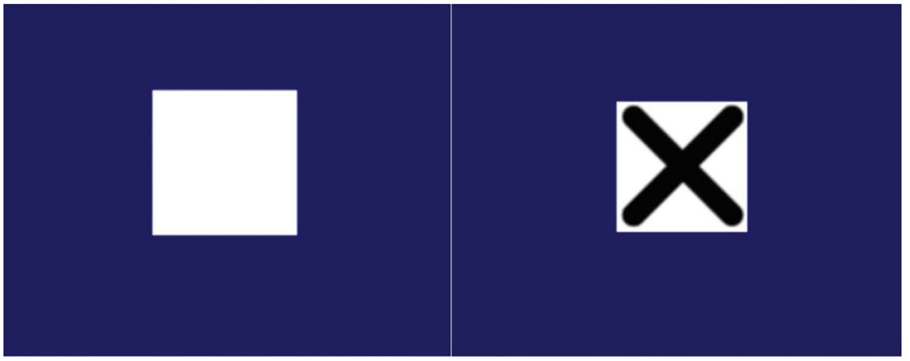


FIGURE 5 | Screen shots of the SRT paradigm; participants respond when an X appears in a central white box.

of heart rate and is the most robust and consistent measure of physiological stress in real-time outdoor data capture (28).

Air Pollution and Noise Levels

Real time air-quality and noise measurements were collected during the walking sessions with handheld mobile devices. Air quality was measured by the Airbeam which detects particulate matter with a diameter equal to or smaller than 2.5 micron ($PM_{2.5}$). Noise measurements were collected by an IK iRig lavalier microphone connected to a smartphone. Each device was held between 1 and 2 meters from the ground. The Airbeam is a low-cost air quality measurement device developed for community-based environmental assessment. While low-cost, California's Air Quality Sensor Performance Evaluation Center finds that Airbeam sensors "had good correlation with the [high performance sensor] from both the field ($R^2 \sim 0.65$–0.70) and laboratory studies ($R^2 > 0.87$)" (SCAQMD 2015). $PM_{2.5}$ and noise (dB) readings were collected at least once per second as participants walked along their routes.

Statistical Analyses

AirBeam Emissions and Noise Comparisons

An independent samples *t*-test was used to compare $PM_{2.5}$ and dB readings between urban gray and urban green conditions for each day of the study. The *t*-test compares whether readings of particulate matter or noise levels in the two urban conditions are significantly different on a given day. In addition, effect sizes for each comparison were calculated using Cohen's d, which is the mean difference divided by the pooled standard deviation of readings for each urban condition.

SWEMWBS

Well-being scores, measured by SWEMWBS, were taken pre-walk on both days. A paired *t*-test was used to determine if SWEMWBS scores significantly differed between the two sessions. The paired *t*-test was used because measurement of SWEMWBS came prior to the walking sessions, so was not affected by the participants' route. Effect sizes were calculated using Cohen's d, calculated as described above.

UWIST

Change scores (post-walk score minus pre-walk score) were computed for each of the UWIST MACL components and analyzed using independent samples *t*-tests on each of the three outcome measures (Hedonic Tone, Stress and Arousal). This would determine any significant difference between the impact of the route on mood, as determined by the magnitude of the change scores. As with the SWEMWBS, effect sizes were calculated using Cohen's d, calculated as described above.

Simple Reaction Time

Two analyses were used to understand the SRT outputs. The first analysis was to understand if there were baseline differences between reaction times prior to the walking sessions on each day. A paired *t*-test was used to compare reaction times for each participant pre-walk on both their testing days (i.e., pre-urban gray vs. pre-urban green). The second analysis used change scores (post-walk reaction time – pre-walk reaction time) calculated for each walking session and used these in an independent samples *t*-test, using route as the grouping variable. As with previous *t*-test analyses, Cohen's d was calculated as described above.

Cognitive Maps

Cognitive maps elements were analyzed descriptively, assessing the mean number of cognitive map features (Usability, Accuracy, Network Quality, Waypoints, and Natural Features) drawn by participants in their sketch maps for urban gray and urban green walks.

HRV

Since data consisted of multiple physiological observations nested within individual participants, a multilevel random coefficient modeling approach with a random intercept for each participant was used. The models were fit using full information maximum likelihood estimation to study the effect of route types on HRV. The first model examines the relationship between HRV (RMSSD) and urban condition only. The second and third models examine the relationship between HRV and the interaction between urban condition and levels of either $PM_{2.5}$ or dB.

TABLE 2 | Participant demographics.

Age	Range	Mean
	57–77 years	64.8 years
Gender	***N***	**Percentage**
Male	6	54.5%
Female	5	45.5%
Ethnicity		
White	8	72.2%
African-American	2	18.2%
Mixed race	1	9.1%
Registered disability		
Registered disabled	7	63.6%
Not registered disabled	4	34.4%
Smoker status		
Yes	3	27.3%
No	8	72.7%
Income coping		
Living very comfortably	1	9.1%
Living a little comfortably	1	9.1%
Living OK	2	18.2%
Living little difficultly	5	45.5%
Living very difficulty	2	18.2%
Education level		
None at all	1	9.1%
Primary school	3	27.3%
Secondary school	2	18.2%
Tertiary (college/university)	5	45.5%

RESULTS

Demographics

Participant demographics from the study participants are presented in **Table 2**, below. One participant did not complete the 2nd walk, resulting in an overall sample of $n = 11$.

Environmental Measures: Noise and Air Pollution

Portable AirBeam Sensors

The AirBeam portable sensors supplied near-continuous (approx. every second) information on pollution and noise levels along the participants' walking routes. **Table 3** describes $PM_{2.5}$ and dB means and ranges for the urban gray and urban green walks the 2 days of the pilot. On Day 1, $PM_{2.5}$ levels were higher during the urban green walk than during the urban gray walk. This was contrary to expectations but can be accounted for by local weather conditions and time of day. The urban green walk occurred later in the morning, and $PM_{2.5}$ levels were building generally in Richmond that morning, even during the course of the urban gray walk. (See **Supplementary Figures 3, 4**, for a map of how $PM_{2.5}$ levels varied during the course of the walks).

Overall, Day 1 had higher $PM_{2.5}$ levels than Day 2, which is reasonable considering the relatively warmer, less windy weather of the first day. Importantly, the mean $PM_{2.5}$ concentrations (measured in $\mu g/m^3$) were relatively low on both days. The World Health Organization recommends that $PM_{2.5}$ concentrations should not exceed 25 $\mu g/m^3$ over a 24-h mean, and these walks are lower than those levels during their short duration (42). While not included here, we also conducted mobile sampling of NO_2 mixing ratios, where NO_2 and $PM_{2.5}$ are both associated with urban combustion pollution, the hour before and hour after participant walking times on Days 1 and 2. The mobile measurements captured general neighborhood-scale spatial patterns in vicinity of the walking routes. We observed that the spatial patterns collected using this repeated mobile sampling were not always consistent with those detected using the AirBeam. For example, on Day 1, mobile NO_2 measurements were higher in the vicinity of the urban gray route than the urban green route, suggesting pollutant concentrations relevant to the scale of this study exhibited high spatiotemporal variability that required the use of the handheld monitoring devices.

TABLE 3 | Means and ranges for AirBeam measured $PM_{2.5}$ ($\mu g/m^3$) and dB levels during walks.

Measure	Day	Environment	Mean	Min-max	Mean difference (Cohen's *d*)
Particulate matter ($PM_{2.5}$)	Day 1	Urban gray	15.85	1.94–35.28	−4.06*** (−0.848)
		Urban green	19.91	2.57–28.23	
	Day 2	Urban gray	9.88	0.86–25.21	1.28* (0.383)
		Urban green	8.60	1.03–13.49	
Noise level (dB)	Day 1	Urban gray	75.19	58.82–87.05	5.20*** (1.157)
		Urban green	69.99	59.39–84.91	
	Day 2	Urban gray	72.15	59.19–86.46	2.98*** (0.640)
		Urban green	69.17	58.88–81.59	

*Mean difference between Urban Gray and Urban Green measures for given day and measure are significantly different at: *p < 0.05, **p < 0.01, ***p < 0.001.*

Noise levels were consistently, significantly lower for the urban green walks relative to the urban gray walks, with moderate to large effect sizes. While ambient road noise is not directly regulated in Richmond, if from a single vehicle, the excursions above 86 dB in the urban gray walks would be violations of city regulations. Results indicate statistically significant differences between the two walk routes for both particulate matter ($PM_{2.5}$) and noise level (dB).

Psychological Outcomes

Subjective Well-Being

There was no significant difference between the SWEMWBS scores on the 2 days [$t_{(9)} = 0.732$, $p = 0.483$; $d = 0.203$] as revealed using a paired t-test to compare samples. The effect size shows only a small effect, further suggesting that the result is non-significant. The SWEMWBS scale is a sub-chronic measure of subjective well-being and shows that, over the duration of the study, subjective well-being was constant in our sample. Overall SWEMWBS scores on Day 1 were 27.4 (sd = 5.4) and on Day 2 were 25.9 (sd = 6.15).

Mood

We examined the change scores between pre- and post-walk assessments of the UWIST MACL (mean scores provided in **Table 4**), allowing for reduced between subject variability. The results showed a significant effect of route type on hedonic tone $(t_{19}) = -2.62$, $p = 0.017$; $d = 1.14$) but not on stress [$t_{19} = 1.64$, $p = 0.117$; $d = 0.73$] or arousal [$t_{19} = -0.864$, $p = 0.399$; $d = 0.37$]. **Figure 6** shows the change scores; the only significant result is the increase in hedonic tone in the urban green condition when compared to the urban gray condition. However, **Figure 6** also shows the hypothesized direction of change for each non-significant condition; stress decreases post-walk at a larger rate than the urban gray (the standard error bars suggest, however, a varied response between participants) and arousal increases in the urban green relative to the urban gray condition. The effect scores show a large effect of route on hedonic tone (1.14), supporting the significance of this result. We also see a medium effect size of route on stress (0.73), suggesting, with appropriately powered participant numbers, there may be an overarching effect. The effect size of route on arousal is small-to-medium (0.37), suggesting there may not be an effect of route on arousal, supported by the non-significant result.

TABLE 4 | Psychological outcomes for subjective wellbeing outcomes (standard deviations in parentheses).

SWEMWBS	Day 1	Day 2
	27.45 (5.47)	25.9 (6.15)
UWIST MACL	**Pre-walk**	**Post-walk**
Hedonic tone: urban gray	26.6 (3.5)	26.8 (3.85)
Hedonic tone: urban green	24.91 (4.85)	27.27 (4.84)
Stress: urban gray	14.7 (4.81)	14.6 (4.74)
Stress: urban green	16.55 (5.36)	13 (4.05)
Arousal: urban gray	23.9 (3.96)	24.9 (3.96)
Arousal urban green	23 (4.27)	25.27 (3.69)
Simple reaction time (ms)		
Urban gray	436.36 (155.88)	459.1 (122.01)
Urban green	427.11 (95.85)	412.64 (134.3)

SWEMWBS scores range between 7 and 35; all three MACL outcome scores range between 8 and 32.

Short Reaction Time Test

Table 4 shows the mean reaction times (ms) pre- and post-walk for the urban gray vs. urban green walk. Participants were counterbalanced between the two conditions to ensure no order effects would be present in the results. Initially, we wanted to check if there were statistically significant differences between the pre-walk conditions (irrespective of the walk). We found no significant difference between baseline (pre-walk) SRT reaction times on each study day [$t_{(9)} = 0.32$, $p = 0.756$; $d = 0.11$], suggesting that any difference between pre- and post-walk SRT score is likely due to condition effects rather than a skewed baseline, supported further by the low effect size. An independent t-test was then used to assess the change from baseline score (post-walk reaction time – pre-walk reaction) and showed no

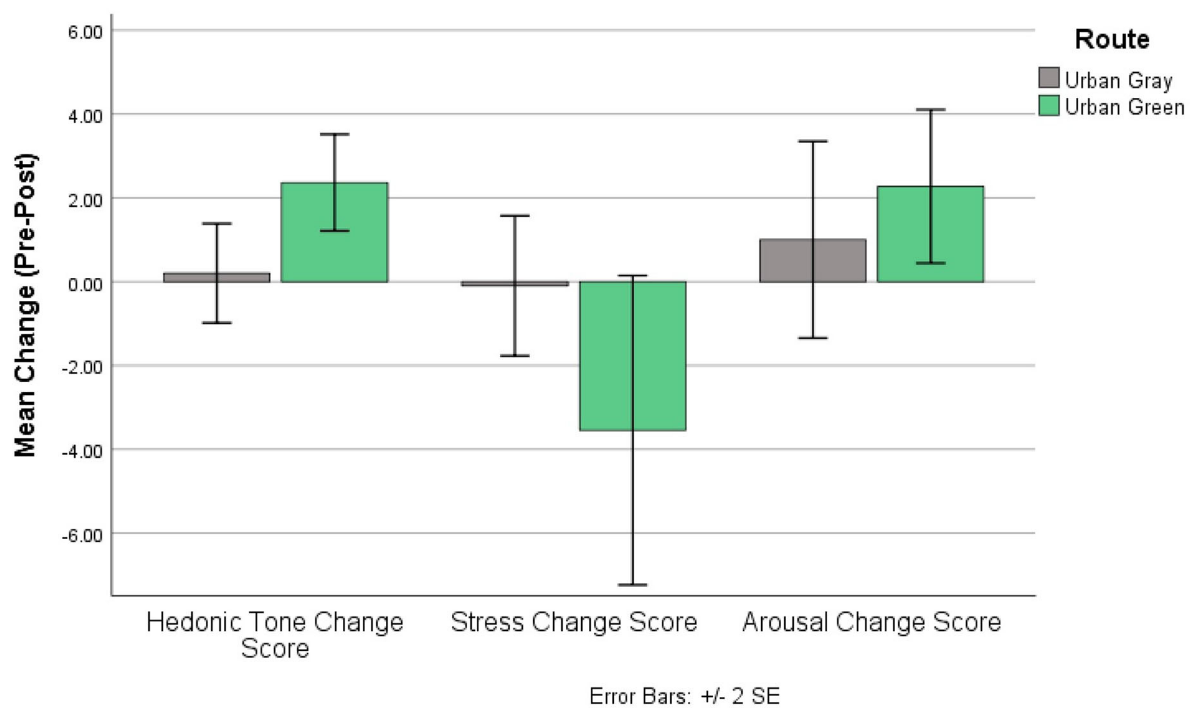


FIGURE 6 | UWIST MACL change scores for each output; change scores generated from post-walk – pre-walk scores of each MACL output.

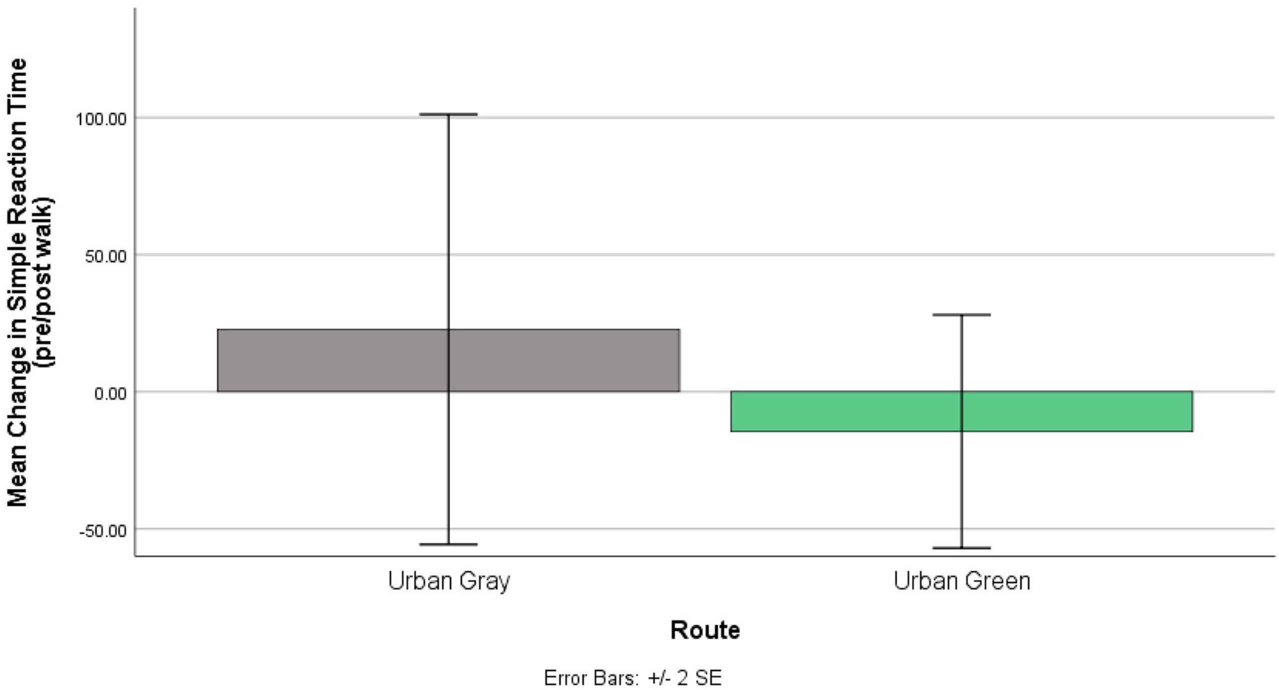


FIGURE 7 | Changes to Short Cognitive Reaction time (ms) pre and post walks. Urban gray shows an increased reaction time while urban green shows decreased reaction time both post-walk.

significant effect of route type on performance [$t_{(19)} = 0.854$, $p = 0.403$; $d = 0.37$). **Figure 7**, however, shows that participants' reaction times improved (i.e., got faster) post-urban green walks compared to reaction times getting slower post-urban gray walks, but the effect size shows that the strength of this effect is small (0.37).

Cognitive Maps

Table 5 presents the cognitive mapping results for the respondents. Overall, most respondents took similar approaches to cognitive mapping, and average usability, accuracy, network quality, and waypoint count were similar between urban gray and urban green maps. Natural features were only used in two of nine urban green maps, but waypoints (landmarks between origin and destination) were included more frequently in the sketch maps of the urban green route.

Physiological Data

Figure 8 shows the difference between the two conditions for HRV. To characterize HRV, we computed the Root Mean Square of the Successive Differences (RMSSD), a well-validated and most accurate measure of Autonomic Nervous System activity (43). HRV is computed and compared across the two conditions in a linear mixed effect model (see **Table 6**, Model 1). The multilevel model revealed a significant effect of walking in an urban gray condition on HRV ($b = -2.16$, $p < 0.001$). Since lower HRV is associated with elevated stress, our finding indicates that the urban gray condition increased stress levels when compared to the urban green condition.

TABLE 5 | Cognitive map assessments by participant.

	Environment type	Mean score/count
Usability	Urban gray	2.8
	Urban green	2.7
Accuracy	Urban gray	3.4
	Urban green	3.3
Network quality	Urban Gray	3.1
	Urban green	3.2
Waypoints	Urban gray	0.7
	Urban green	1.6
Natural features	Urban gray	0.0
	Urban green	0.2

Usability - Could the map objectively be used to give directions to another person? (1 to 5).
Accuracy - Does the map conform to the actual geography of the route? North does not need to be up (1 to 5).
Network - How refined is the network? A highly refined network would label streets, show routing, and use additional streets for context (1 to 5).
Waypoints - How many discernable waypoints (landmarks between origin and destination) does the map include? (Count).
Nature - How many waypoints representative of nature? (Count).

Synthesis of Data

We examined relationships between the environmental and the physiological data collected while participants were walking the urban green and urban gray routes. **Table 6**, Models 2 and 3, show results of linear mixed effects models examining the effect of environmental measures ($PM_{2.5}$ or dB) and their

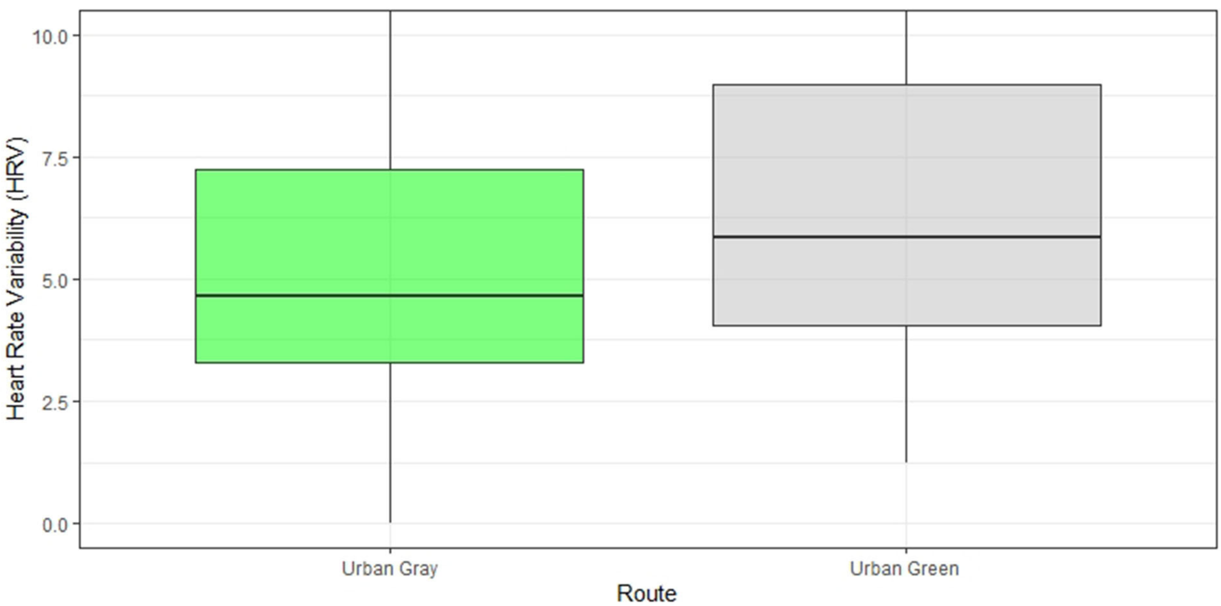


FIGURE 8 | Heart rate variability difference post walk in the "green" vs. "gray" condition. HRV is represented by the Root Mean Square of the Successive Differences (RMSSD). *Note: a lower heart rate variability indicates higher cardiac activation and higher stress*.

TABLE 6 | Associations Between Environmental Conditions and Physiological Responses by Urban Setting (Green vs. Gray).

Linear mixed effects models: dependent variable HRV (RMSSD)			
	Model 1	**Model 2**	**Model 3**
Fixed effects	**Coefficients**		
Urban gray (vs. Urban green)	−2.1689***	16.8136***	−2.0007***
dB		0.0929*	
Urban gray x dB		−0.2609***	
$PM_{2.5}$			−0.1421***
Urban gray x $PM_{2.5}$			0.03904
Intercept	9.8012***	1.70934	
Random effects	**Standard deviations**		
Intercept	1.5690	2.4972	2.3919
Residuals	8.3229	7.4065	7.3910
Model diagnostics			
AIC	9,293.247	36,207.37	36,184.46
BIC	9,313.959	36,246.8	36,223.89
N		5,284	5,284

*Coefficients are significantly different at: *p < 0.05, **p < 0.01, ***p < 0.001.*
Model 1: Interaction between urban conditions and HRV; Model 2: Interaction effect of dB and urban conditions on HRV; Model 3; Interaction effect of $PM_{2.5}$ and urban conditions on HRV.

interactions with urban conditions. To aid interpretation of the interaction terms, **Figure 9** illustrates the fixed effects relationships among urban conditions, environmental measure, and heart rate variability measured as RMSSD, at the ranges for the environmental values measured during the study. Across measures of dB, RMSSD is similar at low noise levels in both the urban green and urban gray conditions, but as dB increases, RMSSD diverges with lower readings (more stress) in the urban gray but relatively even stress levels (taking confidence intervals into account) in the urban green condition. For $PM_{2.5}$, RMSSD decreases (more stress) as particulate matter increases at similar rates in both urban conditions. The difference between RMSSD in the two urban conditions is significant in the model (**Table 6**, Model 3).

Given a significant relationship between noise and stress, we ran further data analyses to explore relationships between noise (dB) and cognitive functioning [i.e., simple reaction times (SRT)]. Results showed no significant effect of noise on SRT.

DISCUSSION

Based on prior research evidence, we posited that older people, on a low income, will benefit from walking in local neighborhoods that include urban street trees, and other urban natural features such as domestic gardens and nearby parks, as measured by indicators of subjective well-being, stress and cognition (Hypothesis 1).

First, for subjective well-being, we found a statistically significant difference between the two walk routes (i.e., urban gray *vs.* urban green) on hedonic tone, which increased more from walking in the urban green route; this is consistent with research showing mood benefits from walking in green *vs.* gray conditions (24, 44). Findings on indicators of arousal (energetic vigor) and perceived stress, whilst not significant, indicate positive outcomes aligning with our hypotheses for the green walk as compared to the gray route. Higher hedonic tone

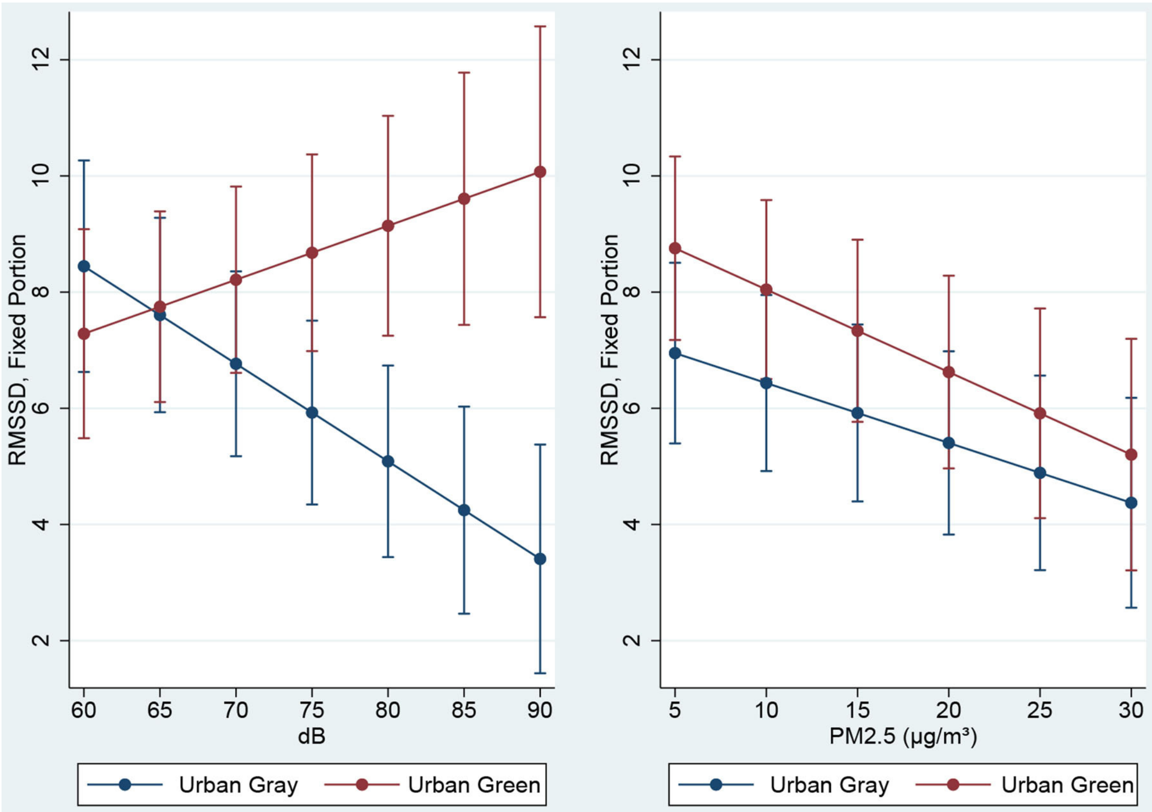


FIGURE 9 | Heart rate variability (RMSSD) by "green" vs. "gray" condition over observed values of dB and $PM_{2.5}$ *Note: a lower heart rate variability indicates higher cardiac activation and higher stress*.

in the green condition is an important outcome, representing an increased capacity to experience pleasure, and a reduced risk of experiencing anhedonia, one of the symptoms of depression (45). Older people are at greater risk of depression owing to increases in adverse life events (e.g., loss of a spouse or close friend), social isolation and financial stressors (46), therefore increasing hedonic capacity in older people via access to walkable, green urban conditions may have important implications for mental health.

Second, on physiological stress outcomes, we found significant differences between walk routes for heart rate and heart rate variability (HRV) with lower stress activation from walking in the urban green route. Our stress response is a complex process that involves two interrelated biologic systems: the sympathetic nervous system that triggers the "flight or fight" response (and provides the body with the energy to take action), and the parasympathetic nervous system that acts as a break (promoting "rest and digest" and calming the body down). Our results for HRV and heart rate suggest walking in green space activates the parasympathetic system and induces a calming effect. This finding is consistent with earlier research in non-laboratory settings showing a positive effect on stress regulation from exposure to green space outdoors (28) as well as increases in alpha brain activity associated with increased relaxation (25). HRV is one of the most consistently and reliable measures of stress physiology in this field of research and, albeit in a small sample size, our results show promising findings for real-time stress monitoring in older people.

The sympathetic and parasympathetic nervous systems work together to achieve allostasis, or the body's ability to maintain stability through change. Allostasis is important for maintaining good stress resilience. Reduced allostatic load (AL) has been associated with higher levels of green space in the neighborhood environment (47). Among older people, AL has been associated with cardiovascular disease, physical decline, cognitive function and depression (48–50). In addition, greater amounts of green space are associated with increased physical activity, and less stress (as measured by self-report) in older people. Alleviation of chronic stress for older people is therefore one important pathway by which to improve overall health. Easy access to walkable residential neighborhoods with green space is therefore one important public health intervention that can support healthy aging.

Third, on cognitive health outcome measures, short reaction time (SRT) results indicate faster reaction times post-urban green walk, albeit not significant in this small sample. This has implications for maintaining mental alertness whilst walking, reducing the risk of trips and falls amongst older people outdoors.

The SRT task is a measure of speed of attention and processing, so further investigation is needed to understand if green spaces can reliably improve attentional capacity in older populations. It also supports previous behavioral research that shows improved directed-attention performance following exposure to walks in nature (51, 52).

On indicators of spatial memory, participants' practical ability to draw usable, accurate route sketch maps did not vary between the two urban conditions. However, waypoints were included at double the rate in the urban green setting compared to the urban gray setting, though with the small sample size ($N = 11$ complete sketch map sets), this mean difference was only significant at the $p < 0.1$ level. The fact that the urban green route did prompt a more detailed recollection of the features of the route, compared to the urban gray route, is worth further consideration. It is possible that the architectural qualities of the urban green route, which proceeded through a historic area, were more memorable than those of the urban gray route on busy Broad Street. Alternatively, the relative calm of the urban green route may have enabled greater attention to surroundings, which could improve recall of waypoints. The literature on variations in cognitive recall of the environment under conditions of stress is limited, and further research in this area could help explain the process by which features of the environment do or do not accrue meaning and value for local residents.

Fourth, we posited that lower levels of air and noise pollution will result in improvements across the mental health outcome measures (Hypothesis 2). We found significant interaction effects between levels of air / noise pollution, urban conditions and stress activation. First, stress levels increased with increasing noise levels (dB) in the urban gray condition; by comparison, stress activation decreased in the urban green condition as dB increased (**Figure 9**). But the effect of noise (dB) on stress activation was stronger from walking in a busy, trafficked urban walk. Chronic noise keeps the body's stress response constantly activated contributing to increased risk of heart disease and mood disturbances (reflected in our finding on hedonic tone above). It appears that urban greenery may be acting as a buffer to stress activation from increasing dB; it's possible we are more tolerant to increasing noise in urban green conditions, a proposition warranting further research. We also found significant effects of air pollution ($PM_{2.5}$) and urban conditions on stress activation; in both conditions stress increased as $PM_{2.5}$ increased, but with no potential buffering effect of green space, although stress activation was greater in the trafficked urban walk (**Figure 9**). Given that other studies have identified associations between mental health (i.e., self-reported anxiety, depression and stress) and heart rate dynamics (i.e., HRV) and exposure to traffic and air pollutants in healthy adults (53, 54), in a larger sample we might expect to see a stronger effect of urban conditions and air pollution on stress activation. It is also possible that a longer exposure time to air pollution may be required to detect differences. A 2-hour walk, for example, on a traffic-polluted street has shown adverse effects on older people's cardio-respiratory health (55). In summary, we found significant interaction effects between levels of noise/air pollution, urban conditions and stress activation, with a stronger effect for noise in busy trafficked conditions. Our study therefore warrants further examination of air-pollution-traffic-mental health associations using mobile health and environmental sensors.

This pilot study seeks to understand relationships between environmental and physiological data, and integrates near-continuous, precise data streams on measures including noise, particulate matter pollution, and heart rate variability. Our protocols utilize both time and place records to match data streams. We established a process to then observe co-variation across time and place, both at the level of individuals and across shared experiences. While our pilot sample was small, these processes were effective and can be applied to larger samples in future research. Increasing sample size will increase power and may lead to statistical significance.

In addition, we also wanted to test the viability of recruiting and implementing a complex study protocol in senior people on lower incomes. There are many challenges to using mobile human health and environmental data sensors. The technology is relatively new, largely tested in younger (student) populations, and its application requires testing in a wider participant demographic. We anticipated it may be challenging for senior people to wear a mobile sensor and comply with stringent criteria about eating, drinking and talking during the experiment, given that our participants – whilst living independently – were also experiencing financial stressors from retirement, and some health challenges (7 participants with a registered disability). A total of 11 participants (from a sample of 12 recruited) were able to comply with our study protocol across two walk days with an intervening period of 1 day between walk days. The older people in our experiment did find some pre- and post-walk tasks difficult (e.g., the short reaction time task was substituted for a complex reaction time task, tested in a pilot, which our participants found mentally challenging).

We did not explore heat stress, but the alleviation of heat stress by tree canopy cover has a significant role to play in aiding mobility for older people during hot summer periods. Urban greenery (e.g., street trees, parks, and front gardens) may reduce surface temperatures to which older populations are more sensitive, highlighting the importance of green infrastructure for "older neighborhoods" associated with particular older demographic groups. This is the focus of a follow-on study.

LIMITATIONS

Our study captured acute stress, and immediate physiologic changes over a short-term period using heart rate measures. Capturing chronic stress requires the repeated capture of diurnal cortisol over time, or measures of allostatic load (indicators of immune, neuroendocrine, and metabolic function) typically captured in saliva.

Our participants self-selected to participate in the study, therefore, bias may have occurred due to non-random selection. We cannot demonstrate any causal mechanisms between outdoor exposure, stress and health. Using RCTs (randomized control trials) – along with bigger samples – is required to increase the generalizability of results. However, given the challenges of combining multiple heterogeneous sensor data streams (e.g., HRV with air pollution) which have different scales, sampling rates and missing data patterns, and due to the complexity of integrating real-time environmental and physiological data sets (with billions of milliseconds of data) with subjective data, the research field will likely grow slowly with small samples to establish robust protocols for both experimental design and data processing/integration approaches. Sampling sizes tend to be small, however, our study, employing a cross-over design and the capture of pre and post data in two dichotomous environments, improves on the experimental work characteristic of the field to date [see (28)].

Given that associations between urban green space and mental health outcomes in older people are significantly modified by race, age, gender, social support, physical function, and socioeconomic status (53, 56) it is important that future research sufficiently power participant sample sizes to explore differences by socio-demographic characteristics. Other variables of interest to future studies exploring mental health-built environment associations in older people include aesthetics (including littering/vandalism/order as well as greenery) which are associated with increased physical activity in older people (57), and walk pace, which is associated with increased life longevity (58).

Our study has taken a closer step toward measuring ways that the local nearby environment relates to human health in older people, which will improve our ability to identify more nuanced relationships between environmental exposure, stress and cognitive health outcomes. We have begun to set out a process by which a complex matrix of physiologic and environmental data can be integrated. Further development of methodological approaches (e.g., use of time-activity monitoring across space and time, developing data fusion techniques to analyze the multimodal data) could help characterize the complex matrix of social and physical circumstances, both indoors and outdoors, that contribute to or mitigate stress. Additionally, given the potential benefits of exposure to natural spaces on stress and cognitive functioning, interventions paired with research are needed most in those neighborhoods that lack close proximity to such space.

CONCLUSION

Our study increases understanding of how walking in the immediate neighborhood environment affects stress and other health indicators in older people. In a vulnerable aging population, we successfully established a protocol for measuring ambulatory heart rate using mobile technologies and correlating them with urban analytical data captured in real-time outdoors. This is the first time, to our knowledge, that the impact of urban greening on real-time stress responses in older populations has been examined using these methods.

As the life longevity and the number of older persons increases globally, a central question is, what changes in the built environment can improve quality of life and sustain health for an aging population? Albeit in a small sample, our study suggests that publicly accessible urban green space offers promising opportunities for supporting mental health in older people. Whilst further research is needed, findings can inform urban planning for health, and help inform global initiatives such as the World Health Organization's 'Age Friendly Cities' program.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Virginia IRB Health Sciences. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JR conceptualized the study design, oversaw participant recruitment, data collection, data analyses and interpretation of findings, and led the writing of the manuscript with input from co-authors. AM led the cognitive mapping exercise, methods for air/pollution data collection, and carried out the data synthesis with physiological data. CN assisted with the study protocol and led the subjective data analyses. LB and MB led the methods and analyses for the real-time stress data capture. SL led the land use data analyses and assisted with the preparation of the manuscript. All authors assisted with data collection in the field.

FUNDING

This study was funded by the Cardiovascular Research Center (CVRC), University of Virginia, Charlottesville, VA, USA.

ACKNOWLEDGMENTS

We thank residents of an independent living facility in Richmond, and their property manager, for facilitating this study. We thank Sally Pusede and Kate Knowles, Environmental Sciences, University of Virginia for carrying out the mobile vehicular sensor study; and Mikala Reiman, Alyson Oliver, also of the University of Virginia, and Lauriane Chalmin-Pui, University of Sheffield, UK for their assistance with data collection in the field.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.575946/full#supplementary-material

REFERENCES

1. Rovio S, Kåreholt I, Helkala E, Viitanen M, Winblad B, Tuomilehto J, et al. Leisure-time physical activity at midlife and the risk of dementia and Alzheimer's disease. *Lancet Neurol.* (2005) 4:705–11. doi: 10.1016/S1474-4422(05)70198-8
2. Hörder H, Johansson L, Guo X, Grimby G, Kern S, Östling S, et al. Midlife cardiovascular fitness and dementia. *Neurology.* (2018) 90:e1298. doi: 10.1212/WNL.0000000000005290
3. Erickson KI, Voss MW, Prakash RS, Basak C, Szabo A, Chaddock L, et al. Exercise training increases size of hippocampus and improves memory. *Proc Natl Acad Sci USA.* (2011) 108:3017–22. doi: 10.1073/pnas.1015950108
4. Won J, Alfini AJ, Weiss LR, Michelson CS, Callow DD, Ranadive SM, et al. Semantic memory activation after acute exercise in healthy older adults. *J Int Neuropsychol Soc.* (2019) 25:557–68. doi: 10.1017/S1355617719000171
5. Smith JC, Nielson KA, Antuono P, Lyons J, Ryan Hanson J, Butts AM, et al. Semantic memory functional MRI and cognitive function after exercise intervention in mild cognitive impairment. *J Alzheimer Dis JAD.* (2013) 37:197–215. doi: 10.3233/JAD-130467
6. Macpherson H, Teo W, Schneider LA, Smith AE. A life-long approach to physical activity for brain health. *Front Aging Neurosci.* (2017) 9:147. doi: 10.3389/fnagi.2017.00147
7. van den Berg PEW, Kemperman ADM, de Kleijn B, Borgers AWJ. Ageing and loneliness: the role of mobility and the built environment. *Travel Behav Soc.* (2016) 5:48–55. doi: 10.1016/j.tbs.2015.03.001
8. CDC. *Physical Activity Guidelines for Americans, 2nd Edition*. U.S. Department of Health and Human Services (2018).
9. Zenko Z, Willis EA, White DA. Proportion of Adults Meeting the 2018. Physical activity guidelines for Americans according to accelerometers. *Front Pub Health.* (2019) 7:135. doi: 10.3389/fpubh.2019.00135
10. Livingston G, Sommerlad A, Orgeta V, Costafreda SG, Huntley J, Ames D, et al. Dementia prevention, intervention, and care. *Lancet.* (2017) 390:2673–734. doi: 10.1016/S0140-6736(17)31363-6
11. Peters R, Ee N, Peters J, Booth A, Mudway I, Anstey KJ. Air pollution and dementia: a systematic review. *J Alzheimer Dis.* (2019) 70:S145–63. doi: 10.3233/JAD-180631
12. Carey IM, Anderson HR, Atkinson RW, Beevers SD, Cook DG, David Strachan P, et al. Are noise and air pollution related to the incidence of dementia? A cohort study in London, England. *BMJ Open.* (2018) 8:e022404. doi: 10.1136/bmjopen-2018-022404
13. Choi W, He M, Barbesant V, Kozawa KH, Mara S, Winer AM, et al. Prevalence of wide area impacts downwind of freeways under pre-sunrise stable atmospheric conditions. *Atmospheric Environ.* (2012) 62:318–27. doi: 10.1016/j.atmosenv.2012.07.084
14. Karner AA, Eisinger DS, Niemeier DA. Near-roadway air quality: synthesizing the findings from real-world data. *Environ Sci Technol.* (2010) 44:5334–44. doi: 10.1021/es100008x
15. Adar SD, Kaufman JD. Cardiovascular disease and air pollutants: evaluating and improving epidemiological data implicating traffic exposure. *Inhalation Toxicol.* (2007) 19(Suppl. 1):135–49. doi: 10.1080/08958370701496012
16. Lipfert FW, Wyzga RE. On exposure and response relationships for health effects associated with exposure to vehicular traffic. *J Exposure Sci Environ Epidemiol.* (2008) 18:588–99. doi: 10.1038/jes.2008.4
17. Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, et al. Auditory and non-auditory effects of noise on health. *Lancet.* (2014) 383:1325–32. doi: 10.1016/S0140-6736(13)61613-X
18. McAlexander TP, Gershon RRM, Neitzel RL. Street-level noise in an urban setting: assessment and contribution to personal exposure. *Environ Health.* (2015) 14:18. doi: 10.1186/s12940-015-0006-y
19. City of Richmond. *Excessive Noise Ordinance*. (2011). Available online at: http://media.rvanews.com/wp-content/uploads/2011/09/noise-ordinance.pdf (accessed June 1, 2020).
20. Allen J, Balfour R. *Natural Solutions for Tackling Health Inequalities*. London: UCL Institute of Health Equity; Natural England. (2014).
21. Dennis M, Scaletta KL, James P. Evaluating urban environmental and ecological landscape characteristics as a function of land-sharing-sparing, urbanity and scale. *PLoS ONE.* (2019) 14:e0215796. doi: 10.1371/journal.pone.0215796
22. Takano T, Nakamura K, Watanabe M. Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces. *J Epidemiol Commun Health.* (2002) 56:913–8. doi: 10.1136/jech.56.12.913
23. Sulander T, Karvinen E, Holopainen M. Urban Green space visits and mortality among older adults. *Epidemiology.* (2016). 27:e34–5 doi: 10.1097/EDE.0000000000000511
24. Roe J, Aspinall P. The restorative benefits of walking in urban and rural settings in adults with good and poor mental health. *Health Place.* (2011) 17:103–13. doi: 10.1016/j.healthplace.2010.09.003
25. Neale C, Aspinall P, Roe J, Tilley S, Mavros P, Cinderby S, et al. The impact of walking in different urban environments on brain activity in older people. *Cities Health.* (2019) 4:1. doi: 10.1080/23748834.2019.1619893
26. Hartig T, Mitchell R, de Vries S, Frumkin H. Nature and health. *Ann Rev Pub Health.* (2014) 35:207–28. doi: 10.1146/annurev-publhealth-032013-182443
27. Wolch JR, Byrne J, Newell JP. urban green space, public health, and environmental justice: the challenge of making cities just green enough. *Landscape Urban Plan.* (2014) 125:234–44. doi: 10.1016/j.landurbplan.2014.01.017
28. Kondo MC, Fluehr JM, McKeon T, Branas CC. Urban green space and its impact on human health. *Int J Environ Res Pub Health.* (2018) 15:445. doi: 10.3390/ijerph15030445
29. Mondschein A, Blumenberg E, Taylor B. Accessibility and cognition: the effect of transport mode on spatial knowledge. *Urban Stud.* (2010) 47:845–66. doi: 10.1177/0042098009351186
30. Loukaitou-Sideris A, Gilbert L. Shades of duality: perceptions and images of downtown workers in Los Angeles. *J Archit Plan Res.* (2000) 17:16–33. doi: 10.1080/02513625.2000.10556729
31. Iaria G, Palermo L, Committeri G, Barton JJS. Age Differences in the formation and use of cognitive maps. *Behav Brain Res.* (2009) 196:187–91. doi: 10.1016/j.bbr.2008.08.040
32. Aspinall P, Mavros P, Coyne R, Roe J. The Urban Brain: analysing outdoor physical activity with mobile EEG. *Br J Sports Med.* (2015) 49:272–6. doi: 10.1136/bjsports-2012-091877
33. Neale C, Aspinall P, Roe J, Tilley S, Mavros P, Cinderby S, et al. The aging urban brain: analyzing outdoor physical activity using the emotiv affectiv suite in older people. *J Urban Health.* (2017) 94:869–80. doi: 10.1007/s11524-017-0191-9
34. Matthews G, Jones DM, Chamberlain AG. Refining the measurement of mood: the UWIST mood adjective checklist. *Br J Psychol.* (1990) 81:17–42. doi: 10.1111/j.2044-8295.1990.tb02343.x
35. Schultheiss OC, Brunstein JC. Goal imagery: bridging the gap between implicit motives and explicit goals. *J Personal.* (1999) 67:1–38. doi: 10.1111/1467-6494.00046
36. Deary IJ, Liewald D, Nissan J. A free, easy-to-use, computer-based simple and four-choice reaction time programme: the deary-liewald reaction time task. *Behav Res Methods.* (2011) 43:258–68. doi: 10.3758/s13428-010-0024-1
37. Chorus CG, Timmermans HJP. Determinants of stated and revealed mental map quality: an empirical study. *J Urban Design.* (2010) 15:211–26. doi: 10.1080/13574801003638095
38. Cohen R, Baldwin LM, Sherman RC. Cognitive maps of a naturalistic setting. *Child Dev.* (1978) 49:1216–8. doi: 10.2307/1128763
39. Rovine MJ, Weisman GD. Sketch-map variables as predictors of way-finding performance. *J Environ Psychol.* (1989) 9:217–32. doi: 10.1016/S0272-4944(89)80036-2
40. Bjerva T, Sigurjónsson T. Wayfinding by means of maps in real-world settings: a critical review. *The J Navigat.* (2017) 70:263–75. doi: 10.1017/S0373463316000643
41. Boukhechba M, Barnes L. *SWear: Sensing Using WEARables. Generalized Human Crowdsensing on Smartwatches*. In. (2020). doi: 10.1007/978-3-030-51828-8_67
42. World Health Organization. *Ambient (Outdoor) Air Pollution*. (2018). Available online at: https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health (accessed June 1, 2020).
43. Berntson GG, Lozano DL, Chen Y. Filter Properties of root mean square successive difference (RMSSD) for heart rate. *Psychophysiology.* (2005) 42:246–52. doi: 10.1111/j.1469-8986.2005.00277.x

44. Tilley S, Neale C, Patuano A, Cinderby S. Older people's experiences of mobility and mood in an urban environment: a mixed methods approach using electroencephalography (EEG) and interviews. *Int J Environ Res Pub Health.* (2017) 14:151. doi: 10.3390/ijerph14020151
45. Sternat T, Katzman MA. Neurobiology of hedonic tone: the relationship between treatment-resistant depression, attention-deficit hyperactivity disorder, and substance abuse. *Neuropsychiatr Disease Treatment.* (2016) 12:2149–64. doi: 10.2147/NDT.S111818
46. Pocklington C. Depression in older adults. *BJMP.* (2017) 10:7.
47. Egorov AI, Griffin SM, Converse RR, Styles JN, Sams EA, Wilson A, et al. Vegetated land cover near residence is associated with reduced allostatic load and improved biomarkers of neuroendocrine, metabolic and immune functions. *Environ Res.* (2017) 158:508–21. doi: 10.1016/j.envres.2017.07.009
48. Juster RP, McEwen BS, Lupien SJ. Allostatic load biomarkers of chronic stress and impact on health and cognition. *Neurosci Biobehav Rev.* (2010) 35:2–16. doi: 10.1016/j.neubiorev.2009.10.002
49. Seeman TE, McEwen BS, Rowe JW, Singer BH. Allostatic load as a marker of cumulative biological risk: macarthur studies of successful aging. *Proc Natl Acad Sci USA.* (2001) 98:4770–5. doi: 10.1073/pnas.081072698
50. Seeman TE, Singer BH, Rowe JW, Horwitz RI, McEwen BS. Price of adaptation–allostatic load and its health consequences. MacArthur studies of successful aging. *Arch Intern Med.* (1997) 157:2259–68. doi: 10.1001/archinte.157.19.2259
51. Berman MG, Jonides J, Kaplan S. The cognitive benefits of interacting with nature. *Psychol Sci.* (2008) 19:1207–12. doi: 10.1111/j.1467-9280.2008.02225.x
52. Berman MG, Kross E, Krpan KM, Askren MK, Burson A, Deldin PJ, et al. Interacting with nature improves cognition and affect for individuals with depression. *J Affect Disord.* (2012) 140:300–5. doi: 10.1016/j.jad.2012.03.012
53. Pun VC, Manjourides J, Suh HH. Close proximity to roadway and urbanicity associated with mental ill-health in older adults. *Sci Total Environ*. (2019) 658:854–60. doi: 10.1016/j.scitotenv.2018.12.221
54. Meier-Girard D, Delgado-Eckert E, Schaffner E, Schindler C, Künzli N, Adam M, et al. Association of long-term exposure to traffic-related PM10 with heart rate variability and heart rate dynamics in healthy subjects. *Environ Int.* (2019) 125:107–16. doi: 10.1016/j.envint.2019.01.031
55. Sinharay R, Gong J, Barratt B, Ohman-Strickland P, Ernst S, Kelly FJ, et al. Respiratory and cardiovascular responses to walking down a traffic-polluted road compared with walking in a traffic-free area in participants aged 60 years and older with chronic lung or heart disease and age-matched healthy controls: a randomised, crossover study. *Lancet*. (2018) 391:339–49. doi: 10.1016/S0140-6736(17)32643-0
56. Pun VC, Manjourides J, Suh HH. Association of neighborhood greenness with self-perceived stress, depression and anxiety symptoms in older U.S adults. *Environ Health*. (2018) 17:39. doi: 10.1186/s12940-018-0381-2
57. Rachele JN, Sugiyama T, Davies S, Loh VHY, Turrell G, Carver A, et al. Neighbourhood built environment and physical function among mid-to-older aged adults: a systematic review. *Health Place*. (2019) 58:102137. doi: 10.1016/j.healthplace.2019.05.015
58. Zaccardi F, Davies MJ, Khunti K, Yates T. Comparative relevance of physical fitness and adiposity on life expectancy: a UK biobank observational study. *Mayo Clin Proc*. (2019) 94:985–94. doi: 10.1016/j.mayocp.2018.10.029

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 30 October 2020
doi: 10.3389/fpubh.2020.578275

Check for updates

Associations of Environmental Features With Outdoor Physical Activity on Weekdays and Weekend Days: A Cross-Sectional Study Among Older People

Kirsi E. Keskinen [1,2]*, Ying Gao [1,3], Merja Rantakokko [4], Taina Rantanen [1] and Erja Portegijs [1]

[1] Faculty of Sport and Health Sciences and Gerontology Research Center, University of Jyväskylä, Jyväskylä, Finland, [2] School of Resource Wisdom, University of Jyväskylä, Jyväskylä, Finland, [3] Department of Sports Science, College of Education, Zhejiang University, Hangzhou, China, [4] School of Health and Social Studies, JAMK University of Applied Sciences, Jyväskylä, Finland

OPEN ACCESS

Edited by:
Maw Pin Tan,
University of Malaya, Malaysia

Reviewed by:
Lené Levy-Storms,
UCLA Luskin School of Public Affairs,
United States
Patricia M. Alt,
Towson University, United States

***Correspondence:**
Kirsi E. Keskinen
kirsi.e.keskinen@jyu.fi

Specialty section:
This article was submitted to
Aging and Public Health,
a section of the journal
Frontiers in Public Health

Received: 30 June 2020
Accepted: 05 October 2020
Published: 30 October 2020

Citation:
Keskinen KE, Gao Y, Rantakokko M, Rantanen T and Portegijs E (2020) Associations of Environmental Features With Outdoor Physical Activity on Weekdays and Weekend Days: A Cross-Sectional Study Among Older People. Front. Public Health 8:578275. doi: 10.3389/fpubh.2020.578275

Background: Physical activity (PA) of higher intensity and longer duration mainly accumulates from older adults' out-of-home activities. Outdoor PA is influenced by environmental features; however, the day-to-day variability of PA and its associations with environmental features have not been widely studied. This study focused on the associations of environmental features with accelerometer-measured PA in older people on weekdays and weekend days.

Methods: The study population comprised 167 community-dwelling older people aged 75–90 years. Accelerometers were worn on 7 consecutive days and a structured interview on physical functioning, health, and socioeconomic factors was administered. A geographic information system (GIS) was used to assess environmental features within a distance of 500 (number of land types, road network slope, intersection, and residential densities) or 1,000 m (habitat diversity within natural and green areas) from participants' homes. Accelerometer-based PA [number of PA bouts >10 min and minutes of moderate to vigorous physical activity (MVPA)] was analyzed for weekdays and weekend days separately. Associations between environmental features and PA were analyzed using linear regression models.

Results: Participants accumulated on average 0.60 PA bouts and 34.2 MVPA minutes on weekdays and 0.50 PA bouts and 31.5 MVPA minutes on weekend days. Especially participants with low overall PA were less active at weekends. Habitat diversity in natural and green areas, intersection density, and residential density were positively associated with numbers of PA bouts and MVPA minutes on weekdays. Moreover, more diversity in natural and green areas was associated with more MVPA minutes on weekend days. A higher road network slope was negatively associated with the number of PA bouts throughout the week and with MVPA minutes on weekend days.

Conclusions: Environmental features close to home, especially PA-supportive infrastructural features and services, were more strongly associated with weekday than weekend PA. This suggests that older people's out-of-home activities, typically conducted on weekdays, are related to service use. However, greater diversity of natural areas close to home seemed to motivate older adults to engage in higher MVPA throughout the week.

Keywords: aging, walking, mobility, GIS, day-to-day variability

INTRODUCTION

Older adults are recommended to engage in moderate to vigorous intensity (MVPA) for at least 150 min a week (1). For older people, a large proportion of their physical activity (PA) accumulates during daily activities, such as walking for transport, and is not necessarily exercise-related (2). Then again, transportation walking may be a form of daily exercise for some older adults or be combined with walking for leisure, which makes categorizing of older adults' PA challenging. Either way, out-of-home activities are associated with higher PA, especially when moving through greater life-space areas (3). A previous study investigating the day-to-day variability of PA found significant differences between weekdays and weekend days in time spent on PA and concluded that these differences in habitual PA were probably explained by daily routines and practices (4). It is not clear whether environmental features in the home neighborhood relate to PA accumulation similarly on weekdays and weekend days among older adults.

For Finnish older adults, shopping, walking for exercise, social visits, and running errands are among the commonest reasons for going outside the home (5). The extent to which neighborhoods and cities offer such destinations and are conducive to PA varies greatly (6) and thus is not the same for all older adults. Based on a large international study, the difference between the least and the most activity-supporting urban environment could mean a difference of more than 60 min in weekly MVPA among adults (6). Recent meta-analyses have showed positive associations between multiple environmental features and PA (7), walking for transport (8), and leisure-time PA (9). It has also been observed that physical functioning (10) and socioeconomic (11) status may be intertwined with associations between objectively defined features of the environment and PA. However, given the variability in daily routines and in the availability of services by the day of the week, environmental features associated with PA may differ across days of the week. To learn more about age-friendly environments calls for information on individuals' health behavior in space and time (12).

Features such as street connectivity, residential density, and mixed land use, whether as separate environmental features or in combination to form a walkability index, are indicative of service availability in the environment, and have all been positively associated with time spent on MVPA (2, 10, 11, 13, 14), although not consistently (15–18). MVPA has shown positive associations with closeness of parks (19) and density of recreation facilities (8), yet the associations have also appeared as non-significant (10, 13). Furthermore, research indicates that for older adults, walking to a daily destination typically takes at least 10 min (20). Thus, to include habitual outdoor activities, it may be necessary to capture continuous bouts of PA lasting at least 10 min. Bouts of at least 10 min have for a long time considered beneficial for health; however, current PA guidelines acknowledge the benefit of any activity and any breaks in sedentary time, regardless of their duration (1).

With declining function, older adults become more vulnerable to environmental barriers (21). Consequently, older adults may modify their behavior, e.g., by resting in the middle of a walk with steep slopes in the immediate home environment (22)—in other words, by shortening their activity bouts. Negative associations between hilly terrain and walking (23), total PA (24), and recreational PA (25) have been reported, although non-significant relationships with leisure-time PA have also been found (26). Nevertheless, to the best of our knowledge, the associations between hilly terrain and PA bouts and MVPA in older adults have not been studied.

The purpose of this study was to gain more understanding on variability in PA levels between weekdays and weekend days and, especially, on which environmental features may support habitual PA of older adults and when. For that, we examined the PA levels on weekdays and weekend days and explored the associations of environmental features with the number of PA bouts and MVPA minutes on weekdays and weekend days in older adults. In addition, by applying a method similar to that used by Sallis et al. (6), we aimed to estimate whether differences in the extent of environmental features supporting PA in a neighborhood would show practical relevance for older adults' PA levels estimated as the number of PA bouts and MVPA minutes. We included environmental features conducive to PA that are related to performing daily errands (intersection density and residential density) and engaging in recreational activities (number of land types, habitat diversity in green areas), and features hindering PA (hilly terrain). Land type, habitat diversity, and slope are also among the natural elements in a neighborhood. Intersection and residential density, in turn, are features of walkability, and thus indicate the amount of infrastructure supporting outdoor mobility (27).

MATERIALS AND METHODS

Study Design

This study is part of the project "Geographic characteristics, outdoor mobility and physical activity in old age" (GEOage) (28). In the project, data on participants' PA were combined with data on the environmental characteristics of their home surroundings. The participant data had earlier been collected in the project "Life-space mobility in old age" (LISPE), which has been described in detail elsewhere (29). For the LISPE study, a random sample of 2,550 community-dwelling older people aged 75–90 living in the neighboring municipalities of Jyväskylä and Muurame in Central Finland, which thereby formed the study area, was drawn from the population register in the winter of 2011/2012. Of these, 848 fulfilled the eligibility criteria (living independently in the recruitment area, being able to communicate, and willing to participate in the study) and were interviewed in their homes, using a structured questionnaire, in spring 2012. Participants signed a written informed consent before the home interview. The ethical committee of the University of Jyväskylä, Finland approved the LISPE and GEOage projects.

Research staff took an accelerometer to the home interview whenever one was available. After completion of the home interview, the interviewer asked verbally whether the participant was willing to participate in the accelerometer sub-study. Based on participant willingness and accelerometer availability, a sub-sample of 190 participants was assigned to wear a tri-axial accelerometer (Hookie AM20 Activity Meter; Hookie Technologies Ltd, Espoo, Finland) for 7 consecutive days following the home interview. The participants were instructed to wear the accelerometer (size 6.6 × 2.7 × 1.3 cm, mass 15 g), which was attached to an elastic belt, on their right hip during waking hours. They were told to take off the accelerometer only when engaging in activities, in which the accelerometer would get into contact with water. After the measurement period, participants returned the accelerometer in a prepaid envelope by mail, or in some cases, the accelerometer was picked up from their home. Data from 16 participants were excluded due to technical problems ending the accelerometer recording abruptly ($n = 3$), the accelerometer being lost in the mail ($n = 1$), accelerometer wear time not meeting the criterion of at least 10 h per day ($n = 11$), and intermissions of more than 1 day between consecutive measurement days ($n = 1$). Of the remaining participants, only those with valid measurement data for at least 2 weekdays (Monday–Friday) and at least one weekend day (Saturday–Sunday) were included in the study (excluded $n = 7$). This resulted in a final sample of 167. On average, those in the accelerometer sub-sample less frequently reported difficulties in walking 500 m (15% of sub-sample participants) than all the LISPE participants combined [26%, $\chi^2_{(1)} = 8.09$, $p < 0.05$]. Otherwise no differences were observed between the two samples in mean age, proportion of women, years of education, or number of chronic conditions (for all $p \geq 0.269$). Those who agreed to participate in the LISPE study were younger, more often lived alone, perceived their health as at least moderate, perceived fewer difficulties in outdoor mobility, and more frequently moved outside daily than those who declined to participate (29).

In the GEOage project, participants' homes, addresses for which were retrieved from the population register, were located on a map (30) using a geographic information system (GIS) (ArcMap version 10.3; Esri, Redlands, CA, USA). Openly available geospatial datasets were imported to the GIS to characterize the environment in the study area and within 500 or 1,000 m from participants' homes. In general, the study area is characterized by lakes, forest, low hills, and relatively continuous areas of built environment surrounded by sparsely populated areas. In the year 2012, the population of the study area was 143,000 inhabitants (31), with the majority concentrated in and around the center areas.

Study Measures

Physical Activity

Participants' PA was objectively assessed by an accelerometer (Hookie AM20 Activity Meter; Hookie Technologies Ltd, Espoo, Finland). The accelerometer records accelerations along three axes, x, y, and z, i.e., vertical, horizontal, and perpendicular, respectively, and has a dynamic range of ±16 g, 13 bits at 100 Hz. With accelerometer raw data available for our use, the resultant acceleration of each recorded sample was calculated and used in all further analyses. Mean amplitude deviation (MAD) (32) was calculated in non-overlapping 5-s epochs and subsequently averaged in 1-min epochs, using a custom-written Matlab script (R2015b, Mathworks, Inc., Natick, MA, USA). The pre-processed 1-min data were divided into 24-h segments from midnight to midnight, and further processing was done in those 24-h segments. Non-wear time was defined as any continuous epochs lasting at least 1 h with all the 1-m MADs below 0.024 g. This non-wear algorithm produced results congruent with self-reported accelerometer non-wear time.

PA was assessed from the 1-m MAD epoch values for each of the 24-h segments. The 1-m values were classified into sedentary (<0.0167 g), light PA (0.0167 to <0.091 g), moderate PA (0.091 to <0.414 g), or vigorous PA (≥0.414 g) after excluding all non-wear minutes. The intensity cut-offs were based on the optimal classification for light PA (0.0167 g) (32), and at MADs corresponding to 3 metabolic equivalents (MET, 0.091 g), and 6 METs (0.414 g) for moderate PA and vigorous PA, respectively (33). MVPA minutes was the sum of the minutes spent in moderate PA and vigorous PA. The accumulation of PA bouts was assessed based on the 1-m epochs of light PA and MVPA (34) and all active bouts lasting >10 min were counted (35). From the number of PA bouts lasting >10 min and total MVPA minutes in each 24-h segment, overall values were calculated as the mean of all the 24-h segments, weekday values as the mean of the 24-h segments from Monday to Friday, and weekend day values as the mean of the 24-h segments from Saturday to Sunday for both the number of PA bouts and MVPA minutes. Similarly, accelerometer wear time overall, on weekdays, and on weekend days was calculated as the mean value of the respective 24-h segments.

Environmental Features

Number of land types [*n*] was recorded as counts of different land types within a 500-m radius of the participant's home (36). The original 48 land type classes in the Corine Land Cover dataset (37) were reclassified into three built and 10 natural environment land types (38). Thus, the value of the variable reflects the variation present especially in the natural environment surrounding the participants' homes.

Habitat diversity in natural and green areas [index, range 0…10] was defined as the highest normalized value of the

Shannon's Diversity Index (SHDI) (36) among natural and green areas, which were of a minimum size of 10 hectares and located at least partly within 1,000 m from participants' homes. We chose a 1,000-m radius for this variable, as previous studies have shown that greenness (39, 40) and attractive destinations (41) at longer distances from the home may be positively associated with parameters of health and PA. To capture the diversity of the participants' natural environments, SHDI values were calculated only considering the nine natural environment land types, excluding water, included in the reclassified Corine Land Cover data (37). To enable meaningful interpretation of the results, the final SHDI value was calculated by multiplying the original index values (range 0–1) by 10.

Road network slope was defined as the average slope [% rise] (where 1% point equals a gradient of 0.45 degrees) in the 500-m road network (42) of each participant. We used the Digital Elevation Model available in the 2 m × 2 m raster dataset (43) to calculate slope values for every 2-m section of the roads in the study area. A participant's road network slope was the mean of the road section slope values in the 500-m road network.

Intersection density [10 intersections/km^2] was calculated as the number of intersections within a 500-m radius of the participant's home divided by the surface area of this zone. To enable meaningful interpretation of the results, this number was subsequently divided by 10. An intersection was defined as the junction of a minimum of three roads, and intersections within a distance of 10 m from one another were merged. In calculating this variable, we used the road data in the Topographic Database 2013 (42).

Residential density [1,000 residents/km^2] was defined as average residential density within a 500-m radius of the participant's home. For meaningful interpretation, this number was divided by 1,000. To calculate mean values, we first transformed the original 1 km × 1 km grid drawn from the Population grid data 2012 (44) into finer cells of 100 m × 100 m.

Covariates

To account for socio-demographic differences (7, 45), age, sex, and years of education were used as covariates in the analyses. Age and sex were retrieved from the national population register. Completed years of education was ascertained during the home interview. No imputation was made for the three missing cases. The moderating effects of the participants' physical functioning on the association between the built environment and physical activity (46–48) were evaluated with the variables walking difficulties and number of chronic conditions. Difficulties in walking 500 m were ascertained during the interview, and those reporting at least some difficulties were assigned to the category of perceived walking difficulties (vs. no walking difficulties). Self-reported number of chronic conditions was summed based on a list of 22 physician-diagnosed chronic conditions and an additional open-ended question (29).

Analysis

Participants and their environments were characterized by means, standard deviations and ranges, by medians and interquartile ranges (IQR), or by percentages depending on variable distribution. Distributions of PA variable values between weekdays and weekend days were compared using the Wilcoxon signed-rank test and Pearson chi-square test. Bland-Altman plots with 95% confidence intervals for differences in mean values between individuals' weekday and weekend day PA, including regression lines (49), were created for PA bouts and MVPA time. Bland-Altman plots are especially suited for visually detecting differences in corresponding values from repeated measurements or from two measurement methods along the measurement scale (50).

The PA variables showed right-skewed distributions and, except for mean MVPA on weekdays, included a substantial proportion of zero values. Hence, for the further analysis, the PA variable values were transformed using a natural logarithm after adding the value of one to remove zeros. Associations of each environmental variable with each of the log-transformed PA variables were studied using linear regression. Associations were adjusted first for age, sex, and accelerometer wear time (Model 1), and then—one at a time due to the relatively small sample size—for perceived difficulties in walking 500 m (Model 2), years of education (Model 3), and chronic conditions (Model 4). To interpret the results, the values of coefficients and confidence intervals from the log-transformed linear regression analyses were exponentiated (marked as $\exp^{\beta}$). In the result tables, the reported $\exp^{\beta}$ value equals the proportional change in the outcome variable value obtained from a one-unit increase in the predictor value. Additional sensitivity analyses were performed by rerunning the analyses with a sample restricted to participants with valid data for 3 or more weekdays and both weekend days ($n = 139$).

To estimate the magnitude of environmental effects on PA, we performed calculations using the results of the Model 2 linear regression analyses, the high-low difference in environmental variable values within the study area, and the median values of the number of PA bouts and MVPA minutes overall. Coefficients and confidence intervals of environmental variables showing statistically significantly associations with PA were multiplied by the value of the high-low difference, which was defined as the difference between the means of the highest and lowest 10% of the environmental variable values. This product was then exponentiated to show the proportional effect on PA of the high-low difference for the environmental variable in question. Furthermore, to express the absolute effects of the high-low difference for the environmental variables in the number of PA bouts and MVPA minutes, the proportional effect values were multiplied by the respective PA median values.

Data analyses were performed with IBM SPSS Statistics for Windows (version 24.0; IBM Corp., Armonk, NY, USA) and R software version 3.5.2 (51). Statistical significance was set at $p < 0.05$ in all tests.

RESULTS

Participant and neighborhood characteristics are presented in **Table 1**. Participant mean age was 80.3 years, 65% were women, and 15% perceived walking difficulties (**Table 1**).

Variability in Physical Activity Levels Between Weekdays and Weekend Days

The median number of accumulated PA bouts on weekdays and weekend days were similar ($p = 0.646$), with values below 1 indicating that the majority of the participants did not engage in a 10-min bout of continuous movement every day (**Table 2**). The median time spent in MVPA was about half an hour and did not differ between weekdays and weekend days ($p = 0.125$). On average, participants wore the accelerometer for a longer time on weekdays than weekend days ($p < 0.001$). The number of participants accumulating zero PA bouts was higher on weekend days (72 participants) than weekdays (43 participants) [$\chi^2_{(1)} = 48.366, p < 0.001$].

The Bland-Altman plot data on individuals showed that the participants accumulated on average 0.06 more PA bouts [$t_{(166)} = 1.015$, $p = 0.311$] and 1.64 fewer MVPA minutes [$t_{(166)} = -0.972$, $p = 0.332$] on weekend days compared to weekdays; however, these mean differences did not statistically significantly differ from zero. However, participants with lower PA in general often exhibited negative differences, indicating greater activity on weekdays compared to weekend days (**Figures 1**, **2**).

Environmental Features Associated With Physical Activity on Weekdays and Weekend Days

The linear regression analyses adjusted for age, sex, average accelerometer wear time, and walking difficulties yielded different environment-PA associations between weekdays and weekend days (**Table 3**). On weekdays, habitat diversity in natural and green areas, intersection density, and residential density were positively associated with both the number of PA bouts and MVPA minutes. On weekend days, only habitat diversity was positively associated with MVPA and had a slightly lower coefficient value than on weekdays. Road network slope showed a negative association with PA bouts on weekdays and weekend days and with MVPA on weekend days only. Number of land types was not associated with PA in any of the analyzed models. **Additional File 1** also shows the results of the models in which associations were adjusted for age, sex, and accelerometer wear time (Model 1), and also for years of education (Model 3), and chronic conditions (Model 4). No substantial differences in results were observed between the models, except for slope, which was associated with MVPA only in the model adjusted for walking difficulties (Model 2). The results of rerunning the models in the sensitivity analyses by including participants with valid accelerometer data for at least 5 days largely resembled those of the full sample, with some associations in the full sample with $p < 0.100$ reaching statistical significance and some associations turning statistically non-significant (p-value between 0.050 and 0.100) (see **Additional File 2**).

Effects of High-Low Differences in Environmental Features on Physical Activity

The proportional and absolute effects on PA of the high-low differences in environmental features in the study area are shown in **Table 4**. The effects were estimated in those environmental features, which were statistically significantly associated with number of PA bouts and MVPA minutes overall on all days. The highest effects were detected in residential density, in which the high-low difference of 4.55 thousand people per km^2 resulted in an increase of 36% in the number of PA bouts and 74% in MVPA minutes overall (proportional effects), which corresponded to 0.21 more PA bouts and 23.1 more MVPA minutes daily (absolute effects). Altogether, the proportional effects of the environmental variables positively associated with PA varied between 21 and 36% for PA bouts and between 57 and 74% for MVPA minutes. Depending on the high-low difference in the environmental feature in question, these resulted in absolute effects between 0.12 and 0.21 more PA bouts and between 18.0 and 23.1 more MVPA minutes daily. Slope was the only environmental feature showing a negative effect, with the high-low difference resulting in a 26%

TABLE 1 | Characteristics of participants and their neighborhood environments ($n = 167$).

	Mean	(Standard deviation)	Range Min–Max
Participant characteristics			
Age [years]	80.3	(4.2)	74.3–89.3
Education [years]	9.9	(4.0)	2–25
Chronic conditions [n]	4.3	(2.3)	0–11
Women [%]	65		
Walking difficulties [%]	15		
Neighborhood characteristics			
Land types [*n*]	6.1	(1.2)	4–9
Habitat diversity [10*SHDI]	4.3	(1.2)	1.3–7.1
Slope [% rise]	2.1	(0.6)	1.1–3.9
Intersection density [10 crossings/km^2]	5.9	(2.4)	0.5–10.9
Residential density [1,000 residents/km^2]	1.8	(1.5)	0.002–5.0

TABLE 2 | Accelerometer-derived PA and wear time overall (all days) and on weekdays and weekend days ($n = 167$).

	Overall		Weekdays		Weekend days		Wilcoxon signed-rank test[a]
	Median	(IQR)	Median	(IQR)	Median	(IQR)	*p*-value
PA bouts [n/day]	0.57	(0.14, 1.33)	0.60	(0.00, 1.33)	0.50	(0.00, 1.50)	0.646
MVPA [min/day]	31.3	(16.7, 54.4)	34.2	(17.8, 56.4)	31.5	(10.5, 50.0)	0.125
Accelerometer wear time [h/day]	13.5	(12.7, 14.3)	13.7	(12.7, 14.5)	13.2	(12.3, 14.2)	**<0.001**

[a]*Comparison between weekday and weekend day values. Values in bold; p < 0.05. IQR, Interquartile range (25%, 75%).*

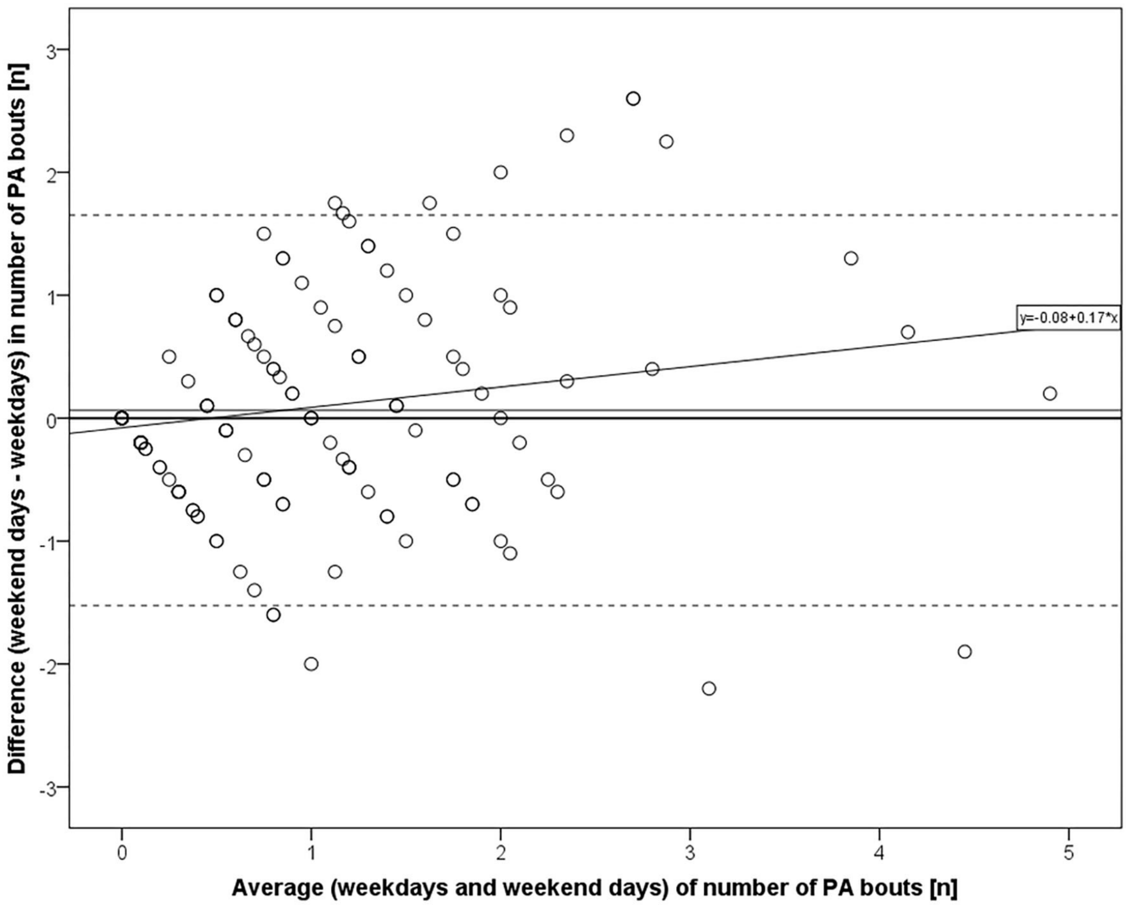


FIGURE 1 | Bland-Altman plot for number of PA bouts on weekend days vs. weekdays ($n = 167$). Mean difference with 95% confidence intervals and regression line ($R^2 = 0.036$, $p = 0.014$ for β).

decrease in PA bouts and 33% in MVPA, equivalent to 0.15 fewer PA bouts and 10.3 fewer MVPA minutes daily.

DISCUSSION

Our results show that several environment variables were associated with PA on weekdays and fewer on weekend days. The positive associations of intersection and residential densities with number of PA bouts and with MVPA minutes found only for weekdays indicate that living in environments with a higher amount of infrastructure supporting outdoor mobility and with the close proximity of service destinations is especially conducive to PA on weekdays but of less relevance at weekends. However, environmental features pertaining to natural elements were more consistently related to PA irrespective of the day of the week. Higher habitat diversity in natural and green areas was associated with more MVPA time on both weekdays and weekend days. The results suggest that older people may engage in partially different activities during weekdays compared to weekends.

Previous studies support our result showing a higher likelihood of PA on weekdays in areas with higher intersection and residential densities. In those, neighborhood walkability has shown a positive, nearly statistically significant trend in the number of MVPA bouts lasting at least 10 min (15). Walking facilities, intersection density, mixed land use, and density of recreation centers were positively associated with walking for errands (19). Walking for transport, typically to destinations at least 10 min away, was positively associated with number of neighborhood amenities and also, to a certain extent, street connectivity (20). Thus, it seems that for older adults, having destinations for daily errands within walking distance may play a major role in accumulating longer lasting and brisk PA, especially on weekdays. Yet in environments providing more services, opportunities to participate in other meaningful activities such as organized activities may be greater as well.

Habitat diversity in natural and green areas was positively associated with MVPA minutes on both weekdays and weekend days as well as with PA bouts on weekdays. These results are in line with previous findings that, in older adults, proximity to or the availability of a park are positively

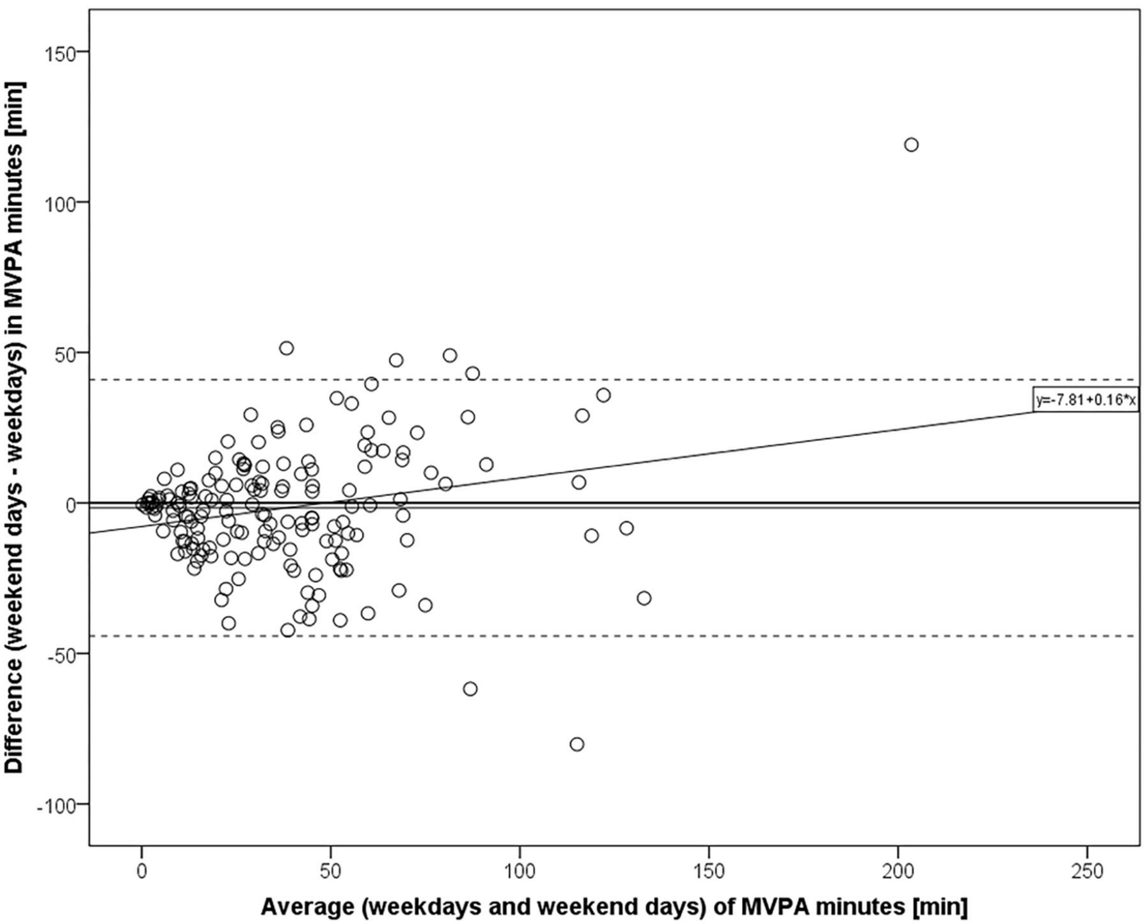


FIGURE 2 | Bland-Altman plot for MVPA minutes on weekend days vs. weekdays (n = 167). Mean difference with 95% confidence intervals and regression line (R^2 = 0.052, p = 0.003 for β).

associated with objectively measured daily MVPA (19) and self-reported leisure-time PA (9) and that several features of recreational destinations are positively associated with self-reported recreational walking (52). Among older adults with good walking capability, natural areas with higher diversity have also been related to higher self-reported PA and to perceptions of nearby nature as a motivator to go outside the home (38). However, no conclusive evidence on the associations between the availability of parks and recreation areas and self-reported active travel among older adults has previously been reported (45). Thus, based on the present results, it seems that attractive nature-based destinations close to home may be important facilitators for outdoor leisure-time and longer lasting and higher intensity exercise-type PA throughout the week among older adults.

In contrast, road network slope was negatively associated with, in particular, long-lasting PA throughout the week and with MVPA on weekend days in our study. These results are in line with earlier observations (23, 24). In addition, our earlier studies showed that perceiving hilliness as an outdoor mobility barrier predicted maladaptive walking modifications, i.e., reducing the frequency of walking or giving up walking (22) and that steeper roads in the home neighborhood predicted the development of walking difficulties (53). In the current study, the lower number of PA bouts and fewer MVPA minutes observed among older adults who live surrounded by a steep road network, supports the earlier finding that steep slopes hinder the daily walking of older adults.

In the current study, the proportion of participants with no 10-min PA bouts was higher during weekend days than weekdays. Those who were less active overall especially tended to accumulate a lower number of PA bouts and fewer MVPA minutes on weekend days than weekdays. These observations support Marshall et al. (54), who found, among those who were the most sedentary overall, that sedentary time on weekend days was greater than on an average weekday. In our study, PA ranges were narrower on weekdays than weekend days, which might suggest higher stability in PA behavior on weekdays than at weekends. Higher variability in weekend-day PA levels, as

TABLE 3 | Associations of environmental features with PA bouts and MVPA on weekdays and weekend days ($n = 167$).

	Number of PA bouts		MVPA minutes	
	Weekdays exp$^{\beta}$ (95% CI)	Weekends exp$^{\beta}$ (95% CI)	Weekdays exp$^{\beta}$ (95% CI)	Weekends exp$^{\beta}$ (95% CI)
Land types [*n*]	1.00 (0.94–1.05)	1.04 (0.98–1.10)	0.99 (0.89–1.09)	1.05 (0.94–1.17)
Habitat diversity [10*SHDI]	**1.07 (1.01–1.12)**	1.02 (0.97–1.08)	**1.16 (1.06–1.28)**	**1.11 (1.00–1.23)**
Slope [% rise]	**0.86 (0.77–0.96)**	**0.85 (0.75–0.97)**	0.82 (0.66–1.01)	**0.78 (0.62–0.98)**
Intersection density [10 crossings/km^2]	**1.03 (1.01–1.06)**	1.01 (0.98–1.05)	**1.07 (1.01–1.12)**	1.03 (0.97–1.09)
Residential density [1,000 residents/km^2]	**1.09 (1.04–1.13)**	1.03 (0.98–1.08)	**1.15 (1.06–1.25)**	1.08 (0.99–1.18)

Results of Model 2; adjusted for age, sex, accelerometer wear time, and difficulties in walking 500 m. Values in bold; $p < 0.05$. Antilogarithm values of unstandardized regression coefficients (exp$^{\beta}$) and their 95% confidence intervals (CI) from univariate linear regression models show a proportional effect of a one-unit increase in the predictor value on the outcome variable value (e.g., a one-unit increase in residential density, equaling an increase of 1,000 residents in a 1-km^2 area, shows a 9% increase in the number of PA bouts and 15% increase in MVPA minutes on weekdays).

TABLE 4 | Proportional and absolute effects of high-low differences in environmental variables on PA ($n = 167$).

Environmental variable	High-low difference [in environmental variable units]	exp$^{\beta}$ (95% CI)[a]	Proportional effect (95% CI)	Absolute effect [in units of PA variable]
Number of PA bouts overall [n/day]				
Land types [*n*]	4.12	1.01 (0.96–1.06)		
Habitat diversity [10*SHDI]	3.84	**1.05 (1.00–1.10)**	1.21 (1.01–1.45)	0.12
Slope [% rise]	1.92	**0.86 (0.77–0.95)**	0.74 (0.61–0.91)	–0.15
Intersection density [10 crossings/km^2]	8.37	**1.03 (1.00–1.05)**	1.26 (1.02–1.56)	0.15
Residential density [1,000 residents/km^2]	4.55	**1.07 (1.03–1.11)**	1.36 (1.13–1.64)	0.21
MVPA minutes overall [min/day]				
Land types [*n*]	4.12	1.00 (0.91–1.10)		
Habitat diversity [10*SHDI]	3.84	**1.15 (1.05–1.26)**	1.72 (1.22–2.41)	22.4
Slope [% rise]	1.92	**0.81 (0.67–0.99)**	0.67 (0.46–0.98)	–10.3
Intersection density [10 crossings/km^2]	8.37	**1.06 (1.01–1.11)**	1.57 (1.05–2.36)	18.0
Residential density [1,000 residents/km^2]	4.55	**1.13 (1.05–1.22)**	1.74 (1.23–2.47)	23.1

[a]Antilogarithm values of unstandardized regression coefficients (exp$^{\beta}$) and their 95% confidence intervals (CI) for univariate linear regression Model 2 adjusted for age, sex, accelerometer wear time, and perceived difficulties in walking 500 m. Values in bold; $p < 0.05$.

also reported by Abel et al. (4), may partly explain why fewer environmental features were related to PA levels on weekend days than weekdays.

The estimated potential effects on PA levels of high-low differences in the values of the environmental variables showed that environmental characteristics could have practical relevance for older adults' PA. Based on our estimation, the number of PA bouts was 36% greater for participants living in high vs. low residential density areas. Similarly, 26% fewer PA bouts were estimated for those living in high vs. low slope areas. Moreover, for participants living in a high habitat diversity area were calculated 72% more minutes of MVPA than for their counterparts living in a low habitat diversity area. Although considerably higher, our results parallel those of Sallis et al. (6), who, in a study on adults in 14 cities worldwide, estimated from 14 to 21% more weekly MVPA minutes for those living in neighborhoods in the highest 5% for PA-supportive environmental features (intersection and residential densities, number of parks) compared to those living in areas in the lowest 5% for these features. However, the large confidence intervals in our hypothetical estimates are a reminder that, rather than exact numbers, the associations and their directions must be considered when assessing the practical implications of these results. Furthermore, it is not possible to generalize these results to the population level, owing to the study area-specific ranges in the environment variables and a study sample consisting of older people with better than average functional capability. However, this estimation exercise shows that even within a relatively small study area, such as the one studied here, the characteristics of different neighborhood environments can vary in ways that, depending on their home location, favor some adults more than others with respect to the extent to which they support outdoor PA. However, since individual health and psychosocial factors seem to explain a larger part of older adults' PA, the contribution of environmental factors to PA levels is necessarily limited (19). Nevertheless, the environment-PA associations that we found were not notably affected by adjustments for health and socioeconomic factors. Hence, the potential effects of environmental features on older adults' PA deserve to be acknowledged, especially as even modest increases in MVPA time are beneficial, especially for the least physically active (1, 55).

The strengths of this study include the use of a population-based sample of community-dwelling people in old age. We had high quality accelerometer-measured PA data, which allowed us to use appropriate measures of outdoor PA and also investigate environment-PA associations for weekdays and weekend days separately. Detailed geospatial data on the study area enabled us to consider several environmental aspects of participants' home surroundings. A weakness is that we had no information on the actual location of PA. Hence, the accelerometer data may at least partly have accumulated from indoor activities or from PA in outdoor environments further away from home. However, moving continuously for a minimum of 10 min or being physically active at a moderate or vigorous level is more likely to take place outside than indoors. We did not take cognitive functioning into account in our analyses, although it has been suggested that cognitive capability moderates the associations between perceived environmental features and PA among older adults (56). We regarded this as unnecessary as our participants generally showed good level of cognitive capability [median 27.0 points, IQR 3.0 in the Mini-Mental State Examination (MMSE), $n = 167$]. Additionally, the rather small study sample living in one geographical area may limit the generalizability of the results to different areas.

To conclude, our results suggest that PA behavior on weekdays compared to weekend days is more closely coupled with environmental features in the vicinity of the home. Based on the differences found in the type and numbers of environmental features associated with weekday and weekend day PA, it seems reasonable to speculate that individual objectives motivating PA might underlie temporal variation in environment-PA associations. As those older adults, who are the least physically active overall, seem to engage in less PA on weekends than weekdays, it is possible that underlining the importance of establishing daily PA routines and organizing more activities that entice older people to go outside home at weekends as well as weekdays could increase their weekly PA. In addition, neighborhood environments with high walkability, attractive destinations, and routes with low gradients as enablers of higher PA, especially on weekdays, might help older people to undertake higher weekly amounts of PA. However, to develop effective interventions, more research on the temporal, spatial, and behavioral aspects of PA in older people is needed.

DATA AVAILABILITY STATEMENT

Due to ethical and legal restrictions pseudonymized datasets are available only upon request from Taina Rantanen (taina.rantanen@jyu.fi). External collaborators may use data upon agreement on the terms of data use and publication of results.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the ethical committee of the University of Jyväskylä, Finland. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KK, YG, and EP conceived and designed the study. MR, TR, and EP contributed to the participant data collection. YG processed the accelerometer raw data and was responsible for describing the physical activity measures in the manuscript. KK retrieved and processed the geospatial data, conducted the statistical analyses, and was the major contributor in interpreting the results and writing the manuscript. All authors critically revised the paper and read and approved the final manuscript.

FUNDING

This work was financially supported by grants from the Foundation for Municipal Development and the Finnish Cultural Foundation (KK), the Finnish Ministry of Education and Culture (TR and EP), the Academy of Finland [grant no. 255403 (TR)], and the European Research Council [advanced grant no. 693045 (TR)]. The study sponsors had no role in designing the study or in collecting, analyzing, and interpreting the data, or in writing the report or deciding to submit the article for publication.

ACKNOWLEDGMENTS

The authors would like to thank the participants for supporting our study with their time and effort. The Gerontology Research Center is a joint effort between the University of Jyväskylä and the University of Tampere.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.578275/full#supplementary-material

REFERENCES

1. Piercy KL, Troiano RP, Ballard RM, Carlson SA, Fulton JE, Galuska DA, et al. The physical activity guidelines for Americans. *JAMA*. (2018) 320:2020–8. doi: 10.1001/jama.2018.14854
2. Colley RC, Christidis T, Michaud I, Tjepkema M, Ross NA. The association between walkable neighbourhoods and physical activity across the lifespan. *Health Rep*. (2019) 30:3–13. doi: 10.25318/82-003-x201900900001-eng
3. Portegijs E, Tsai LT, Rantanen T, Rantakokko M. Moving through life-space areas and objectively measured physical activity of older people. *PLoS ONE*. (2015) 10:e0135308. doi: 10.1371/journal.pone.0135308

4. Abel B, Pomiersky R, Werner C, Lacroix A, Schäufele M, Hauer K. Day-to-day variability of multiple sensor-based physical activity parameters in older persons with dementia. *Arch Gerontol Geriatr.* (2019) 85:103911. doi: 10.1016/j.archger.2019.103911
5. Tsai LT, Rantakokko M, Viljanen A, Saajanaho M, Eronen J, Rantanen T, et al. Associations between reasons to go outdoors and objectively-measured walking activity in various life-space areas among older people. *J Aging Phys Act.* (2016) 24:85–91. doi: 10.1123/japa.2014-0292
6. Sallis JF, Cerin E, Conway TL, Adams MA, Frank LD, Pratt M, et al. Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. *Lancet.* (2016) 387:2207–17. doi: 10.1016/S0140-6736(15)01284-2
7. Barnett DW, Barnett A, Nathan A, Van Cauwenberg J, Cerin E, Council on Environment and Physical Activity (CEPA)—Older Adults, Working Group. Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act.* (2017) 14:103. doi: 10.1186/s12966-017-0558-z
8. Cerin E, Zhang CJP, Barnett A, Sit CHP, Cheung MMC, Johnston JM, et al. Associations of objectively-assessed neighborhood characteristics with older adults' total physical activity and sedentary time in an ultra-dense urban environment: findings from the ALECS study. *Health Place.* (2016) 42:1–10. doi: 10.1016/j.healthplace.2016.08.009
9. Van Cauwenberg J, Nathan A, Barnett A, Barnett DW, Cerin E, Council on Environment and Physical Activity (CEPA)-Older Adults Working Group. Relationships between neighbourhood physical environmental attributes and older adults' leisure-time physical activity: a systematic review and meta-analysis. *Sports Med.* (2018) 48:1635–60. doi: 10.1007/s40279-018-0917-1
10. Ding D, Sallis JF, Norman GJ, Frank LD, Saelens BE, Kerr J, et al. Neighborhood environment and physical activity among older adults: do the relationships differ by driving status? *J Aging Phys Act.* (2014) 22:421–31. doi: 10.1123/JAPA.2012-0332
11. Van Cauwenberg J, Van Holle V, De Bourdeaudhuij I, Van Dyck D, Deforche B. Neighborhood walkability and health outcomes among older adults: the mediating role of physical activity. *Health Place.* (2016) 37:16–25. doi: 10.1016/j.healthplace.2015.11.003
12. Noordzij JM, Beenackers MA, Diez Rouxb AV, van Lenthe FJ. Age-friendly cities: challenges for future research. *Bull World Health Organ.* (2019) 97:436–7. doi: 10.2471/BLT.18.224865
13. Carlson JA, Sallis JF, Conway TL, Saelens BE, Frank LD, Kerr J, et al. Interactions between psychosocial and built environment factors in explaining older adults' physical activity. *Prev Med.* (2012) 54:68–73. doi: 10.1016/j.ypmed.2011.10.004
14. Van Holle V, Van Cauwenberg J, Gheysen F, Van Dyck D, Deforche B, Van de Weghe N, et al. The association between Belgian older adults' physical functioning and physical activity: what is the moderating role of the physical environment? *PLoS ONE.* (2016) 11:e0148398. doi: 10.1371/journal.pone.0148398
15. Amagasa S, Inoue S, Fukushima N, Kikuchi H, Nakaya T, Hanibuchi T, et al. Associations of neighborhood walkability with intensity- and bout-specific physical activity and sedentary behavior of older adults in Japan. *Geriatr Gerontol Int.* (2019) 19:861–7. doi: 10.1111/ggi.13730
16. Chen BI, Hsueh MC, Rutherford R, Park JH, Liao Y. The associations between neighborhood walkability attributes and objectively measured physical activity in older adults. *PLoS ONE.* (2019) 14:e0222268. doi: 10.1371/journal.pone.0222268
17. Pettigrew S, Rai R, Jongenelis MI, Jackson B, Beck B, Newton RU. The potential importance of housing type for older people's physical activity levels. *J Appl Gerontol.* (2020) 39:285–91. doi: 10.1177/0733464819840978
18. Timmermans EJ, Schaap LA, Visser M, van der Ploeg HP, Wagtendonk AJ, van der Pas S, et al. The association of the neighbourhood built environment with objectively measured physical activity in older adults with and without lower limb osteoarthritis. *BMC Public Health.* (2016) 16:710. doi: 10.1186/s12889-016-3347-8
19. Thornton CM, Kerr J, Conway TL, Saelens BE, Sallis JF, Ahn DK, et al. Physical activity in older adults: an ecological approach. *Ann Behav Med.* (2017) 51:159–69. doi: 10.1007/s12160-016-9837-1
20. Perchoux C, Brondeel R, Wasfi R, Klein O, Caruso G, Vallée J, et al. Walking, trip purpose, and exposure to multiple environments: a case study of older adults in Luxembourg. *J Transp Health.* (2019) 13:170–84. doi: 10.1016/j.jth.2019.04.002
21. Lawton MP, Nahemow L. Ecology and the aging process. In: Eisdorfer C, Lawton MP, editors. *The Psychology of Adult Development and Aging.* Washington, DC: American Psychological Association (1973). p. 619–74.
22. Skantz H, Rantanen T, Rantalainen T, Keskinen KE, Palmberg L, Portegijs E, et al. Associations between perceived outdoor environment and walking modifications in community-dwelling older people: a two-year follow-up study. *J Aging Health.* (2020). doi: 10.1177/0898264320944289. [Epub ahead of print].
23. Gómez LF, Parra DC, Buchner D, Brownson RC, Sarmiento OL, Pinzón JD, et al. Built environment attributes and walking patterns among the elderly population in Bogotá. *Am J Prev Med.* (2010) 38:592–9. doi: 10.1016/j.amepre.2010.02.005
24. Tanaka T, Tanaka K, Suyama K, Honda S, Senjyu H, Kozu R. A comparison of objective physical activity, muscle strength, and depression among community-dwelling older women living in sloped versus non-sloped environments. *J Nutr Health Aging.* (2016) 20:520–4. doi: 10.1007/s12603-015-0602-0
25. Wu ZJ, Song Y, Wang HL, Zhang F, Li FH, Wang ZY. Influence of the built environment of Nanjing's Urban Community on the leisure physical activity of the elderly: an empirical study. *BMC Public Health.* (2019) 19:1459. doi: 10.1186/s12889-019-7643-y
26. Ribeiro AN, Mitchell R, Sá Carvalho M, de Fátima de Pina M. Physical activity-friendly neighbourhood among older adults from a medium size urban setting in Southern Europe. *Prev Med.* (2013) 57:664–70. doi: 10.1016/j.ypmed.2013.08.033
27. Frank LD, Schmid TL, Sallis JF, Chapman J, Saelens BE. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. *Am J Prev Med.* (2005) 28:117–25. doi: 10.1016/j.amepre.2004.11.001
28. Portegijs E, Keskinen KE, Tsai LT, Rantanen T, Rantakokko M. Physical limitations, walkability, perceived environmental facilitators and physical activity of older adults in Finland. *Int J Environ Res Public Health.* (2017) 14:333. doi: 10.3390/ijerph14030333
29. Rantanen T, Portegijs E, Viljanen A, Eronen J, Saajanaho M, Tsai LT, et al. Individual and environmental factors underlying life space of older people—study protocol and design of a cohort study on life-space mobility in old age (LISPE). *BMC Public Health.* (2012) 12:1018. doi: 10.1186/1471-2458-12-1018
30. Finnish Transport Infrastructure Agency. *Digiroad Road and Street Database, R-Format.* Helsinki: CSC—IT Center for Science Ltd (2013). Available online at: https://avaa.tdata.fi/web/paituli (accessed September 23, 2013).
31. Official Statistics of Finland (OSF). *Population Structure.* Helsinki: Statistics Finland. Available online at: http://www.stat.fi/til/vaerak/index_en.html (accessed April 2, 2019).
32. Vähä-Ypyä H, Vasankari T, Husu P, Suni J, Sievänen H. A universal, accurate intensity-based classification of different physical activities using raw data of accelerometer. *Clin Physiol Funct Imaging.* (2015) 35:64–70. doi: 10.1111/cpf.12127
33. Vähä-Ypyä H, Vasankari T, Husu P, Mänttäri A, Vuorimaa T, Suni J, et al. Validation of cut-points for evaluating the intensity of physical activity with accelerometry-based mean amplitude deviation (MAD). *PLoS ONE.* (2015) 10:e0134813. doi: 10.1371/journal.pone.0134813
34. Chastin SFM, Winkler EAH, Eakin EG, Gardiner PA, Dunstan DW, Owen N, et al. Sensitivity to change of objectively-derived measures of sedentary behavior. *Meas Phys Educ Exerc Sci.* (2015) 19:138–47. doi: 10.1080/1091367X.2015.1050592
35. Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation.* (2007) 116:1081–93. doi: 10.1161/CIRCULATIONAHA.107.185649
36. Magurran AE. *Ecological Diversity and its Measurement.* London: Croom Helm (1988). p. 179.
37. Finnish Environment Institute (SYKE) (partly Metla, Mavi, LIVI, VRK, MML Topographic Database 05/2012). *Corine Land Cover 2012 National Datasets (20m).* Helsinki: Finnish Environment Institute (2014). Available

online at: https://www.syke.fi/en-US/Open_information/Spatial_datasets/Downloadable_spatial_dataset#C (accessed November 20, 2014).
38. Keskinen KE, Rantakokko M, Suomi K, Rantanen T, Portegijs E. Nature as a facilitator for physical activity: defining relationships between the objective and perceived environment and physical activity among community-dwelling older people. *Health Place.* (2018) 49:111–9. doi: 10.1016/j.healthplace.2017.12.003
39. Ekkel ED, de Vries S. Nearby green space and human health: evaluating accessibility metrics. *Landsc Urban Plan.* (2017) 157:214–20. doi: 10.1016/j.landurbplan.2016.06.008
40. Browning M, Lee K. Within what distance does "greenness" best predict physical health? a systematic review of articles with GIS buffer analyses across the lifespan. *Int J Environ Res Public Health.* (2017) 14:675. doi: 10.3390/ijerph14070675
41. Portegijs E, Keskinen KE, Eronen J, Saajanaho M, Rantakokko M, Rantanen T. Older adults' physical activity and the relevance of distances to neighborhood destinations and barriers to outdoor mobility. *Front Public Health.* (2020) 8:335. doi: 10.3389/fpubh.2020.00335
42. National Land Survey of Finland. *Topographic Database 2013. 1:10 000.* Helsinki: CSC—IT Center for Science Ltd (2015). urn:nbn:fi:csc-kata00001000000000000181 (accessed September 17, 2014).
43. National Land Survey of Finland. *Digital Elevation Model 2008-2010, 2 m x 2 m.* Helsinki: CSC—IT Center for Science Ltd (2012). urn:nbn:fi:csc-kata00001000000000000187 (accessed December 12, 2014).
44. Statistics Finland. *Population Grid Data 2012 1 km × 1 km.* Helsinki: CSC—IT Center for Science Ltd (2015). urn:nbn:fi:csc-kata00001000000000000222 (accessed March 30, 2017).
45. Cerin E, Nathan A, Van Cauwenberg J, Barnett DW, Barnett A. The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act.* (2017) 14:15. doi: 10.1186/s12966-017-0471-5
46. Satariano WA, Ivey SL, Kurtovich E, Kealey M, Hubbard AE, Bayles CM, et al. Lower-body function, neighborhoods, and walking in an older population. *Am J Prev Med.* (2010) 38:419–28. doi: 10.1016/j.amepre.2009.12.031
47. King AC, Sallis JF, Frank LD, Saelens BE, Cain K, Conway TL, et al. Aging in neighborhoods differing in walkability and income: associations with physical activity and obesity in older adults. *Soc Sci Med.* (2011) 73:1525–33. doi: 10.1016/j.socscimed.2011.08.032
48. Gong Y, Gallacher J, Palmer S, Fone D. Neighbourhood green space, physical function and participation in physical activities among elderly men: the Caerphilly Prospective study. *Int J Behav Nutr Phys Act.* (2014) 11:40. doi: 10.1186/1479-5868-11-40
49. Bland JM, Altman DG. Measuring agreement in method comparison studies. *Stat Methods Med Res.* (1999) 8:135–60. doi: 10.1191/096228099673819272
50. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet.* (1986) 327:307–10. doi: 10.1016/S0140-6736(86)90837-8
51. R Core Team. *R: A Language and Environment for Statistical Computing.* Vienna: R Foundation for Statistical Computing (2018). Available online at: https://www.R-project.org.
52. Sugiyama T, Neuhaus M, Cole R, Giles-Corti B, Owen N. Destination and route attributes associated with adults' walking: a review. *Med Sci Sports Exerc.* (2012) 44:1275–86. doi: 10.1249/MSS.0b013e318247d286
53. Keskinen KE, Rantakokko M, Suomi K, Rantanen T, Portegijs E. Hilliness and the development of walking difficulties among community-dwelling older people. *J Aging Health.* (2020) 32:278–84. doi: 10.1177/0898264318820448
54. Marshall S, Kerr J, Carlson J, Cadmus-Bertram L, Patterson R, Wasilenko K, et al. Patterns of weekday and weekend sedentary behavior among older adults. *J Aging Phys Act.* (2015) 32:534–41. doi: 10.1123/japa.2013-0208
55. Hupin D, Roche F, Gremeaux V, Chatard J-C, Oriol M, Gaspoz J-M, et al. Even a low-dose of moderate-to-vigorous physical activity reduces mortality by 22% in adults aged ≥60 years: a systematic review and meta-analysis. *Br J Sports Med.* (2015) 49:1262–7. doi: 10.1136/bjsports-2014-094306
56. Gheysen F, Herman K, Van Dyck D. Cognitive functioning as a moderator in the relationship between the perceived neighborhood physical environment and physical activity in Belgian older adults. *J Aging Phys Act.* (2019) 27:890–8. doi: 10.1123/japa.2018-0277

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 05 November 2020
doi: 10.3389/fpubh.2020.577140

Associations Between Built Environment Characteristics and Walking in Older Adults in a High-Density City: A Study From a Chinese Megacity

Hui He[1], *Tingting Li*[1], *Yanwei Yu*[1] *and Xiaowu Lin*[2]*

[1] *School of Architecture and Urban Planning, Huazhong University of Science and Technology, Wuhan, China,* [2] *Xiamen Urban Planning & Design Institute, Xiamen, China*

OPEN ACCESS

Edited by:
Erja Portegijs,
University of Jyväskylä, Finland

Reviewed by:
Erik Timmermans,
Amsterdam University Medical Center (UMC), Netherlands
Caroline Diane Bergeron,
Public Health Agency of Canada (PHAC), Canada

***Correspondence:**
Xiaowu Lin
973742941@qq.com

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *28 June 2020*
Accepted: *02 October 2020*
Published: *05 November 2020*

Citation:
He H, Li T, Yu Y and Lin X (2020) Associations Between Built Environment Characteristics and Walking in Older Adults in a High-Density City: A Study From a Chinese Megacity. Front. Public Health 8:577140. doi: 10.3389/fpubh.2020.577140

The built environment is an important factor affecting physical activity, especially walkability. Walkability is used to characterize the user friendliness of outdoor physical activity. However, studies on walkability and physical activity are mainly concentrated on low-density Western cities. Study on the walkability of high-density cities in Asia, especially with the elderly, is seriously lacking. And walkability is often used as a composite indicator. This study mainly re-examines the relationship between the common indicators of walkability (population density, street connectivity, land-use mix, and retail density), transport-related walking, and leisure-time walking with older adults in China's megacities. Twelve housing estates in Wuhan were selected for study areas. We explored the association between the walking activities of 1,161 elderly people (≥60 years old) and the indicators of walkability in their neighborhoods. Socio-demographic characteristics were controlled in the multilevel logistic regression models of the built environment walking associations. We found that there was no significant correlation between the four indicators of walkability and transport-related walking. Street connectivity is significantly positively correlated with the participants' leisure-time walking (OR = 1.499, 95% CI = 1.068∼2.103), and there was no significant correlation between the other indicator of walkability and leisure-time walking. The results show that there was no statistical correlation between walkability and transport-related walking in the elderly, and only one indicator was related to leisure-time walking. It is extremely important to re-examine the characteristics of built environments and elderly walking activities in high-density cities. Only by implementing effective intervention strategies in different urban backgrounds can cities move toward a more active and healthier path.

Keywords: high-density city, walking, transport-related walking, leisure-time walking, older adults, walkability

INTRODUCTION

At present, the acceleration of population aging has become a common phenomenon in megacities around the world. How to deal with the negative impact of population aging is a serious challenge facing humanity. According to a report released by the World Health Organization (WHO), the elderly population will exceed that of children, and 80% of the elderly will live in developing countries by 2050 (1). Chinese population aging is much faster than many middle and low income countries, and China's population aging has two characteristics: on the one hand, the process is accelerating in recent years; on the other hand, the number will triple (402 million people) by 2040 (2). Under the current situation of global aging and the shortage of medical resources, encouraging older people to participate in physical activities to improve their health is of greater significance than clinical treatment. The World Health Organization encourages the elderly to participate in at least 150 min of aerobic physical activity every week to protect their health (3). Empirical studies have shown that regular and adequate levels of physical activity can provide mental and physical health benefits and can also reduce the risk of many chronic diseases (4, 5). Despite such obvious benefits of physical activity, a WHO global health survey found that the percentage of the population that meets the recommended amount of exercise is decreasing with age (6). In 2013, nearly 50% (100 million) of older people in China experienced non-communicable diseases. According to the 2010 Chronic Disease Risk Factor Surveillance Survey, nearly 84% of older people do not engage in regular physical activities. And there was a marked difference among older people in urban (24%) compared to rural areas (7.1%) (7). The combination of population aging and physical inactivity reduces the quality of life of older adults and increases the burden of health care. Therefore, from the perspective of public health, it is essential to explore the relevant factors that promote the physical activity of the elderly and propose effective intervention strategies.

Compared with people of other ages, the elderly are often physically impaired and generally do not commute. They often engage in outdoor activities in spaces near their residential area (8, 9), so the characteristics of the neighborhood environment can affect the physical activity of the elderly. It is essential to explore the relationship between built environment and physical activity of the elderly in order to guide the construction of age-friendly communities to promote physical activity of the elderly, which will help maintain good physical function of the elderly and thus prolong independent community life. In the theoretical study of social ecological models, the built environment is one of the most important factors affecting physical activity (10, 11). In a number of systematic reviews, the researchers determined that built environment characteristics are related to physical activity of the elderly, including walkability, overall access to destinations and services, land-use combinations, and a walk-friendly infrastructure (12, 13). Most research cites two definitions of measurement range of a neighborhood environment. One defines the buffer zone geographically (generally within a 1,000 m buffer zone around the participant's residence). A study from Hong Kong defined an 800 m circular buffer zone of the neighborhood (14), and a study from Seattle defined a 500 m circular buffer zone (15). Researchers generally use GIS tools to audit the environmental attributes of a buffer zone. The second way of defining a measurement range is from the home starting point of participants to a self-aware walking area of 10 to 20 min (16, 17). The general neighborhood environmental perception questionnaire is used to assess the environmental attributes.

The 3D (Density, Diversity, and Design) environmental elements have also been shown to relate to the physical activity of the elderly (especially walking activities) in land-use mix, population density, street connectivity, and retail facilities (18–20). In the study of low-density cities in western developed countries, it was found that the above environmental factors are more positively related to the promotion of outdoor physical activities. Therefore, based on research results of the 3D elements, the researchers put forward a composite indicator of walkability that characterizes the degree of friendliness of the built environment to the physical activities of residents (21, 22). The combined indicators of walkability generally include residential density, street connectivity, land-use mix, and the retail building area ratio (23, 24). When calculating walking ability, the measured values are standardized and then weighted together (25, 26).

As mentioned earlier, relevant research between the indicators of walkability and physical activity is carried out frequently on low-density cities in the West, and most research results show that indicators of walkability promote residents' physical exercise. However, there are relatively few studies on high-density cities in China, especially China's megacities. What is more, the population density of China's megacities is much higher than that of many cities in Western countries, and the differences between urban built environments and culture may result in different research results. Taking population density as an example, academic circles have found relevant research results in China's megacities: some research results show that it is negatively correlated with adolescents' entertainment physical activity (27, 28), or they show no correlation (29); another study found that it is negatively related to the leisure physical activities of adult women (30). Therefore, it is particularly important to re-examine the relationship between the built environment of megacities and the physical activity of residents. Research should focus on the elderly because the population aging degree in China's megacities is acute. It is critical to intervene in the health of the elderly from the aspect of built environment. The local government should promote the physical activity of the elderly from the aspects of planning policy and urban design, which can reduce the pressure of elderly care (31).

Related research shows that walking is the most popular physical activity for the elderly (32), so this study focuses on the relationship between elderly walking activities and the built environment. Two points need to be emphasized. First, the existing calculation formula of walkability is based on the fact that all indicators are positively correlated with physical activity, but some indicators of walkability may not be positively correlated with physical activity. Secondly, current research mainly studies the built environment from the perspective of a single type of physical activity, and there is a lack of comparison between different categories. In this study, however, the elderly walking activities are divided into transport-related walking and leisure-time walking, and we compare the differences of the relationship between built environment and two types of walking activities in the elderly.

In summary, this study examined the relationship between two types of walking and the walkability index of the elderly in 12 residential areas in Wuhan, China. We hypothesize that there are positive relationships between the four indicators of walkability and both types of walking based on the findings of previous studies.

METHODS

Study Areas and Sampling Approach

Wuhan is a megacity in central China (**Figure 1A**). The proportion of the aging population of Wuhan has been increasing in the past two decades, and the aging rate of 7 administrative districts located in the main urban area has exceeded 20% since 2018. The main urban area of Wuhan has a much higher aging rate than the suburban areas (**Figure 1B**) (33). The population density of the main urban area of Wuhan is 5,898∼25,790 people/km^2 (34), the minimum population density (5,898 people/km^2) in our study is still much higher than 500 persons/km^2, the cutoff for high residential density in Western countries (35). During the selection, we chose residential areas with a high aging rate so that the researchers could collect enough data. We also sought to select housing estates with similar homogeneous socioeconomic (SES) profiles; thus, we selected housing estates with a similar median house price. Based on those criteria, we selected 12 housing estates in the main urban area as our sample (**Figure 1C**).

We conducted the study from October to November 2019, when the weather is cool and pleasant for walking activities with older adults. Trained interviewers visited the selected housing estates and interviewed 80–120 older adults, using a random sampling method in each housing estate. All participants were able to engage in physical activity independently and had lived in the residence for over 1 year. A total of 1,161 valid questionnaires were collected.

Walking Data

The times the adults walked were obtained through questionnaire interviews. The content and form of the questionnaire were optimized based on the International Physical Activity Questionnaire. Because older adults may have difficulty reading or filling out the questionnaire, the survey was completed by trained interviewers after face-to-face interviews with participants. The survey mainly investigated the transport-related walking activities and leisure-time walking activities of the elderly in the neighborhood. The following four questions were asked:

1. In the last 7 days, how many days have you carried out transport-related walking for at least 10 min (e.g., walking to the bus station, shopping, seeing a doctor, etc.)?
2. How much time do you usually spend walking in a day when you have transport-related walking?
3. In the last 7 days, how many days did you have a leisure-time walking activity that lasted for at least 10 min (excluding the transport-related walking activities mentioned in question 2)?
4. How much time do you usually spend a day on leisure-time walking?

We multiplied the average duration of walking time (in minutes) by the number of days engaged in walking in the past 7 days to obtain the total time of the two types of walking in older adults. As the total duration distribution of the two types of walking activities was highly skewed, with many participants reporting few transport-related walking (38.16%), but much leisure-time walking (66.93%) being reported, the total minutes of walking time per week was transformed into binary variables. We transformed transport-related walking into binary categorical variables of ≥150 vs. <150 min/per week [WHO recommends that the elderly exercise "150 min/week" to protect their health (3)], and we transformed leisure-time walking into binary categorical variables of ≥150 vs. <150 min/per week.

Built Environment Variables

The built environment variables select common indicators in walkability, including population density, street connectivity, land-use mix, and retail density. The measurement range of environment variables is within an 800 m circular buffer zone around the housing estate of participants. The selection of the 800 m buffer was based on average walking distance and it is the area within 10 to 15 min elderly walking distance. Population density is defined as the resident population per unit of land area where the participant is located. Street connectivity measures the inter-connectedness of the street network within a participant's walkable service area. The measure is a ratio of the count of three (or more) way intersections over the area (km^2). In the mixed land-use calculation, the land types are mainly divided into three categories: residential, commercial, and office (21); Retail business density measures the convenience of daily shopping within a participant's walkable service area. The four built environment variables are described along with applicable data sources in **Table 1**.

Individual Covariances

Individual covariates include gender, age, and education level; the participants' ages were transformed into a categorical variable with three levels: 60–69 years (reference category), 70–79 years, and ≥80 years. Education levels were transformed into a categorical variable with four levels: primary school and below (reference category), middle school, high school, and postsecondary school.

Data Analysis

In this study, 1,210 eligible participants were recruited, while 1,161 completed the survey (response rate = 96%). Multilevel logistic regression models were conducted to investigate the relationship between the built environment and the two types of walking activities for older adults. The

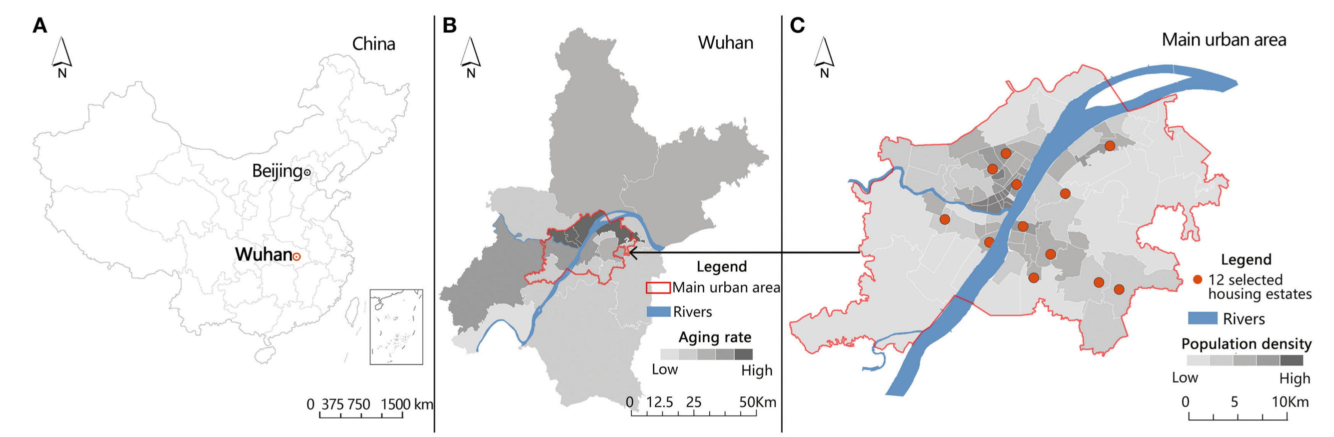


FIGURE 1 | **(A)** Location of Wuhan in China; **(B)** Proportion of the aging population in different administrative districts of Wuhan; and **(C)** The 12 selected housing estates in Wuhan.

TABLE 1 | Built environment measures.

Measure	Definition	Scale of measurement for target area selection	Equation	Data source(s)
Population density	Resident population per unit of land area	Administrative Street[a]	Count of resident population/area of administrative Street	The Sixth National Census in Wuhan (2010)
Street connectivity	Number of street intersections per unit of land area	800 m circular buffer	Number of intersections/area of 800 m circular buffer	Baidu Maps (accessed September 17, 2019)
Land-use mix	Evenness of distribution of residential, commercial, and office per unit of land area	800 m circular buffer	Equation below[b]	Urban Master Planning of Wuhan (2010–2020)
Retail density	Number of retail shops per unit of land area	800 m circular buffer	Number of retail shops/area of 800 m circular buffer	Amap (accessed September 10, 2019)

[a] *Administrative street is the smallest unit of urban population statistics in China.*
[b]

$$land-use\ mix = \frac{(-1) \times \left[\left(\frac{b1}{a}\right) \times \ln\left(\frac{b1}{a}\right) + \left(\frac{b2}{a}\right) \times \ln\left(\frac{b2}{a}\right) + \left(\frac{b3}{a}\right) \times \ln\left(\frac{b3}{a}\right)\right]}{\ln 3}.$$

[a] *(total square footage of commercial, residential, and office),* [b] *(square footage of commercial, residential, or office). The formula for land use mix presented ranges from 0 to 1, and a high score indicates high heterogeneity of land use.*

house estates were assigned a random effect that accounts for the clustering in the physical activity of participants in the house estates. Model 1 included built environment variables, and Model 2 included further controlled individual covariates. All model analysis results reported Odds Ratios (ORs) and their 95% confidence intervals (95% CI) and *p*-values. These analyses were conducted with R and a multilevel package lme4 (36).

RESULTS

The descriptive data are shown in **Table 2**. Approximately 38% of the participants performed at least 150 min of transport-related walking in a week; ∼67% of the participants performed at least 150 min of leisure-time walking in a week.

The results of the multilevel logistic regression model of the participants' transport-related walking time and built environment variables are shown in **Table 3**. The four indicators of walkability (population density, street connectivity, land-use mix, and retail density) were not significantly correlated with the likelihood of engaging in at least 150 min of transport-related walking in Models 1 & 2. Among the individual covariates, age was significantly related to the likelihood of participating in transport-related walking for at least 150 min. Participants over 70 years old were less likely to conduct transport-related walking than participants who were 60–69 years old (70–79 years old: OR = 0.561, 95% CI = 0.423∼0.745; ≥80 years old: OR = 0.242, 95% CI = 0.159∼0.368), and middle school education level was negatively associated with the likelihood of participating in transport-related walking for at least 150 min (OR = 0.684, 95% CI = 0.490∼0.954). Gender and other education levels had no significant association with the amount of transport-related walking. The direction and magnitude of the effect of built environment variables on transport-related walking time was similar across Model 1 and Model 2.

TABLE 2 | Descriptive information for participants' walking data, socio-demographic characteristics, and built environment variables.

Variables	Mean (SD)/%
Outcome (*N* = 1,161)	
Transport-related walking, % ≥150 min	38.16%
Leisure-time walking, % ≥150 min	66.93%
Socio-demographic variables (*N* = 1,161)	
Age	71.22
Gender, % male	46.43%
Education level	
Primary school and below	36.86%
Middle school	26.79%
High school	15.76%
Postsecondary school	20.59%
Built environment factors (*N* = 12)	
Population density (person/km^2)	25539.00 (10868.01)
Street intersection density (#/km^2)	15.00 (10.69)
Land-use mix	0.60 (0.16)
Number of retail shops(#/km^2)	423.00 (233.81)

The results of the multilevel logistic regression model of the participants' leisure-time walking time and built environment variables are shown in **Table 4**. Street connectivity was positively correlated (OR = 1.516, 95% CI = 1.083∼2.123 in Model 1; OR = 1.499, 95% CI = 1.068∼2.103 in Model 2) with the likelihood of participating in a minimum of 150 min of leisure-time walking, and participants exposed to a high street connectivity were significantly more likely to perform regular leisure-time walking. There was no significant correlation between the other three indicators (population density, land-use mix, and retail density) and the likelihood of participating in a minimum of 150 min of leisure-time walking. Among the individual covariates, postsecondary school education level was negatively associated with the likelihood of participating in leisure-time walking for at least 150 min (OR = 0.649, 95% CI = 0.453∼0.929). Gender, age, and other education levels were not significantly related to the possibility of participating in leisure-time walking for at least 150 min a week. The direction and magnitude of the effect of built environment variables on leisure-time walking time was similar across both models.

DISCUSSION

Major Findings

This study further promotes the development of the content of healthy physical activity from two aspects. First, previous research has mainly focused on cities with low- and medium-density populations in the West. This study for a relatively large sample size focused on Wuhan, a megalopolis with a high-density population that has not been previously studied. Second, this study specifically subdivides elderly walking activities into transport-related walking and leisure-time walking so that the different effects of walkability indicators on the different types of walking activities can be showed. The results of this study show that the associations of walkability factors and two types of walking activities are weaker or insignificant in high-density city.

We found leisure-time walking time only related to street connectivity. In this study, street connectivity is positively related to elderly leisure-time walking. Previous studies have shown that streets are the main public space for residents' leisure activities (37, 38). More street intersections provide the elderly with more path options for leisure-time walking, and the elderly choose streets with better space quality for walking activities. There is no significant correlation between population density, land use combination, retail business density and leisure-time walking among the elderly. Some studies have reported the correlation between walkability indicators and leisure-time walking among adults (39). The reason for the differences in the results may be that older adults have relatively more discretionary time to make better use of the relatively good environment around them compared with young people. There may also be another reason that these factors may affect the frequency of walking rather than the time of walking (40).

In our results, we found no significant correlation between transport-related walking time and the four indicators of walkability. According to informal Interviews, old adults have some negative comments on environmental attributes, with respondents citing reasons for not going out, such as too many road cars and speed on the road too fast. These traffic problems may be due to the over-dwelling population leading to increased motor vehicle use in the neighborhood (41). However, the result of our study shows that there is no significant correlation between transport-related walking time and the four indicators of walkability in the elderly, which is similar to the results of a recent study in China (42). The reason may be that for the elderly in Chinese cities, these venues often play an important role in housekeeping during their later years of life, helping families to shop, transport grandchildren to and from school, and accompany grandchildren to outdoor leisure and entertainment activities. Their travel purpose is clear, and these activities belong to the necessary activities of a family, even the old adults are not satisfied with the environment, they also need to travel on a regular basis. This also explains why transport-related walking is related to age. Older people are less likely to undertake outdoor family activities, so older people have less transport-related walking.

Different from the western studies that showed a positive correlation between the indicators of walkability and physical activity, in this study, we found largely non-significant correlations between older adults' walking behaviors and objectively measured built environment factors in walkability. Recent studies conducted in other high-density cities also find these factors tend to be insignificant (14). Therefore, further studies are needed to examine the relationship between factors of walkability and walking for older adults in cities with different urban density. At the same time, some studies in China have shown that population density was negatively correlated with the two types of walking activities (41), but the existing calculation formula of walkability is based on the fact that all indicators are

TABLE 3 | Logistic regression of built environment and achieving ≥150 min of transport-related walking a week.

Model predictor	Model 1			Model 2		
	OR	95% CI	*p*-value	OR	95% CI	*p*-value
Built environment						
Population density	0.728	0.508∼1.043	0.083	0.788	0.556∼1.117	0.181
Street intersection density	1.000	0.725∼1.379	0.999	1.091	0.798∼1.491	0.586
Land-use mix	1.164	0.850∼1.594	0.345	1.164	0.858∼1.579	0.330
Number of retail shops	1.183	0.809∼1.730	0.386	1.179	0.815∼1.706	0.381
Individual characteristics						
Gender						
Male (reference group)						
Female				1.278	0.986∼1.656	0.064
Age (years)						
60–69 (reference group)						
70–79				0.561	0.423∼0.745	0.000***
≥80				0.242	0.159∼0.368	0.000***
Education level						
Primary school and below (reference group)						
Middle school				0.684	0.490∼0.954	0.025*
High school				1.112	0.756∼1.635	0.590
Postsecondary school				0.713	0.497∼1.023	0.066
−2 Log-likelihood		1524.395			1430.428	

*<0.05; **<0.01; ***<0.001.*

TABLE 4 | Logistic regression of built environment and achieving ≥150 min of leisure-time walking a week.

Model predictor	Model 1			Model 2		
	OR	95% CI	*p*-value	OR	95% CI	*p*-value
Built environment						
Population density	0.777	0.540∼1.116	0.172	0.782	0.542∼1.127	0.187
Street intersection density	1.516	1.083∼2.123	0.015*	1.499	1.068∼2.103	0.019*
Land-use mix	1.325	0.967∼1.816	0.080	1.336	0.973∼1.835	0.073
Number of retail shops	0.774	0.526∼1.139	0.194	0.787	0.533∼1.161	0.227
Individual characteristics						
Gender						
Male (reference group)						
Female				0.875	0.671∼1.143	0.327
Age (years)						
60–69 (reference group)						
70–79				1.019	0.758∼1.370	0.901
≥80				0.953	0.651∼1.393	0.802
Education level						
Primary school and below (reference group)						
Middle school				0.848	0.603∼1.193	0.334
High school				0.974	0.647∼1.466	0.900
Postsecondary school				0.649	0.453∼0.929	0.018*
−2 Log-likelihood		1417.000			1386.878	

*<0.05; **<0.01; ***<0.001.*

positively correlated with physical activity (43, 44) therefore, the formula may need further study to improve the applicability of walkability.

In addition to the factors we studied, air pollution, traffic noise, traffic safety and crime may also affect older people's walking. There have been a lot of studies on these factors in

Western countries (12), but there are still few in China. The built environment and social conditions among countries are greatly different. It is also of great value to study the correlation between these factors and walking among the elderly in China's cities and villages. China's air quality has improved so much since the eco-civilization strategy was introduced. Most people would hardly notice small changes in air quality. But older people with respiratory problems may be more likely to notice. In China, the relationship between traffic noise and walking in the elderly also was rarely studied. For China, such a high population density, crowded traffic countries, it is particularly important to figure out the associations between traffic noise, traffic congestion and elderly walking in order to better provide information for the construction of elderly friendly communities. In China, traffic safety always be mentioned, but there was little mention of crime, which may have something to do with the fact that there are so many people on the streets in China, and there is more surveillance to keep pedestrians safe. However, the large number of vehicles and fast speed were a big safety hazard.

A number of existing studies relied mainly on objective measurements, but there is no consensus on what defines a "neighborhood" (e.g., shape or size). Some studies have reported that the scale and shape of buffers can have an impact on study results (45). However, the use of different buffer radii did not alter the observed relationship in the two studies (46, 47). At the same time, some studies have begun to explore the impact of neighborhood buffer size across various adult life stages (48). However, little attention is focused on the buffer zones of these two types of walking may also differ.

Limitations

This study has several limitations. First, the cross-sectional research design cannot explain the causal relationship between the high-density urban built environment and elderly walking activities. Second, all measured built environment variables were collected using a single buffer size, and there was a lack of comparison of multiple buffer measurement results. The observed correlation may vary depending on the buffer size, and the range of participants' walking activities may exceed the buffer range. Thirdly, although this study included data on 1,161 individuals, it included only 12 housing estates. This might have affected the power for finding statistically significant associations between environmental attributes and two types of walking. To avoid such a problem, it may be necessary to select more housing estates with each housing estate still including a reasonable number of individuals (49). Finally, the study was conducted in a high-density city in China; and in order to verify the reliability of the results, more evidence from other high-density cities is needed.

CONCLUSION

This study examines the relationship between the characteristics of the built environment of high-density cities and the walking activities of the elderly in Wuhan. After emphasizing the different built environmental characteristics and the background of cultural life, it is obvious that the composite indicator of walkability needs to be revised to increase its applicability. Furthermore, the evidence provided by this study will help to clarify the various influential factors that affect the walking activity of the elderly in China's megacities, thereby helping to provide optimized strategies for the healthy development of elderly city residents.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the dataset is a part of the project "Intelligent Recognition of Street Space Quality and its Planning Application: a Case Study of Wuhan" funded by the National Natural Science Foundation of China, 2020.01-2023.12. So the dataset is confidential during this period. Requests to access the datasets should be directed to Xiaowu Lin, 973742941@qq.com.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

HH conceived of the study, and participated in its design and coordination. XL and TL led the manuscript preparation. XL contributed to data collection and analysis. TL and YY contributed to data collection. All authors read, contributed to, and approved the final manuscript.

FUNDING

This study was funded by the National Natural Science Foundation of China (Grant No. 51978300).

REFERENCES

1. World Health Organization. *Global Age-Friendly Cities: A Guide*. (2007). Available online at: https://www.who.int/ageing/age_friendly_cities_guide/en/ (accessed August 22, 2019).
2. World Health Organization. *China Country Assessment Report on Ageing and Health*. (2016). Available online at: https://www.who.int/ageing/publications/china-country-assessment/en/ (accessed August 22, 2019).
3. World Health Organization. *Global Recommendations on Physical Activity for Health*. (2010). Available online at: https://www.who.int/dietphysicalactivity/factsheet_recommendations/en/ (accessed August 22, 2019).
4. Warburton DER, Nicol CW, Bredin SSD. Health benefits of physical activity: the evidence. *Can Med Assoc J*. (2006) 174:801–9. doi: 10.1503/cmaj.051351
5. Bauman AE. Updating the evidence that physical activity is good for health: an epidemiological review 2000–2003. *J Sci Med Sport*. (2004) 7:6–19. doi: 10.1016/S1440-2440(04)80273-1

6. World Health Organization. *World Report on Ageing and Health*. (2015). Available online at: https://www.who.int/ageing/publications/world-report-2015/en/ (accessed August 22, 2019).
7. World Health Organization. *China Country Assessment Report on Ageing and Health*. (2015). Available online at: https://www.who.int/ageing/publications/china-country-assessment/en/ (accessed August 12, 2020).
8. Barnes LL, Wilson RS, Bienias JL, Mendes de Leon CF, Nicole Kim H-j, Buchman AS, et al. Correlates of life space in a volunteer cohort of older adults. *Exp Aging Res.* (2007) 33:77–93. doi: 10.1080/03610730601006420
9. Huang JZ, Zhang RQ, Hu GY. A research of the elderly's daily life circle based on spatial-temporal behavior—analysis of place recognition and spatial features. *Urban Planning Forum.* (2019) 03:87–95. doi: 10.16361/j.upf.201903011
10. Stokols D. Establishing and maintaining healthy environments: toward a social ecology of health promotion. *Am Psychol.* (1992) 47:6–22. doi: 10.1037/0003-066X.47.1.6
11. Sallis JF, Cervero RB, Ascher W, Henderson KA, Katherine Kraft M, Kerr J. An ecological approach to creating active living communities. *Annu Rev Public Health.* (2006) 27:297–322. doi: 10.1146/annurev.publhealth.27.021405.102100
12. Barnett DW, Barnett A, Nathan A, van Cauwenberg J, Cerin E. Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act.* (2017) 14:103. doi: 10.1186/s12966-017-0558-z
13. Cerin E, Nathan A, van Cauwenberg J, Barnett DW, Barnett A. The neighbourhood physical environment and active travel in older adults: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act.* (2017) 14:1–23. doi: 10.1186/s12966-017-0471-5
14. Yang YY, He DS, Gou ZH, Wang RY, Liu Y, Lu Y. Association between street greenery and walking behavior in older adults in Hong Kong. *Sust Cities Soc.* (2019) 51:101747. doi: 10.1016/j.scs.2019.101747
15. Carlson JA, Sallis JF, Conway TL, Saelens BE, Frank LD, Kerr J, et al. Interactions between psychosocial and built environment factors in explaining older adults' physical activity. *Prev Med.* (2012) 54:68–73. doi: 10.1016/j.ypmed.2011.10.004
16. Barnett A, Cerin E, Zhang CJP, Sit CHP, Johnston JM, Cheung MMC, et al. Associations between the neighbourhood environment characteristics and physical activity in older adults with specific types of chronic conditions: the ALECS cross-sectional study. *Int J Behav Nutr Phys Act.* (2016) 13:53. doi: 10.1186/s12966-016-0377-7
17. Inoue S, Ohya Y, Odagiri Y, Takamiya T, Kamada M, Okada S, et al. Perceived neighborhood environment and walking for specific purposes among elderly japanese. *J Epidemiol.* (2011) 21:481–90. doi: 10.2188/jea.JE20110044
18. Brownson RC, Hoehner CM, Day K, Forsyth A, Sallis JF. Measuring the built environment for physical activity: state of the science. *Am J Prev Med.* (2009) 36:S99–123. e12. doi: 10.1016/j.amepre.2009.01.005
19. McCormack GR, Shiell A. In search of causality: a systematic review of the relationship between the built environment and physical activity among adults. *Int J Behav Nutr Phys Act.* (2011) 8:125. doi: 10.1186/1479-5868-8-125
20. Koh PP, Wong YD. Comparing pedestrians' needs and behaviours in different land use environments. *J Transp Geogr.* (2013) 26:43–50. doi: 10.1016/j.jtrangeo.2012.08.012
21. Frank LD, Andresen MA, Schmid TL. Obesity relationships with community design, physical activity, and time spent in cars. *Am J Prev Med.* (2004) 27:87–96. doi: 10.1016/j.amepre.2004.04.011
22. Frank LD. Public health and the built environment: emerging evidence and complexity. *Can J Diet Pract Res.* (2004) 65:1–4. Available online at: https://search.proquest.com/docview/220825016/fulltext/619807A10296432FPQ/1?accountid=11524
23. Frank L, Kerr J, Rosenberg D, King A. Healthy aging and where you live: community design relationships with physical activity and body weight in older Americans. *J Phys Act Health.* (2010) 7:S82–90. doi: 10.1123/jpah.7.s1.s82
24. King AC, Sallis JF, Frank LD, Saelens BE, Cain K, Conway TL, et al. Aging in neighborhoods differing in walkability and income: associations with physical activity and obesity in older adults. *Soc Sci Med.* (2011) 73:1525–33. doi: 10.1016/j.socscimed.2011.08.032
25. Frank LD, Sallis JF, Conway TL, Chapman JE, Saelens BE, Bachman W. Many pathways from land use to health: associations between neighborhood walkability and active transportation, body mass index, and air quality. *J Am Plann Assoc.* (2006) 72:75–87. doi: 10.1080/01944360608976725
26. Frank LD, Saelens BE, Powell KE, Chapman JE. Stepping towards causation: do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity? *Soc Sci Med.* (2007) 65:1898–914. doi: 10.1016/j.socscimed.2007.05.053
27. Xu F, Li JQ, Liang YQ, Wang ZY, Hong X, Ware RS, et al. Associations of residential density with adolescents' physical activity in a rapidly urbanizing area of Mainland China. *J Urban Health.* (2010) 87:44–53. doi: 10.1007/s11524-009-9409-9
28. An RP, Shen J, Yang QY, Yang Y. Impact of built environment on physical activity and obesity among children and adolescents in China: a narrative systematic review. *J Sport Health Sci.* (2019) 8:153–69. doi: 10.1016/j.jshs.2018.11.003
29. Lin CW, Han XL, Fan J. Impacts of land development intensity on children's outdoor physical activities: a case study of shenzhen. *City Plann Rev.* (2018) 42:97–102. doi: 10.11819/cpr20181112a
30. Su M, Tan Yy, Liu Qm, Ren Yj, Kawachi I, Li Lm, et al. Association between perceived urban built environment attributes and leisure-time physical activity among adults in Hangzhou, China. *Prev Med.* (2014) 66:60–4. doi: 10.1016/j.ypmed.2014.06.001
31. Vogel T, Brechat PH, Leprêtre PM, Kaltenbach G, Berthel M, Lonsdorfer J. Health benefits of physical activity in older patients: a review. *Int J Clin Pract.* (2009) 63:303–20. doi: 10.1111/j.1742-1241.2008.01957.x
32. Cunningham GO, Michael YL. Concepts guiding the study of the impact of the built environment on physical activity for older adults: a review of the literature. *Am J Health Promot.* (2004) 18:435–43. doi: 10.4278/0890-1171-18.6.435
33. Civil Administration Burea of Wuhan. *An Analysis of the form of Population Aging in Wuhan in 2018*. (2019). Available online at: http://mzj.wuhan.gov.cn/zwgk_918/fdzdgk/gysyjs/shfl/201901/t20190125_1000644.shtml (accessed September 5, 2019).
34. Statistics Department of Hubei province. *2018 Wuhan Statistical Yearbook*. (2019). Available online at: http://tjj.hubei.gov.cn/tjsj/sjkscx/tjnj/gsztj/whs/201911/P020191104653356795480.pdf (accessed September 5, 2019).
35. Alexander FE, Boyle P, Carli PM, Coebergh JW, Ekbom A, Levi F, et al. Population density and childhood leukaemia: results of the EUROCLUS study. *Eur J Cancer.* (1999) 35:439–44. doi: 10.1016/S0959-8049(98)00385-2
36. Vienna, Austria: R Foundation for Statistical Computing 2014. *R: A language and environment for statistical computing.* (2014). Available online at: http://www.R-project.org (accessed September 8, 2020).
37. Giles-Corti B, Donovan RJ. The relative influence of individual, social and physical environment determinants of physical activity. *Soc Sci Med.* (2002) 54:1793–812. doi: 10.1016/S0277-9536(01)00150-2
38. Huston SL, Evenson KR, Bors P, Gizlice Z. Neighborhood environment, access to places for activity, and leisure-time physical activity in a diverse North Carolina population. *Am J Health Promot.* (2003) 18:58–69. doi: 10.4278/0890-1171-18.1.58
39. Siqueira Reis R, Hino AAF, Ricardo Rech C, Kerr J, Curi Hallal P. Walkability and physical activity: findings from Curitiba, Brazil. *Am J Prev Med.* (2013) 45:269–75. doi: 10.1016/j.amepre.2013.04.020
40. Owen N, Cerin E, Leslie E, duToit L, Coffee N, Frank LD, et al. Neighborhood walkability and the walking behavior of Australian adults. *Am J Prev Med.* (2007) 33:387–95. doi: 10.1016/j.amepre.2007.07.025
41. Wang ZY, Qin ZZ, He J, Ma YY, Ye Q, Xiong YQ, et al. The association between residential density and physical activity among urban adults in regional China. *BMC Public Health.* (2019) 19:1279. doi: 10.1186/s12889-019-7593-4
42. Lu Y, Xiao Y, Ye Y. Urban density, diversity and design: Is more always better for walking? A study from Hong Kong. *Prev Med.* (2017) 103:S99–S103. doi: 10.1016/j.ypmed.2016.08.042
43. Frank LD, Sallis JF, Saelens BE, Leary L, Cain K, Conway TL, et al. The development of a walkability index: application to the neighborhood quality of life study. *Br J Sports Med.* (2010) 44:924. doi: 10.1136/bjsm.2009.058701

44. Peiravian F, Derrible S, Ijaz F. Development and application of the pedestrian environment index (PEI). *J Transp Geogr*. (2014) 39:73–84. doi: 10.1016/j.jtrangeo.2014.06.020
45. James P, Berrigan D, Hart JE, Aaron Hipp J, Hipp A, Kerr J, et al. Effects of buffer size and shape on associations between the built environment and energy balance. *Health Place*. (2014) 27:162–1170. doi: 10.1016/j.healthplace.2014.02.003
46. Nagel CL, Carlson NE, Bosworth M, Michael YL. The relation between neighborhood built environment and walking activity among older adults. *Am J Epidemiol*. (2008) 168:461–8. doi: 10.1093/aje/kwn158
47. Berke EM, Koepsell TD, Vernez Moudon A, Hoskins RE, Larson EB. Association of the built environment with physical activity and obesity in older persons. *Am J Public Health*. (2007) 97:486–92. doi: 10.2105/AJPH.2006.085837
48. Villanueva K, Knuiman M, Nathan A, Giles-Corti B, Christian H, Foster S, et al. The impact of neighborhood walkability on walking: does it differ across adult life stage and does neighborhood buffer size matter? *Health Place*. (2014) 25:43–6. doi: 10.1016/j.healthplace.2013.10.005
49. Wendel-Vos GCW, van Hooijdonk C, Uitenbroek D, Agyemang C, Lindeman EM, Droomers M. Environmental attributes related to walking and bicycling at the individual and contextual level. *J Epidemiol Community Health*. (2008) 62:689. doi: 10.1136/jech.2007.062869

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 03 December 2020
doi: 10.3389/fpubh.2020.587363

Community Environments That Promote Intergenerational Interactions vs. Walking Among Older Adults

Sinan Zhong*, Chanam Lee and Hanwool Lee

Department of Landscape Architecture and Urban Planning, College of Architecture, Texas A&M University, College Station, TX, United States

Background: Intergenerational interactions and walking are two of the most beneficial forms of activities for older adults. As older adults spend most of their time at or near home, the characteristics of the proximate residential environments are particularly important for supporting those activities. This study aims to (1) explore places used for various social interactions older adults engage in, (2) examine specific neighborhood environmental features associated with intergenerational interactions, and (3) compare similarities and differences in environmental correlates of intergenerational interactions vs. walking.

Methods: This cross-sectional study analyzed self-reported survey data from 455 community-dwelling adults aged 65+ from Austin, Texas, as well as Geographic Information System (GIS) measures capturing the neighborhood environment around each participant's home. Descriptive statistics were used for Aim 1. Multivariable binary logistic models were used for Aims 2 and 3, to identify environmental variables predicting the odds of participating in intergenerational interactions (with children 1+ times/week, and with children, teenagers, or adults 1+ times/week) in one's neighborhood, as well as walking 1+ times/week for transportation or recreation purposes.

Results: Participants had a mean age of 73 years, and were primarily female (72.1%) and non-Hispanic white (72.8%). Older adults interacted frequently with adults (79.2%, 1+ times/week) and other older adults (66.9%) in their neighborhood, while less frequently with children (28.0%) and teenagers (21.9%). Recreational walking (73.3%, 1+ times/week) was more popular for older adults than transportation walking (43.8%). Multivariable analyses showed that neighborhood perceptions, transportation infrastructure, land uses, land covers, population densities, development activities, and composite scores were significant predictors of intergenerational activities. Both similarities and differences were found in terms of the neighborhood environmental factors associated with intergenerational interactions vs. walking although differences were more evident in the domains of land covers, development activities, and composite scores.

Conclusions: Given the significant health benefits, promoting intergenerational interactions and walking among older adults should be a national/global responsibility.

OPEN ACCESS

Edited by:
Louise Lafortune, University of Cambridge, United Kingdom

Reviewed by:
Caryn Etkin, Northwestern University, United States
Calum Mattocks, University of Cambridge, United Kingdom

****Correspondence:***
Sinan Zhong
zsn198838@tamu.edu

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *25 July 2020*
Accepted: *21 October 2020*
Published: *03 December 2020*

Citation:
Zhong S, Lee C and Lee H (2020) Community Environments That Promote Intergenerational Interactions vs. Walking Among Older Adults. Front. Public Health 8:587363. doi: 10.3389/fpubh.2020.587363

Further work is needed to improve our understanding of the specific social and physical environmental facilitators as well as barriers to creating intergenerational communities that can support healthy living of all generations.

Keywords: intergenerational communities, interactions with children, intergenerational interactions, transportation walking, recreational walking, older adults

INTRODUCTION

Demographic aging is a global issue that can bring tremendous economic, social, and medical challenges. The United States (US) population aged 65 years and over more than tripled from 13.0 million in 1950 to 53.3 million in 2019 and is expected to increase to 84.8 million in 2050 (1). Ageism, which is defined as negative stereotypes based on age, is another challenge that the aging society faces. Ageism originates from a fear of being older, a shortage of knowledge about aging, and limited interactions with the elderly, which can result in serious adverse effects on older adults (2). Engaging in intergenerational activities is increasingly recognized as a promising means to reduce ageism and social isolation while also promoting active and healthy lifestyles in old age. As older adults spend most of their time at home and in their neighborhood, understanding the relationships between neighborhood environments and older adults' intergenerational interactions is critical to creating/retrofitting neighborhood environments that can support active and healthy aging in place.

Increasing empirical investigations indicate the significant roles of intergenerational interactions in maintaining older adults' health. Specifically, a number of program-based intergenerational activities have been shown to be positively correlated with older adults' physical health (3–8), psychosocial health (e.g., reduced depression) (7, 9–14), self-reported quality of life/well-being (15, 16), and social relationships (e.g., reduced social isolation) (6, 17, 18). Additionally, participation in intergenerational programs has been linked with physical activity (6, 19–24) and social activity (19) among older adults.

Physical activity is another major factor that can contribute to promoting and maintaining health in aging populations (25). Walking is one of the most popular and accessible forms of physical activity among older adults, even though there are a variety of ways to stay physically active (26, 27). The significant health benefits of walking for aging populations have been well-documented in many empirical studies. Hakim et al. (28) reported that regular walking was linked with lower mortality rates among non-smoking retired men. Moreover, several studies on walking and depression demonstrated positive associations between walking and reduced depressive symptoms among older adults (26, 29, 30).

Despite its significant health benefits, most older adults do not engage in sufficient amounts of physical activity. According to the 2018 Behavioral Risk Factor Surveillance System data (31), ∼30.3% of the US population aged 65 years and over reported no physical activity other than those done as part of work/jobs. The prevalence of physical inactivity among the US older populations increases significantly with age. Approximately 35.1% of the US populations aged 75 years and over reported no leisure time physical activity compared to 26.9% among those aged 65–74 years in 2018 (31). The high prevalence of inactivity among older adults in the US has brought attention to the need for broader environmentally-based approaches to facilitate population level behavioral changes.

According to M. Powell Lawton's influential work on environments and aging (32), our environments (e.g., personal, social, and physical environments) play essential roles in promoting older adults' health. Many empirical studies have evinced that neighborhood environments (e.g., walkability) are associated with older adults' physical activity including walking (33, 34). Evidence has also been accumulating about the significant roles of neighborhood environments in maintaining older adults' physical health (35, 36), mental health (37), and quality of life (38, 39). However, limited studies have investigated the associations between neighborhood environments and intergenerational interactions among older adults. Only a small number of empirical studies have reported significant correlations between neighborhood environments (e.g., walkability, accessibility) and older adults' social interactions/participations (40, 41). These studies have considered overall social activities, without fully addressing the influences of neighborhood environments on older adults' intergenerational interactions.

This study aims to (1) explore places used for various social interactions older adults engage in, (2) examine specific neighborhood environmental features associated with older adults' intergenerational interactions, and (3) compare similarities and differences in environmental correlates of intergenerational interactions vs. walking. Going beyond the scope of existing empirical studies on environments and aging, this study provides a systematic examination of physical elements/features of the community environment that can promote intergenerational interactions and/or walking.

MATERIALS AND METHODS

Conceptual Framework

Lawton's seminal work on environments and aging, the social ecological model of health promotion (42), and prior literature on this topic as described above point to personal and environmental factors as major determinants of older adults' intergenerational interactions and walking. **Figure 1** shows a conceptual framework with the hypothesized relationships among neighborhood environments (i.e., perceived and objectively measured physical environments), intergenerational interactions (i.e., social interactions with children, intergenerational interactions), walking (i.e., transportation and recreational walking), and personal factors

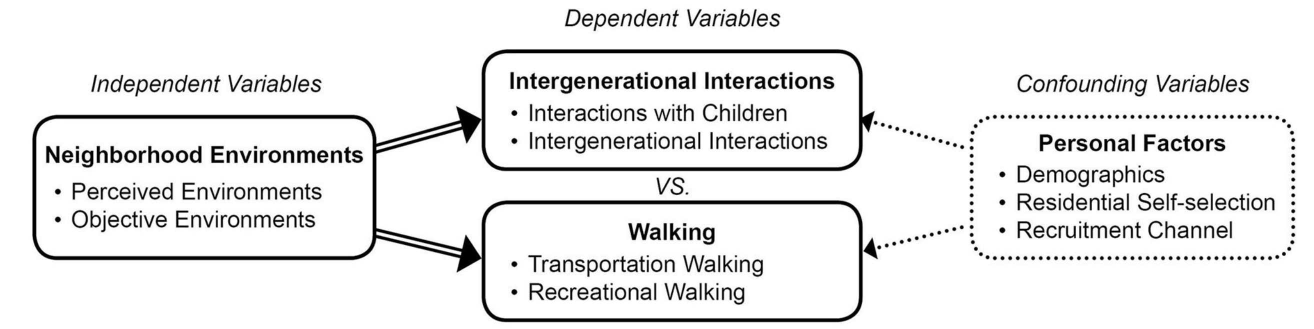


FIGURE 1 | Conceptual framework for environmental correlates of intergenerational interactions vs. walking among older adults.

(i.e., demographics, residential self-selection, recruitment channel) among older adults. The conceptual framework is developed to guide the data collection and analysis process for achieving the three research aims and answering the following research questions:

- How can neighborhood environments contribute to promoting or inhibiting older adults' intergenerational interactions?
- What differential roles do neighborhood environments play in older adults' intergenerational interactions vs. walking?

Study Setting and Population

This cross-sectional study was carried out in the city of Austin, Texas, US, which has a wide range of services and programs supporting older adults, diverse environmental characteristics, and a diverse mix of different age groups. The target population is community-dwelling Austin residents who are 65 years and older. The age limit of 65 years is a commonly used threshold for defining older adults in the US (43). Although Austin had a relatively lower percentage of older residents 65 years and older (9.4%) compared to Texas (12.0%) and the US (15.2%) as of 2018 (44), its aging population was growing at a rate (85.2%) much faster than Texas (61.1%) and the US (40.7%) from 2000 to 2018 (44, 45).

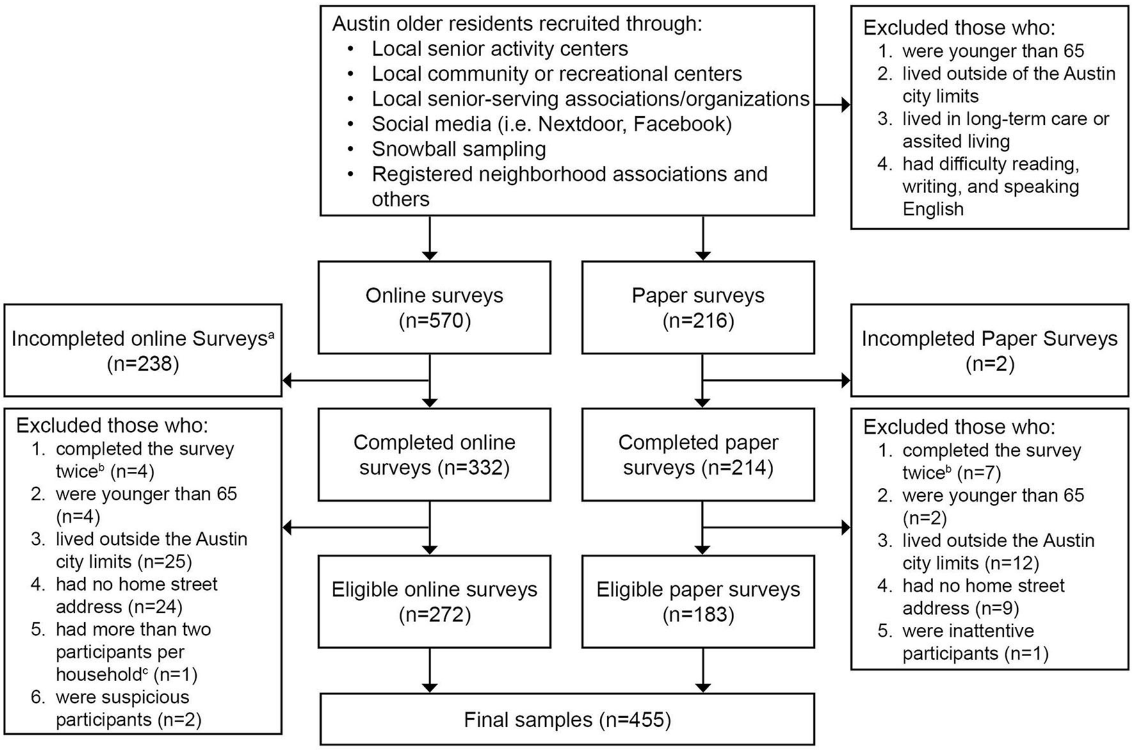
Recruitment and Data Collection

Data for this study included both subjective measures of self-report surveys and objective measures from Geographic Information System (GIS) and Walk Score (walkscore.com) capturing the neighborhood environment around each survey participant's home. The survey was offered both online and in paper form, took ∼30 minutes to complete, and captured variables related to (1) physical activities and walking, (2) quality of life and mental health (i.e., depression), (3) intergenerational and other social activities, (4) neighborhood environments, (5) supportive services or programs, and (6) demographic and socioeconomic characteristics. The survey was available in English only, as the majority (∼91.8%) of Austin residents 65 years and over reported sufficient English proficiency (i.e., speak only English, speak English very well, and speak English well) (44).

The survey development and data collection processes were carried out in four phases, starting from a three-phase process to develop and test the preliminary and final survey instrument, which was critical to ensure the validity and reliability of the data collected for this study. The process included (1) a pilot study to solicit input on the design and content of the preliminary paper survey through focus groups (Phase 1: May–June 2018); (2) a pre-test of the preliminary online and paper survey among a small number of participants (Phase 2: August–October 2018); and (3) a test-retest reliability assessment of the final survey instrument (Phase 3: January 2019–June 2019). The last phase (Phase 4: October 2018–June 2019) involved actual data collection using the finalized survey instrument. All study protocols and materials were approved by the Texas A&M University Institutional Review Board.

Figure 2 summarizes the detailed steps during the Phase 4 survey data collection and screening process. After excluding 91 respondents who failed to meet the eligibility criteria, a total of 455 eligible older adult respondents completed the survey, containing 272 online and 183 paper surveys. To be eligible, the respondents had to be the residents of Austin, Texas who (1) are 65 years or older, (2) live in the ordinary communities instead of long-term care or assisted living facilities, and (3) have basic English language skills. Up to two eligible participants per household could join the survey. Convenience sampling strategy was used due to the typically low response and eligibility rates expected from random sampling for studies like this and due to the limited resources available for this study. Participant characteristics were closely monitored throughout the survey process to ensure adequate spatial and sociodemographic diversity and representativeness of the samples.

Recruitment efforts targeted the senior participants/members at local senior-serving centers [number of participants (n) = 225, 49.6%]. These centers included (a) three senior activity centers containing Lamar ($n = 54$, 11.9%), South Austin ($n = 55$, 12.1%), and Conley Guerrero senior activity centers ($n = 46$, 10.1%); and several community or recreational centers ($n = 28$, 6.2%) managed by the City of Austin Parks and Recreation Department, (b) WellMed Charitable Foundation Senior Community Center ($n = 45$, 9.9%), and (c) Oak Hill Senior Center managed by the Meals on Wheels ($n = 6$, 1.3%). Study flyers were also distributed



Note: [a] Among 238 online survey responses in progress, 166 responses (approximately 70%) were less than 10% completed, and 220 responses (approximately 92%) were less than 50% completed.
[b] The second survey was excluded for those who completed the survey twice.
[c] The third participant was excluded.

FIGURE 2 | Survey data collection and screening process.

by various local senior-serving associations/organizations (n = 40, 8.8%), including AustinUp, Aging is Cool, Aging2.0 Austin, American Association of Retired Persons, AGE of Central Texas, Capital City Village, and Austin Retired Teachers Association. Additionally, social media (i.e., Nextdoor and Facebook) were utilized to recruit 78 study participants (17.2%), and a snowball sampling was applied to recruit 79 study participants (17.4%) by asking existing participants to share the study information with their families, friends, and neighbors. Finally, 38 more study participants (8.4%) were recruited from registered neighborhood associations, churches, and community gardens in Austin, Texas. Eighteen participants indicated that they learned about our study from more than one source.

Measures

Dependent Variables

Intergenerational Interactions

No validated instruments were available to capture intergenerational and other social activities in one's neighborhood (46). Therefore, relevant items were newly developed for this study, after several rounds of pilot studies/pretests as described earlier. The finalized survey question, "in your neighborhood, how many days in a typical week do you spend at least 10 minutes interacting (talking, spending time together) with others of different ages?" was used to measure study participants' social interactions with children, teenagers, adults, and older adults, separately. After checking the distribution of the original data, two binary outcome variables were generated to capture older adults' intergenerational interactions: interacting with children 1+ times/week in one's neighborhood, and interacting with children, teenagers, or adults 1+ times/week in one's neighborhood.

Walking

Walking for transportation (e.g., walking to get to and from places) and recreation (e.g., walking for recreation, sport, exercise, or leisure) were captured by four survey questions adapted from the International Physical Activity Questionnaires (47). We used two questions: "in a typical week, how many days do you walk for transportation (for recreation)?' and "how much time do you usually spend walking for transportation (for recreation) on one of those days?" to measure each of the two walking types. Transportation walking and recreation walking were recoded as two binary variables (i.e., walking 1+ times/week vs. not for recreation/transportation) as a considerable proportion of the study participants reported not walking for transportation (56.2%) or recreation (26.7%) in a typical week.

Independent Variables: Neighborhood Environments

Perceived Physical Environments

The survey questions evaluating neighborhood environments were extracted or adapted primarily from the Neighborhood Environment Walkability Scale (48, 49). Residence in a newly built neighborhood was measured through a multiple-choice question, "do you currently live in…?" that included a response item of "newly built neighborhood (built in the last 10–15 years)." One statement on a four-point Likert scale from strongly disagree to strongly agree, "there are benches on most of the sidewalks in my neighborhood," was used to measure the availability of benches, which was dichotomized as strongly disagree vs. others because of its uneven distribution.

Three more latent factor variables, including neighborhood walkability, neighborhood aesthetics, and traffic safety, were generated by conducting the principal component analysis with the Promax oblique rotation among the neighborhood environment survey items captured on a four-point Likert scale from strongly disagree to strongly agree. Specifically, the neighborhood walkability factor captured four survey items: "stores are within easy walking distance of my home," "there are many places to go within easy walking distance of my home," "it is easy to walk to a transit stop (bus, train) from my home," and "it is easy to walk to healthcare/medical services (e.g., hospital, doctor's office, pharmacy)." Another four survey items were used to extract the neighborhood aesthetics factor: "there are many interesting things to look at while walking in my neighborhood," "my neighborhood is generally free from litter," "there are many attractive natural sights in my neighborhood (such as landscaping, views)," and "there are attractive buildings/homes in my neighborhood." The traffic safety latent factor contained four reversed coding survey items: "there is so much traffic along the street I live on that it makes it difficult or unpleasant to walk in my neighborhood," "there is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighborhood," "when walking in my neighborhood, there are a lot of exhaust fumes (such as from cars, buses)," and "most drivers exceed the posted speed limits while driving in my neighborhood."

Objective Physical Environments

We examined five domains of objective physical environments, including (1) transportation, (2) land uses, (3) land covers, (4) population densities and development activities, and (5) composite scores, which were selected based on the previous literature on environment-walking and environment-social interaction relationships (33, 34, 40, 50). The first four domains were measured through GIS variables captured within a ½-mile buffer around the participants' homes and as the shortest network distances. This study incorporated two types of ½-mile buffers, including airline and street network-based "sausage" buffers. The sausage buffer referred to buffering all streets located within a ½-mile street distance from each participant's home, and for a "radius" of 100 feet on both sides of the street center line (51–53). This buffer is superior to airline or standard street network buffers in that it better estimates the street environment that pedestrians are actually exposed to. Most of the GIS variables were captured within the ½-mile sausage buffer, covering the domains of transportation infrastructure, general and destination land uses, and land covers (i.e., area of tree canopies). Additionally, the ½-mile airline buffer was used to capture several additional attributes related to parks, water bodies, development permits, and population densities, which tend to be more sensitive to the dependent variables when captured within the larger airline buffer (54, 55).

The raw data for the GIS measures used in this study were collected as part of the Active Living Austin research project sponsored by NIH (R01CA197761). Most of the raw data were downloaded from the Austin Open Data Portal (data.austintexas.gov), including 2019 data for street segments, sidewalks, general land uses, and development permits, as well as 2016 water body data. Destination land use data for retail/services, institutional, sports and fitness, and undesirable destinations were downloaded from the ESRI business analyst webpage (bao.arcgis.com) in 2019. Public transit data regarding transit stops and transit routes were downloaded from the Capital Area Metropolitan Planning Organization (data.texas.gov) in 2019. The stop sign and park-related data were collected from the Austin Transportation Department in 2017 and the Austin Park and Recreation Department in 2019, respectively. Tree canopies were calculated based on the 2016 Texas NAIP Imagery data downloaded from the Texas Natural Resources Information System (data.tnris.org). The street intersection variables were calculated based on the street segment layer. Street intersections with stop signs were calculated if the distance between each intersection and its closest stop sign was <50 feet. The population density variable was calculated based on the 2018 census block group population data (44) using the following formula: $\mathrm{POP}_{density} = \sum_{i=1}^{n} NiPi/A$, where $\mathrm{POP}_{density}$ is the population density within the ½-mile airline buffer; Ni is the number of people within each census block group; Pi is the percentage of the residential land use located within the ½-mile airline buffer for each census block group; n is the total number of census block groups within the ½-mile airline buffer; and A is the area of the residential land use within the ½-mile airline buffer or the area of the ½-mile airline buffer for calculating the net or gross population density, respectively.

In addition to these detailed disaggregated measures, widely available aggregated measures including Walk Score, Transit Score, and Bike Score were collected through the 2019 Walk Score (walkscore.com) and examined as supplementary variables in this study. Empirical studies investigated that these composite scores served as validated measures of overall neighborhood walkability (56, 57) and for considering mobility and walking among older adults (50, 58).

Confounding Variables

Demographics

All survey questions measuring participants' demographics and socioeconomic characteristics were extracted or adapted from the Behavioral Risk Factor Surveillance System (59); the American Community Survey (60); two survey instruments developed by the AdvantAge Initiative, Center for Home Care Policy & Research, Visiting Nurse Service of New York; and the Neighborhood Quality of Life Survey for Seniors (33). Seven variables were included in all regression models: age (years), gender (male vs. female), race and ethnicity (non-Hispanic White vs. others), marital status (married or unmarried couples vs. others), education attachment (nine levels from less than high school to doctorate degree), income (i.e., low, lower-middle, upper-middle, high, don't know/prefer not to answer/missing), and general health conditions (i.e., excellent, very good, good, fair, poor). Another seven variables that were included in at least one model included: housing types (one-family detached house vs. others), having a dog in the household (yes vs. no), employment status (employed vs. not employed), daily sleep time (hours), difficulty walking (yes/don't know/prefer not to answer vs. no), mobility aids (yes vs. no), and the significant life event regarding personal illness (yes vs. no). Other variables that were tested but insignificant in the multivariable regression analyses included body mass index, home ownership, having a cat in the household, living arrangement (except living with a spouse that was highly correlated with marital status), caregiving status, diseases (e.g., anxiety, depression, cancer), difficulty hearing or seeing, alcoholic consumption, history of falls, and significant life events (i.e., illness of a family member or friend, death of a spouse, family member, or friend, non-medical events).

Residential Self-Selection

Residential self-selection factors are important to help address the self-selection bias inherent in cross-sectional studies like this (61). In this research, those factors were measured by asking participants to rate the importance of a series of reasons behind their residential location choice: "how important are the following reasons for you to choose living in your current home?" with a four-point Likert response option (i.e., not at all important, slightly important, moderately important, very important). The variable capturing the diversity of age groups in the neighborhood was retained as an important individual variable for this study focusing on intergenerational activities, instead of entering into the factor analysis. The diversity of ethnic groups was excluded due to its high correlation with the diversity of age groups ($r = 0.798$). Another two variables were dichotomized and considered as individual variables because they fail to be properly loaded to a single latent factor: affordability (very important vs. others) and proximity to public transportation (not at all important vs. others). Affordability was not included in this study as it had no significant associations with any of the outcomes.

The principal component analysis with the Promax oblique rotation was conducted with the remaining twelve items to generate two latent factor variables measuring participants' self-selection on neighborhood environments and neighborhood social cohesions. The neighborhood environment self-selection factor was loaded with eight survey items: "ease of walking," "neighborhood aesthetics or beautiful scenery," "sense of community," "close to parks and natural open spaces," "neighborhood safety," "close to shops and services," "close to healthcare/medical facilities," and "close to entertainment facilities." Another four survey items were included to measure their residential self-selection based on neighborhood social cohesions: "close to friends," "presence of other older residents," "access to supportive programs," and "close to family members."

Recruitment Channel

Participants were asked to indicate how they learned about the study on a multiple-choice question: "how did you hear about this study?" with options for different recruitment channels used in this study. Each recruitment option was converted into a binary variable and tested in the multivariable regression models. Only one variable, social media recruitment (yes vs. no), was significant and controlled for recreational walking.

Statistical Analyses

This study used IBM SPSS Statistics 25.0 to generate all descriptive and inferential statistics. Descriptive statistics, including central tendency, dispersion or variation, and distribution, were examined to understand the basic features of the study variables. Bivariate analyses (i.e., independent samples *t*-test, chi-square test) were conducted between the independent/confounding variables and each of the four outcome measures (results not reported).

Multivariable binary logistic regressions were estimated in two steps to identify significant ($p < 0.05$) correlates of intergenerational interactions and walking among older adults. The first step was to build a base model for each of the four outcomes by regressing individual intergenerational interaction or walking variable on significant demographic/socioeconomic, residential self-selection, and recruitment channel variables (confounding variables) identified in the previous bivariate analyses. The second step was to conduct one-by-one tests where the physical environmental variables (independent variables) were added to the base models one at a time. Because many of the physical environmental variables were strongly associated with each other, this one-by-one testing approach helped examine the statistical significance of each independent variable without the impact of other correlated variables, to guide the selection of optimal variables for further consideration in the final multivariable model. The Variance Inflation Factors (VIFs) were examined to assess the potential for multicollinearity problems in all multivariable models, and the values ranged from 1.0 to 1.6 suggesting low/minimal risks.

RESULTS

Participant Characteristics

Table 1 summarizes the study characteristics in terms of personal factors, intergenerational interactions and walking, and neighborhood environments. The age range was 65 to 95, with a mean age of 73. Participants were about 72.1% female, 72.8% Non-hispanic white, and 41.7% married. Approximately 85.7% of respondents had at least some college education. As for the general health conditions, the majority (86.4%) reported their health to be good, very good, or excellent.

Our final sample was shown to be generally representative of Austin's older populations based on the key demographic characteristic factors and the overall geographic distribution. However, it had an over-representation of females and highly

TABLE 1 | Study characteristics.

Variable	*N*	Mean/Freq (SD/%) Min-Max	Variable	*N*	Mean/Freq (SD/%) Min-Max
DEMOGRAPHICS					
Age (years)	455	73.06 (6.19)	General health condition: Poor	449	7 (1.6%)
		65-95	Fair		54 (12.0%)
Gender: Male	455	127 (27.9%)	Good		159 (35.4%)
Female		328 (72.1%)	Very Good		160 (35.6%)
Race and ethnicity: Non-Hispanic White	452	329 (72.8%)	Excellent		69 (15.4%)
Others		123 (27.2%)	Income: Low income (below $20,000)	455	65 (14.3%)
Marital status: Married or unmarried couple	453	205 (45.3%)	Lower-middle income ($20,000-$39,999)		86 (18.9%)
Others		248 (54.7%)	Upper-middle income ($40,000-$79,999)		125 (27.5%)
Education: Less than high school	455	8 (1.8%)	High income ($80,000 or more)		99 (21.8%)
Some high school, but no degree		12 (2.6%)	Don't know/prefer not to answer/missing		80 (17.6%)
High school diploma/GED		45 (9.9%)	Having a dog in the household: Yes	455	113 (24.8%)
Some college		64 (14.1%)	No (or missing)		342 (75.2%)
Associate degree		27 (5.9%)	Mobility aid: Yes	441	56 (12.7%)
Bachelor's degree		122 (26.8%)	No		385 (87.3%)
Master's degree		110 (24.2%)	Personal illness: Yes	448	192 (42.9%)
Professional degree		25 (5.5%)	No		256 (57.1%)
Doctorate degree		42 (9.2%)	Daily sleep time (hours)	444	7.25 (1.36)
Employment status: Employed	455	82 (18.0%)			2–16
Not employed		373 (82.0%)	Difficulty walking: Yes/don't know/prefer not to answer	453	103 (22.7%)
Housing type: One-family detached house	455	344 (75.6%)	No		350 (77.3%)
Others		111 (24.4%)			
RESIDENTIAL SELF-SELECTION AND RECRUITMENT CHANNEL					
Diversity of age groups: Not at all important	455	115 (25.3%)	Neighborhood environments (factor scores)	455	0.00 (0.99)
Slightly important		106 (23.3%)			−2.71–1.54
Moderately important		144 (31.6%)	Close to public transportation: Not at all important	455	172 (37.8%)
Very important		90 (19.8%)	Others		283 (62.2%)
Social cohesion and support (factor scores)	455	0.00 (0.99)	Social media (i.e., Nextdoor, Facebook): Yes	454	78 (17.2%)
		−1.74–2.40	No		376 (82.8%)
INTERGENERATIONAL INTERACTIONS AND WALKING					
Social interactions with children: Yes	453	127 (28.0%)	Transportation walking: Yes	441	193 (43.8%)
No		326 (72.0%)	No		248 (56.2%)
Intergenerational interactions: Yes	453	363 (80.1%)	Recreational walking: Yes	442	324 (73.3%)
No		90 (19.9%)	No		118 (26.7%)
PERCEIVED PHYSICAL ENVIRONMENTS					
Newly built neighborhood: Yes	455	50 (11.0%)	Neighborhood aesthetics (factor scores)	455	0.00 (1.00)
No (or missing)		405 (89.0%)			−3.22–1.31
Neighborhood walkability (factor scores)	455	0.00 (1.00)	Traffic safety (factor scores)	455	0.00 (1.00)
		−1.50–1.94			−2.47–1.61
Benches on most of the sidewalks[a]: Yes	455	149 (32.7%)			
No		306 (67.3%)			
OBJECTIVE PHYSICAL ENVIRONMENTS (SAUSAGE BUFFER)					
Transportation			***Transportation***		
Street length (miles)	453	6.69 (3.01)	Number of Intersections with 3 or more ways (n)	453	44.77 (25.01)
		0.36–15.53			0–129
Sidewalk length (miles)	453	11.04 (5.08)	Density of intersections with 3 or more ways (n/acre)	453	6.43 (1.39)
		0.24–24.93			0–9.55

(Continued)

TABLE 1 | Continued

Variable	*N*	Mean/Freq (SD/%) Min-Max	Variable	*N*	Mean/Freq (SD/%) Min-Max
Length of high–speed streets (>30 mph) (miles)	453	2.79 (1.67)	***Land Uses***		
		0.00–11.17	Area of offices (acres): 0	453	140 (30.9%)
Percentage of high-speed streets	453	42.2% (17.8%)	>0–<1.5		155 (34.2%)
(>30 mph)		0.0–100.0%	≥1.5		158 (34.9%)
Number of transit stops (n): 0	453	105 (23.2%)	Percentage of offices: 0%	453	140 (30.9%)
1–5		121 (26.7%)	>0% – <2%		210 (46.4%)
6–10		100 (22.1%)	≥2%		103 (22.7%)
11 or more		127 (28.0%)	Presence of food stores: Yes	453	160 (35.3%)
Density of transit stops (n/100 acres):	453		No		293 (64.7%)
Lower density: 0 – <10		349 (77.0%)	Presence of religious destinations: Yes	453	195 (43.0%)
Higher density: ≥10		104 (23.0%)	No		258 (57.0%)
Number of total transit routes (n)	453	3.80 (4.43)	Presence of trails in parks: Yes	453	161 (35.5%)
		0–35	No		292 (64.5%)
Number of stop signs (n)	453	45.53 (35.09)	Presence of sports and fitness destinations: Yes	453	115 (25.4%)
		0–184	No		338 (74.6%)
Density of stop signs (n/acre)	453	6.14 (2.58)	Presence of locally undesirable destinations: Yes	453	203 (44.8%)
		0–15.02	No		250 (55.2%)
Number of intersections with stop signs (n)	453	25.53 (17.99)	***Land Covers***		
		0–97	Area of tree canopies (acres)	453	42.46 (23.48)
Percentage of intersections with stop signs	453	53.5% (19.9%)			2.37–122.42
		0.0–92.9%			
OBJECTIVE PHYSICAL ENVIRONMENTS (AIRLINE BUFFER)					
Land Uses			***Land Covers***		
Presence of greenbelts: Yes	453	191 (42.2%)	Presence of water bodies: Yes	453	53 (11.7%)
No		262 (57.8%)	No		400 (88.3%)
Number of parks, excluding natural	453	2.35 (1.97)	***Development Activities***		
preserved and greenbelt types (n)		0–11	Number of all development permits issued in 2019 [ln(n)]	442	3.80 (1.50)
Population Densities					0.00–6.74
Net population density (n/acre)	453	18.31 (9.32)	Commercial permits issued in 2019: Yes	453	199 (43.9%)
		2.84–82.68	No		254 (56.1%)
Gross population density (n/acre)	453	8.24 (3.69)	Residential permits issued in 2019: Yes	453	345 (76.2%)
		1.17–28.36	No		108 (23.8%)
OBJECTIVE PHYSICAL ENVIRONMENTS (SHORTEST NETWORK DISTANCE)					
Transportation			***Land Uses***		
Proximity to the closest transit stop [ln(miles)]	450	−1.36 (1.16)	Proximity to the closest food store (miles)	455	0.65 (0.50)
		−8.72–1.60			0.00–5.11
Proximity to the closest rail station [ln(miles)]	452	1.26 (0.77)	Proximity to the closest park with/next to a water	452	0.81 (1.27)
		−2.59–2.83	body [ln(miles)]		−5.07–2.71
Transit routes at the closest stop (n): 1	455	283 (62.2%)			
2 or more		172 (37.8%)			
OBJECTIVE PHYSICAL ENVIRONMENTS (COMPOSITE SCORES)					
Walk Score (0–100)	455	44.03 (23.73)	Bike Score (0–100)	453	59.13 (20.29)
		0–92			2–99
Transit Score (0–100)	455	35.45 (15.47)			
		0–69			

a: Four-point Likert scale recoding: yes = somewhat disagree + somewhat agree + strongly agree, no = strongly disagree.

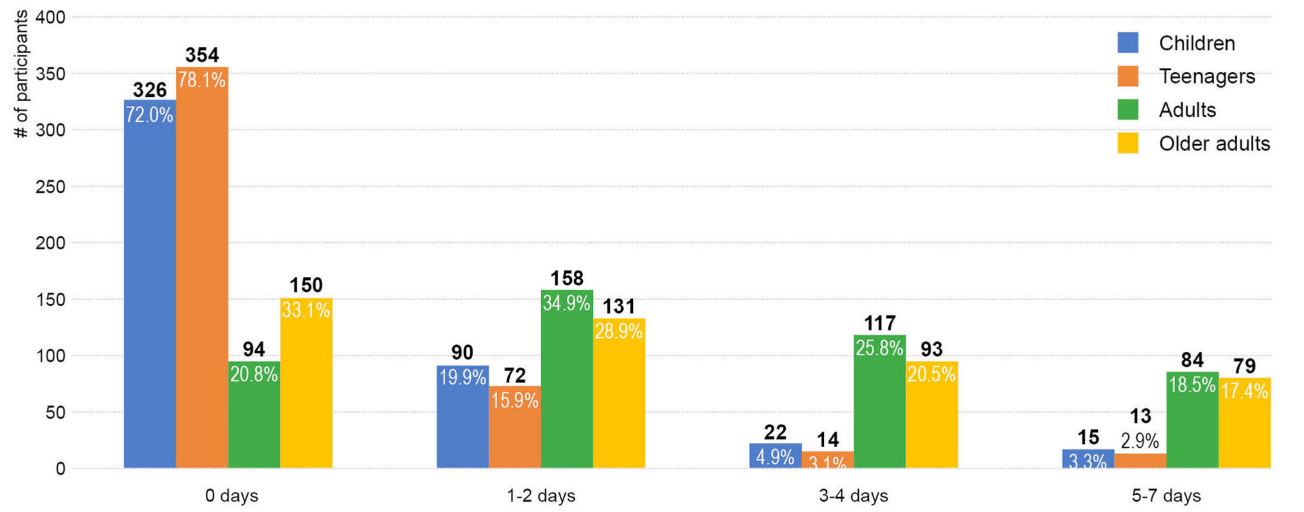
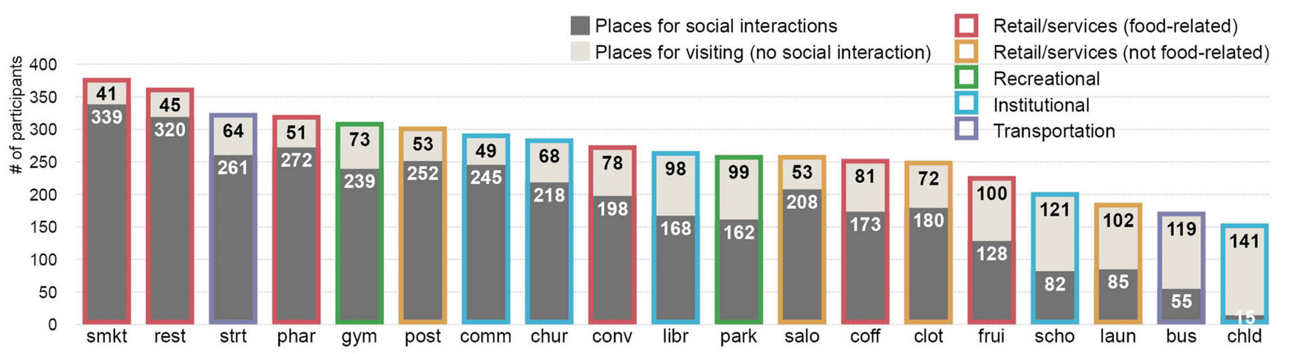


FIGURE 3 | Days of intergenerational and other social activities in a typical week in the neighborhood.



Note: bus=bus stop/light rail station; chld=child daycare; chur=church; clot=clothing store; coff=coffee place/bakery; comm=community center/senior center; conv=convenience store/small grocery store; frui=fruit/vegetable market; gym=gym/fitness facility/recreation center; laun=Laundry/dry cleaner; libr=library/book store; park=park/trail; phar=pharmacy/drug store; post=post office/bank/credit union; rest=restaurant; salo=salon/barber shop; scho=school/university; strt=street (on the street/sidewalks); smkt=supermarket

FIGURE 4 | Places for visiting and social interactions at least once a week.

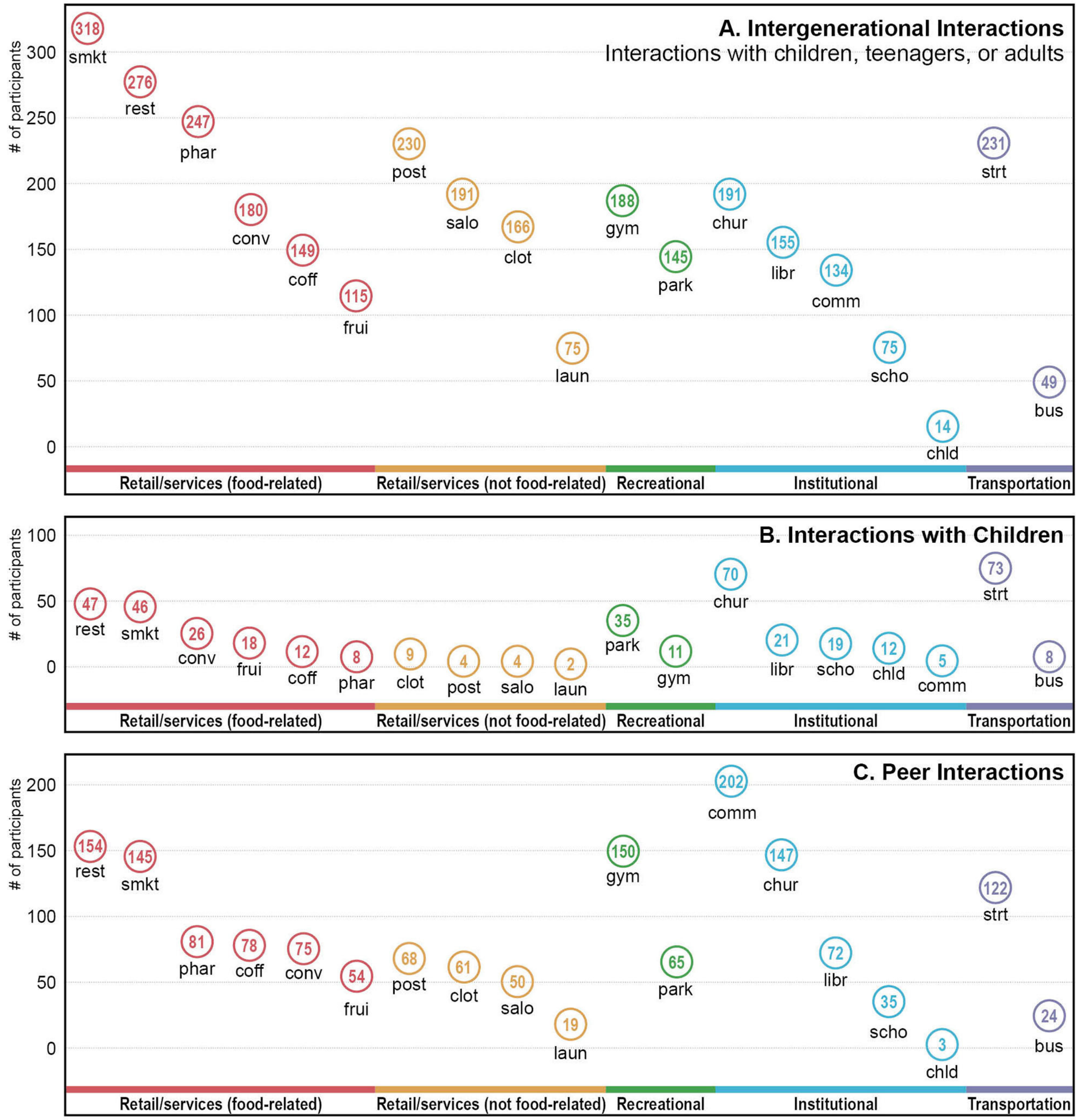
educated people, which may be attributable to the length and content of our survey questionnaire. The paper and online survey participants also showed significant differences in several demographic characteristics, but the binary variable capturing paper vs. online surveys tested in the base models were not significant.

Social Patterns and Places

Older adults' social interactions with people of different ages in the neighborhood varied dramatically in frequency. **Figure 3** shows that older adults interacted at least once a week with adults (79.2%) and other older adults (66.9%) at much higher rates than with children (28.0%) and teenagers (21.9%).

There were a variety of places where participants reported visiting or interacting with others of different ages on a weekly basis (**Figure 4**). The four most common places for older adults' social interactions were the supermarket, restaurant, street (on the street or sidewalks), and pharmacy/drug store. Additionally, the majority of the study participants interacted with others in three more places, including the gym, fitness facility, or recreation center; post office, bank, or credit union; and community or senior center.

Figure 5 further illustrates popular places used for the three specific types of social activities among older adults, including intergenerational interactions (interactions with children, teenagers, or adults), interactions with children, and peer interactions (interactions with other older adults). Frequently used places for older adults' intergenerational interactions were (1) supermarket, (2) restaurant, (3) pharmacy or drug store, (4) street (on the street or sidewalks), and (5) post office, bank, or credit union. Places popularly used by older adults to engage in peer interactions were (1) community or senior center, (2)



Note: bus=bus stop/light rail station; chld=child daycare; chur=church; clot=clothing store; coff=coffee place/bakery; comm=community center/senior center; conv=convenience store/small grocery store; frui=fruit/vegetable market; gym=gym/fitness facility/recreation center; laun=Laundry/dry cleaner; libr=library/book store; park=park/trail; phar=pharmacy/drug store; post=post office/bank/credit union; rest=restaurant; salo=salon/barber shop; scho=school/university; strt=street (on the street/sidewalks); smkt=supermarket

FIGURE 5 | Places for intergenerational and peer interactions at least once a week.

restaurant, (3) gym, fitness facility, or recreation center, (4) church, and (5) supermarket. As for social interactions with children, the five most popular places were (1) street (on the street or sidewalks), (2) church, (3) restaurant, (4) supermarket, and (5) park.

Walking

Recreational walking was more popular for older adults compared to transportation walking (**Figure 6**). The majority of the participants (73.3%) reported walking for recreation at least once in a typical week, while only 43.8% walked for

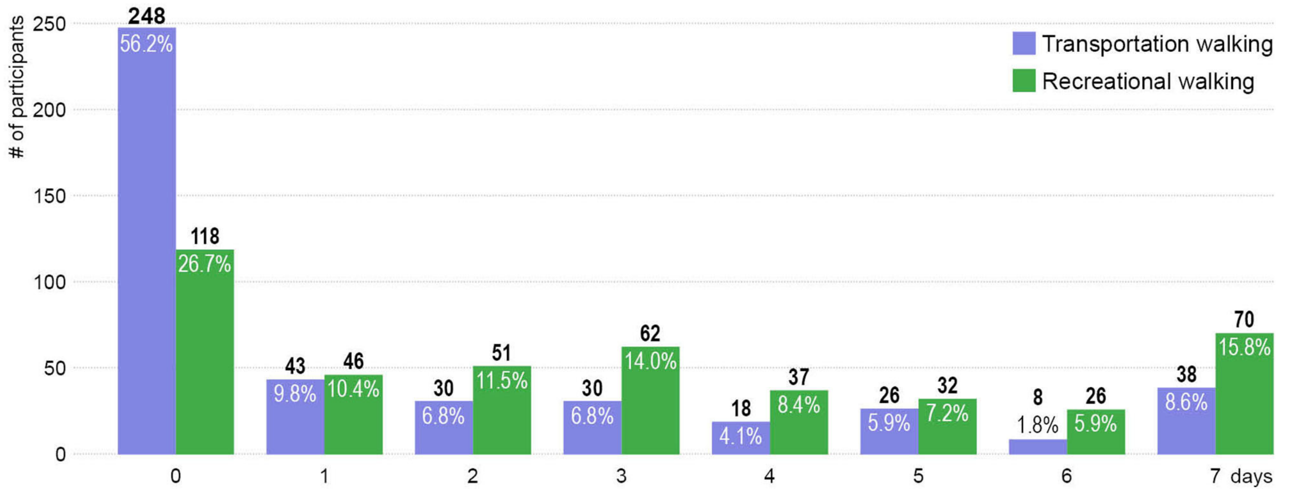


FIGURE 6 | Days of transportation and recreational walking in a typical week.

transportation at least once a week. Moreover, the number of participants (227, 51.4%) who walked for recreation 3+ days in a typical week were almost two times higher than those (120, 27.2%) who walked for transportation 3+ days per week. The two binary walking variables utilized in the bivariate and multivariable regression analyses were transportation walking (43.8% walked vs. 56.2% did not walk at least once a week) and recreational walking (73.3% walked vs. 26.7% did not walk at least once a week).

Correlates of Intergenerational Interactions and Walking Among Older Adults

Perceived Physical Environments

Table 2 summarizes the one-by-one (partially adjusted) model results for the perceived physical environmental variables. Controlled for the base model variables, living in a newly built neighborhood was negatively associated with the odds of interacting with younger generations in the neighborhood (OR = 0.460, $p = 0.047$). Neighborhood walkability was linked with higher odds of interacting with younger generations (OR = 1.461, $p = 0.013$) and being a transportation walker (OR = 1.428, $p = 0.005$). The availability of benches along neighborhood sidewalks was positively correlated with the likelihood of being a recreational walker (OR = 1.966, $p = 0.024$). Neighborhood aesthetics was positively correlated with the likelihood of interacting with children in the neighborhood (OR = 1.401, $p = 0.023$). Traffic safety was linked with lower odds of interacting with younger generations in the neighborhood (OR = 0.676, $p = 0.009$), which might be attributed to neighborhood awareness. For example, older adults who are more socially active may spend more time outdoors in their neighborhood and tend to be more aware of problems like traffic safety issues (e.g., high traffic speeds).

Objective Physical Environments

Objectively measured physical environments are also important for promoting or hindering older adults' intergenerational interactions and/or walking. **Table 3** shows a total number of 37 objectively measured physical environmental variables significantly associated with one or two of the outcomes. These environmental variables contained domains of transportation infrastructure (16, 43.2%), land uses (11, 29.7%), land covers (2, 5.4%), population densities and development activities (5, 13.5%), and composite scores (3, 8.1%). Furthermore, most of the environmental variables were correlated with older adults' intergenerational interactions (29, 78.4%), while significantly fewer environmental variables were associated with older adults' interactions with children (9, 24.3%), transportation walking (13, 35.1%), and recreational walking (2, 5.4%).

Transportation

Our study suggested that neighborhood *streets and sidewalks* and *street connectivity* were significant correlates of older adults' intergenerational interactions and transportation walking. The street length was linked with higher odds of participating in intergenerational interactions in the neighborhood (OR = 1.181, $p = 0.001$) and being a transportation walker (OR = 1.112, $p = 0.006$). The sidewalk length was also positively associated with engaging in intergenerational interactions in the neighborhood (OR = 1.094, $p = 0.002$) and being a transportation walker (OR = 1.061, $p = 0.010$). Two street connectivity variables, the number and density of street intersections, were also positively correlated with intergenerational interactions and transportation walking.

Measures of *stop signs* capturing crossing safety in the neighborhood were significant correlates of older adults' intergenerational interactions and transportation walking. The number of intersections with stop signs were positively associated with engaging in intergenerational interactions (OR = 1.398, $p = 0.001$) and being a transportation walker (OR = 1.144, $p = 0.038$). Another three measures, including the number and

TABLE 2 | Perceived environmental correlates of intergenerational interactions vs. walking, from partially adjusted models[#].

Variables	Intergenerational interactions				Walking			
	Children[a]		Intergenerational[b]		Transportation[c]		Recreation[d]	
	OR	*P*-value	OR	*P*-value	OR	*P*-value	OR	P-value
Newly built neighborhood (yes vs. no)			0.460*	0.047				
Neighborhood walkability (factor scores; unit: 1)			1.461*	0.013	1.428**	0.005		
Benches on most of the sidewalks[e] (yes vs. no)							1.966*	0.024
Neighborhood aesthetics (factor scores; unit: 1)	1.401*	0.023						
Traffic safety (factor scores; unit: 1)			0.676**	0.009				

**p* < 0.05, ***p* < 0.01, OR: Odds Ratio.

#: Results from one-by-one tests where physical environmental variables were added to the base models one at a time.

a. The base model for social interactions with children included nine demographic and socioeconomic variables (i.e., age, gender, race and ethnicity, marital status, education, income, general health conditions, mobility aid, and personal illness) and two residential self-selection variables (i.e., diversity of age groups, social cohesion and support).

b. The base model for social interactions with children, teenagers, or adults included eight demographic and socioeconomic variables (i.e., age, gender, race and ethnicity, marital status, education, income, general health conditions, and employment status) and two residential self-selection variables (i.e., diversity of age groups, social cohesion and support).

c. The base model for transportation walking included 12 demographic and socioeconomic variables (i.e., age, gender, race and ethnicity, marital status, education, income, general health conditions, housing type, having a dog in the household, employment status, daily sleep time, and mobility aids) and two residential self-selection variables (i.e., neighborhood environments, close to public transportation).

d. The base model for recreational walking included 10 demographic and socioeconomic variables (i.e., age, gender, race and ethnicity, marital status, education, income, general health conditions, difficulty walking, having a dog in the household, and employment status), two residential self-selection variables (i.e., neighborhood environments, close to public transportation), and one recruitment channel variable (i.e., recruited from social media).

e: Four-point Likert scale recoding: yes = somewhat disagree + somewhat agree + strongly agree, no = strongly disagree.

density of stop signs and the percentage of intersections with stop signs, were positively correlated with the odds of interacting with younger generations only.

Two variables measuring the *traffic speed* showed different correlations with older adults' social interactions with people of different age groups. The length of high-speed streets was positively associated with the likelihood of interacting with children, teenagers, or adults in the neighborhood (OR = 1.267, $p = 0.013$), while the percentage of high-speed streets was linked with lower odds of interacting with children in the neighborhood (OR = 0.797, $p = 0.002$).

Among the six measures of *transit stops*, the density of transit stops showed positive associations with participating in intergenerational interactions in the neighborhood (OR = 2.592, $p = 0.013$) and being a recreational walker (OR = 2.165, $p = 0.024$). However, the other five measures were positively correlated with intergenerational interactions only: the number of transit stops, the number of total transit routes, the number of transit routes at the closest stop, proximity to the closest transit stop, and proximity to the closest rail station. For the proximity variables in this study, OR < 1 is considered as having a "positive" correlation with the outcomes as a shorter distance means closer proximity and higher accessibility.

Land Uses

Among the 12 general (aggregated) land use variables (e.g., residential, recreational) tested in this study, two variables capturing the *office land use* were significantly correlated with older adults' intergenerational interactions and transportation walking. Older adults who had 1.5+ acres of the office land use in the neighborhood had more than twice the odds of interacting with younger generations in the neighborhood (OR = 2.216, $p = 0.021$) and being a transportation walker (OR = 2.087, $p = 0.010$) than those lacking the office land use in the neighborhood. The percentage of the office land use (2+% vs. 0% in the buffer) was also positively correlated with intergenerational interactions (OR = 2.300, $p = 0.034$) and transportation walking (OR = 2.105, $p = 0.020$).

In terms of the destination land use variables, nine variables showed significant associations with one or both outcomes. Older adults living in the neighborhood with *food stores* (i.e., supermarkets, grocery stores, convenience stores without gas stations) were ∼2.3 times more likely than those without food stores to participate in intergenerational interactions in the neighborhood ($p = 0.009$). Another measure of food stores, the proximity to the closest food store, showed positive associations with both intergenerational interactions and transportation walking. Several types of institutional destinations were also examined in this study, including educational and community destinations (e.g., school), banks and post offices, offices, and religious destinations. However, only the presence of *religious destinations* was linked with higher odds of engaging in intergenerational interactions in the neighborhood (OR = 2.180, $p = 0.008$) and being a transportation walker (OR = 1.587, $p = 0.045$).

Five measures of recreational destinations were significantly correlated with at least one of the outcomes. Older adults living in the neighborhood with *sports and fitness destinations* were ∼1.8 times more likely than those without sports and fitness destinations to interact with children in the neighborhood ($p = 0.023$). The presence of *greenbelts* was negatively associated with the likelihood of interacting with children (OR = 0.561, $p = 0.022$) and being a transportation walker (OR = 0.580, $p = 0.018$), likely due to the limited accessibility and amenities in this type of green space. However, each additional *park* (excluding natural preserved and greenbelt

TABLE 3 | Objective environmental correlates of intergenerational interactions vs. walking, from partially adjusted models[#].

Variables	Intergenerational Interactions				Walking			
	Children[a]		Intergenerational[b]		Transportation[c]		Recreation[d]	
	OR	*P*-value	OR	*P*-value	OR	*P*-value	OR	*P*-value
TRANSPORTATION								
Streets and sidewalks								
Street length (miles; unit: 1)			1.181**	0.001	1.112**	0.006		
Sidewalk length (miles; unit: 1)			1.094**	0.002	1.061*	0.010		
Street connectivity								
Number of Intersections with 3 or more ways (*n*; unit: 10)			1.247**	0.001	1.169**	0.001		
Density of intersections with 3 or more ways (n/acre; unit: 1)			1.212*	0.048	1.240*	0.012		
Stop signs								
Number of stop signs (*n*; unit: 10)			1.226***	0.001				
Density of stop signs (n/acre; unit: 1)			1.183**	0.003				
Number of intersections with stop signs (*n*; unit: 10)			1.398***	0.001	1.144*	0.038		
Percentage of intersections with stop signs (%; unit: 1%)			6.327**	0.006				
Traffic speed								
Length of high-speed streets (>30 mph) (miles; unit: 1)			1.267*	0.013				
Percentage of high-speed streets (>30 mph) (%; unit: 10%)	0.797**	0.002						
Transit stops								
Number of transit stops (*n*): 1–5 (vs. 0)			1.010	0.977				
6–10 (vs. 0)			1.927	0.107				
11 or more (vs. 0)			3.271**	0.007				
Density of transit stops (≥10/100 acres vs. <10/100 acres)			2.592*	0.013			2.165*	0.024
Proximity to the closest transit stop [ln(miles); unit: 1]			0.749*	0.027				
Proximity to the closest rail station [ln(miles); unit: 1]			0.495***	0.000				
Number of total transit routes (n; unit: 1)			1.155**	0.003				
Number of transit routes at the closest stop (1 route vs. 2 or more routes)			1.817*	0.041				
LAND USES								
Office land use								
Area of offices (acres): >0–<1.5 (vs. 0)			1.340	0.360	1.389	0.242		
≥1.5 (vs. 0)			2.216*	0.021	2.087*	0.010		
Percentage of offices (%): >0%–<2% (vs. 0%)			1.476	0.198	1.536	0.104		
≥2% (vs. 0%)			2.300*	0.034	2.105*	0.020		
Food stores								
Presence of food stores (yes vs. no)			2.299**	0.009				
Proximity to the closest food store (miles; unit: 1)			0.606*	0.046	0.576*	0.037		
Religious destinations								
Presence of religious destinations (yes vs. no)			2.180**	0.008	1.587*	0.045		
Recreational destinations								
Presence of sports and fitness destinations (yes vs. no)	1.834*	0.023						
Presence of greenbelts (yes vs. no)	0.561*	0.022			0.580*	0.018		
Number of parks, excluding natural preserved and greenbelt types (n; unit: 1)	1.134*	0.033			1.118*	0.049		
Presence of trails in parks (yes vs. no)			1.888*	0.041	1.885**	0.007		
Proximity to the closest park with/next to a water body [ln(miles); unit: 1]	0.803*	0.030	0.644***	0.001				
Undesirable destinations								
Presence of locally undesirable destinations (yes vs. no)			2.425**	0.003				
LAND COVERS								
Area of tree canopies (acres; unit: 10)			1.133*	0.044				
Presence of water bodies (yes vs. no)	2.604*	0.010						
POPULATION DENSITIES AND DEVELOPMENT ACTIVITIES								
Net population density (n/acre; unit: 1)			1.038*	0.038	1.029*	0.036		

(Continued)

TABLE 3 | Continued

Variables	Intergenerational Interactions				Walking			
	Children[a]		Intergenerational[b]		Transportation[c]		Recreation[d]	
	OR	*P*-value	OR	*P*-value	OR	*P*-value	OR	*P*-value
Gross population density (n/acre; unit: 1)							**0.928***	**0.044**
Number of all development permits issued in 2019 [ln(*n*); unit: 1]	**1.243***	**0.011**	**1.225***	**0.035**				
Commercial permits issued in 2019 (yes vs. no)	**1.819***	**0.016**						
Residential permits issued in 2019 (yes vs. no)	**2.195***	**0.015**						
COMPOSITE SCORES								
Walk Score (scores; unit: 10)			**1.171****	**0.009**				
Transit Score (scores; unit: 10)			**1.290****	**0.003**				
Bike Score (scores; unit: 10)			**1.213****	**0.006**				

**p* < 0.05, ***p* < 0.01, ****p* < 0.001, OR: Odds Ratio. Significant (*p* < 0.05) correlations are highlighted in bold.
#: Results from one-by-one tests where physical environmental variables were added to the base models one at a time.
a. The base model for social interactions with children included nine demographic and socioeconomic variables (i.e., age, gender, race and ethnicity, marital status, education, income, general health conditions, mobility aid, and personal illness) and two residential self-selection variables (i.e., diversity of age groups, social cohesion and support).
b. The base model for social interactions with children, teenagers, or adults included eight demographic and socioeconomic variables (i.e., age, gender, race and ethnicity, marital status, education, income, general health conditions, and employment status) and two residential self-selection variables (i.e., diversity of age groups, social cohesion and support).
c. The base model for transportation walking included 12 demographic and socioeconomic variables (i.e., age, gender, race and ethnicity, marital status, education, income, general health conditions, housing type, having a dog in the household, employment status, daily sleep time, and mobility aids) and two residential self-selection variables (i.e., neighborhood environments, close to public transportation).
d. The base model for recreational walking included 10 demographic and socioeconomic variables (i.e., age, gender, race and ethnicity, marital status, education, income, general health conditions, difficulty walking, having a dog in the household, and employment status), two residential self-selection variables (i.e., neighborhood environments, close to public transportation), and one recruitment channel variable (i.e., recruited from social media).

types) in the neighborhood was associated with 13.4% and 11.8% increases in the odds of interacting with children ($p = 0.033$) and being a transportation walker ($p = 0.049$), respectively. Furthermore, the presence of *trails in parks* was linked with higher odds of engaging in intergenerational interactions (OR = 1.888, $p = 0.041$) and being a transportation walker (OR = 1.885, $p = 0.007$). The proximity to the *closest park with/next to a water body* was also positively correlated with both social interactions with children and intergenerational interactions.

Finally, we also examined potential negative roles of undesirable destinations, which included manufacturing (1018, 95.0%), electric generating (28, 2.6%), and warehousing and storage facilities (26, 2.4%) reflecting local land use conditions in Austin, Texas. However, our study indicated that such *locally undesirable destinations* were positively associated with the likelihood of interacting with younger generations in the neighborhood (OR = 2.425, $p = 0.003$).

Land Covers

Two types of land covers, *tree canopies* and *water bodies*, showed significant correlations with older adults' intergenerational interactions. For example, each 10-acre increase of tree canopies in the neighborhood was linked with a 13.3% increase in the odds of participating in intergenerational interactions in the neighborhood ($p = 0.044$). Older adults living in the neighborhood with water bodies (e.g., lakes, rivers, ponds) were ∼2.6 times as likely as those without water bodies to interact with children in the neighborhood ($p = 0.010$).

Population Densities and Development Activities

In terms of population densities, the *net population density* was linked with higher odds of engaging in intergenerational interactions (OR = 1.038, $p = 0.038$) and being a transportation walker (OR = 1.029, $p = 0.036$). The *gross population density* was linked only with a lower likelihood of being a recreational walker (OR = 0.928, $p = 0.044$).

This study also suggested positive associations between property development activities (captured with a proxy measure of development permits issued) and older adults' intergenerational interactions in the neighborhood. Specifically, the number of *all development permits* issued in 2019 was positively associated with the likelihood of interacting with children (OR = 1.243, $p = 0.011$) and participating in intergenerational interactions (OR = 1.225, $p = 0.035$) in the neighborhood. Furthermore, older adults living in the neighborhood with one or more *commercial* or *residential permits* issued were ∼1.8 ($p = 0.016$) or 2.2 ($p = 0.015$) times more likely to interact with children in the neighborhood, than those living in areas with no development permits issued in 2019.

Composite Scores

Walk Score, Transit Score, and Bike Score were associated only with older adults' intergenerational interactions in the neighborhood. Every 10-point increase in Walk Score, Transit Score, and Bike Score was associated with 17.1% ($p = 0.009$), 29.0% ($p = 0.003$), and 21.3% ($p = 0.006$) increases in older adults' intergenerational interactions in the neighborhood, respectively.

TABLE 4 | Consistent correlates of intergenerational interactions and walking.

Domain	Variable	Intergenerational interactions	Walking
Neighborhood perceptions	Neighborhood walkability (S)	+	+
Transportation	Street length (O)	+	+
	Sidewalk length (O)	+	+
	Street connectivity (O)	+	+
	Stop signs (O)	+	+
	Number of intersections with stop signs		
	Transit stops (O)	+	+
	Density of transit stops		
Land uses	Office land use (O)	+	+
	Food stores (O)	+	+
	Proximity to the closest food store*		
	Religious destinations (O)	+	+
	Greenbelts (O)	–	–
	Parks, excluding natural preserved and greenbelt types (O)	+	+
	Trails in parks (O)	+	+
Population densities	Net population density (O)	+	+

(S): Subjective Measures, (O): Objective Measures, +: Significant ($p < 0.05$) Positive Correlates, –: Significant ($p < 0.05$) Negative Correlates.
**The odds ratio of <1 is considered as having a "positive" correlation with the outcomes as a shorter distance means closer proximity and higher accessibility.*

Synthesis of Similarities and Differences

This section explores similarities and differences in correlates of intergenerational interactions and walking, regardless of their specific type, to facilitate the synthesis and contextualization of the results from multiple models. To guide the development of relevant policy and intervention programs, it is important to understand which neighborhood factors may bring multiple, synergistic benefits to older adults.

Similarities between correlates of intergenerational interactions and correlates of walking among older adults are summarized in **Table 4**. For the subjective measures, neighborhood walkability was positively associated with both intergenerational interactions and walking. In terms of the objective measures, positive predictors of older adults' intergenerational interactions and walking contained three domains: transportation (i.e., street length, sidewalk length, street connectivity, stop signs, and transit stops), land uses (i.e., office land use, food stores, religious destinations, parks excluding natural preserved and greenbelt types, and trails in parks), and population densities (i.e., net population density). Meanwhile, the presence of greenbelts was a negative correlate of both outcomes.

Differences were more evident than similarities in terms of the environmental factors associated with older adults' intergenerational interactions vs. walking (**Table 5**). Most of these variables were significantly associated with intergenerational interactions only, while another two variables (i.e., benches on sidewalks and gross population density) were significant only for walking. For older adults' intergenerational interactions, positive correlates involved domains of neighborhood perception (i.e., neighborhood aesthetics), transportation (i.e., other measures of stop signs and transit stops), land uses (i.e., another measure of food stores, sports, and fitness destinations, locally undesirable destinations, and parks with/next to a water body), land covers (i.e., tree canopies and water bodies), development activities (i.e., development permits), and composite scores (i.e., Walk Score, Transit Score, and Bike Score). Another two negative correlates of older adults' intergenerational interactions were residence in a newly built neighborhood and traffic safety condition of the neighborhood. Furthermore, different measures of traffic speeds showed both negative and positive correlations with older adults' intergenerational interactions depending on the specific age groups.

DISCUSSION AND CONCLUSION

This is one of the first studies that explored specific places older adults used for intergenerational interactions. It also identified significant elements and features of their neighborhood physical environments linked with intergenerational interactions and compared similarities and differences in environmental correlates of older adults' intergenerational interactions vs. walking. This study provided evidence supporting the significant roles of neighborhood environments in promoting older adults' intergenerational interactions and walking, which can further contribute to expanding the existing body of knowledge on environments and aging.

Environmental predictors of older adults' social interactions with children only vs. with all younger age groups (intergenerational interactions) in the neighborhood showed fairly inconsistent patterns. More environmental variables were significant in predicting intergenerational interactions (32 environmental predictors) compared to interactions with

TABLE 5 | Inconsistent correlates of intergenerational interactions and walking.

Domain	Variable	Intergenerational interactions	Walking
Neighborhood Perceptions	Newly built neighborhood (S)	–	
	Neighborhood aesthetics (S)	+	
Transportation	Benches on sidewalks (S)		+
	Stop signs (O)	+	
	Number of stop signs		
	Density of stop signs		
	Percentage of intersections with stop signs		
	Traffic safety (S)	–	
	Traffic speed (O)	+ –	
	Length of high-speed streets		
	Percentage of high-speed streets		
	Transit stops (O)	+	
	Number of transit stops		
	Proximity to the closest transit stop*		
	Proximity to the closest rail station*		
	Number of total transit routes		
	Number of transit routes at the closest stop		
Land Uses	Food stores (O)	+	
	Presence of food stores		
	Sports and fitness destinations (O)	+	
	Locally undesirable destinations (O)	+	
	Parks with/next to a water body* (O)	+	
Land Covers	Tree canopies (O)	+	
	Water bodies (O)	+	
Population Densities and	Gross population density (O)		–
Development Activities	Development permits (O)	+	
Composite Scores	Walk Score (O)	+	
	Transit Score (O)	+	
	Bike Score (O)	+	

(S): Subjective Measures, (O): Objective Measures, +: Significant ($p < 0.05$) Positive Correlates, –: Significant ($p < 0.05$) Negative Correlates.
**The odds ratio of <1 is considered as having a "positive" correlation with the outcomes as a shorter distance means closer proximity and higher accessibility.*

children (10 environmental predictors). Only two variables (i.e., proximity to the closest park with/next to a water body and development permits issued in 2019) were correlated with both social interactions with children and intergenerational interactions. Future efforts with fully adjusted models examining the influences of neighborhood environments on various types of social interactions among older adults can contribute to a more comprehensive understanding of the similarities and differences in personal and environmental correlates of various social interactions (e.g., intergenerational vs. peer interactions).

For the environmental correlates of intergenerational interactions vs. walking, intergenerational interactions shared many similar correlates with transportation walking, but not with recreational walking. Only three environmental variables (i.e., benches on most of the sidewalks, the transit stop density, and the gross population density) showed significant associations with older adults' recreational walking, of which only one (transit stop density) was also associated with intergenerational interactions.

We also found counter-intuitive results. For example, locally undesirable destinations (i.e., manufacturing, electric generating, and warehousing and storage facilities), generally considered as negative for outdoor activities, were linked with higher odds of engaging in intergenerational interactions in the neighborhood. Further examinations of the relevant GIS data showed that the manufacturing land uses in our study community consisted mainly of small-scale light manufacturing (e.g., winery, music instrument manufacturing, and digital printing) instead of heavy production manufacturing facilities. These light manufacturing facilities tended to be clustered with other major destinations (e.g., supermarkets, grocery stores) shown to support diverse social activities. The Chi-square test further demonstrated that the presence of locally undesirable destinations was positively correlated with the presence of food stores ($x^2 = 45.969$, $df = 1$, $p < 0.001$), which were most popularly used for social interactions in this study (**Figures 4**, **5**). Thus, this study suggested that the presence of manufacturing facilities was a proxy for small mixed use and retail centers that might have provided opportunities for social interactions across different generations in Austin, Texas and similar communities in the US. A previous study, although in smaller communities, showed such small-scale, light manufacturing facilities were positively associated with transportation walking (62). Another counter-intuitive finding was the positive association between the length of high-speed streets and older adults' intergenerational interactions. A similar possibility is that the length of high-speed streets may also capture other environmental elements and features that can promote intergenerational interactions, such as population densities, walking/cycling facilities, and family-friendly destinations. Bivariate analyses indicated that the length of high-speed streets was positively correlated with the net (Pearson R $= 0.387$, $p < 0.001$) and gross (Pearson R $= 0.345$, $p < 0.001$) population density, the length of sidewalks (Pearson R $= 0.589$, $p < 0.001$), and the presence of food stores (independent sample t-test $= -10.290$, $p < 0.001$) in the neighborhood. However, the percentage of high-speed streets in the neighborhood was negatively correlated with interactions with children only, which may be attributed to traffic safety concerns that may be more important for children than for older age groups.

Development permits were positively associated with the likelihood of interacting with younger generations in the neighborhood. The permits issued in 2019 in Austin, Texas included 3,652 commercial and 21,155 residential permits. Locations where these permits were issued during the study period suggest many new infill developments and infrastructure improvements, creating vibrant, age-diverse, and socially engaging environments. Further research is needed to better understand how this widely available variable may help capture some of the difficult-to-quantify aspects of the neighborhood characteristics that are potentially meaningful for residents' social and physical activities.

Walk Score, Bike Score, and Transit Score were positively correlated with older adults' intergenerational interactions in the neighborhood. While developed as primarily destination-driven composite measures to estimate the environmental friendliness to support walking, biking, and transit use, respectively, our study showed that these measures were also significant predictors of social interactions. Previous studies have shown that these scores are linked with health behaviors and outcomes (63–65). Given their ease of use and wide availability, these scores have the potential to promote the consideration of physical environmental variables in intergenerational interaction literature that has largely overlooked the roles of physical environments.

Limitations

This study has five major limits. First, this was a cross-sectional study that generated results predicting correlations only with no ability to draw causality between variables. Second, another source of limitation is residential self-selection. Although it is possible that older adults who are active or prefer activities choose to live in the neighborhood with features supporting intergenerational interactions and walking, relevant variables (i.e., reasons for selecting their current residence) were controlled in all models, which helped address the potential bias. Third, the survey recall bias and potential measurement errors associated with using newly developed questions posed challenges to this study, but the survey was the only feasible way to collect the data from a sufficient number of eligible participants for this research. To maximize the validity and reliability of the survey instrument, most questions were adapted from existing validated questionnaires. The final instrument was developed after a series of pilot tests (i.e., focus group, one-on-one in-depth discussions) to ensure appropriate length, completeness, clarity, and organization of the questionnaire. The test-retest reliability results suggested acceptable levels of reliability and did not suggest serious recall bias. Fourth, the convenience sampling method led to sample bias (e.g., an over-representation of active and healthy older adults). Relevant variables were tested during the modeling process, and those significant ones (e.g., employment status) were retained in the models. However, many of those variables (e.g., diseases, living arrangements) were not significant suggesting that the risk of serious sampling bias is small. Fifth, generalizability of the significant findings from this research is limited to older adults living in Austin, Texas and in similar communities/cities in the US.

Implications for Future Research, Practice, and Policy

Responding to the major study limitations discussed above, future studies are needed to utilize more rigorous sampling and analytical strategies, apply case-control and pre-post comparisons, and involve additional locations or communities. As this study has relied only on subjective measures of intergenerational interactions and walking, future research involving objective outcome measures can offer more evidence with more accurate measures. Furthermore, given the significant differences we found for different types of intergenerational interactions, more efforts are needed to investigate the influences of neighborhood environments on various types of intergenerational and other social interactions, such as naturally occurring interactions, casual daily interactions, and formal social interactions. These social interactions can also differ by the locations in which they occur; amount of interactions and their health-significant thresholds; quality of interactions considering emotional preference, experience, satisfaction, etc.; specific age groups older adults interact with; and the level of intimacy. Another area needing more efforts is the development of a clear definition of intergenerational community to guide its operationalization in research and practice, contributing to promoting healthy aging in place.

This study offers insights on the environmental strategies to promote routine intergenerational activities among community-dwelling older adults living in urban communities like those in Austin, Texas. Findings from this study provide practical guidelines for policymakers and design professionals to support the development of age-friendly communities that promote intergenerational interactions and healthy aging in place. Moreover, the evidence supporting the relationships between physical environments and older adults' intergenerational interactions and walking can be translated into evidence-based design and policy principles for creating age-friendly or intergenerational communities. These principles may target transportation infrastructure, land uses, land covers, and neighborhood developments.

Additionally, while it is beyond the scope of this study, the current circumstances affected by COVID-19 bring additional challenges to older adults and their ability to engage in intergenerational interactions and physical activities. Due to their high vulnerability to this virus, older adults are more likely to be socially isolated. The situation is even worse for those who are living in long-term care or assisted living facilities because of the current lockdown of the facilities. Future research appears necessary to understand the impacts of pandemics like this on social/physical activities among older adults and identify effective community-level intervention strategies for supporting social/physical activities while ensuring the safety and health of older adults during pandemics such as COVID-19.

CONCLUSIONS

Our study findings suggest that neighborhood physical environments play essential roles in promoting older adults' intergenerational interactions and walking. Given the significant health benefits, promoting intergenerational interactions and walking among older adults should be viewed as a national/global responsibility. Future policymakers, researchers, and professionals should further investigate social and physical environmental facilitators as well as barriers to creating intergenerational communities that can support healthy living of all generations.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board at Texas A&M University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

SZ collected the subjective and objective data, conducted statistical analyses, and drafted the manuscript. CL guided the data collection, analysis, and manuscript drafting process, and revised the draft manuscript. HL collected the objectively measured environmental data, ran the GIS models, and drafted part of the MATERIALS AND METHODS section of the manuscript. All authors contributed to the article and approved the submitted version.

FUNDING

This study was funded by the American Institute of Architects' Design for Aging Knowledge Community for data collection and by the Office of Graduate and Professional Studies at Texas A&M University for data analysis and writing. The open access publishing fees for this article have been covered by the Texas A&M University Open Access to Knowledge Fund (OAKFund), supported by the University Libraries.

REFERENCES

1. United Nations. *Profiles of Ageing*. (2019). Available online at: https://population.un.org/ProfilesOfAgeing2019/index.html
2. Ory M, Kinney Hoffman M, Hawkins M, Sanner B, Mockenhaupt R. Challenging aging stereotypes: strategies for creating a more active society. *Am J Prev Med.* (2003) 25:164–71. doi: 10.1016/S0749-3797(03)00181-8
3. Barron JS, Tan EJ, Yu Q, Song M, McGill S, Fried LP. Potential for intensive volunteering to promote the health of older adults in fair health. *J Urban Health.* (2009) 86:641–53. doi: 10.1007/s11524-009-9353-8
4. Dorgo S, King GA, Bader JO, Limon JS. Comparing the effectiveness of peer mentoring and student mentoring in a 35-week fitness program for older adults. *Arch Gerontol Geriatr.* (2011) 52:344–9. doi: 10.1016/j.archger.2010.04.007
5. Dorgo S, King GA, Bader JO, Limon JS. Outcomes of a peer mentor implemented fitness program in older adults: a quasi-randomized controlled trial. *Int J Nurs Stud.* (2013) 50:1156–65. doi: 10.1016/j.ijnurstu.2012.12.006
6. Fried LP, Carlson MC, Freedman M, Frick KD, Glass TA, Hill J, et al. A social model for health promotion for an aging population: initial evidence on the experience corps model. *J Urban Health.* (2004) 81:64–78. doi: 10.1093/jurban/jth094
7. Hong SI, Morrow-Howell N. Health outcomes of experience corps: a high-commitment volunteer program. *Soc Sci Med.* (2010) 71:414–20. doi: 10.1016/j.socscimed.2010.04.009
8. Seeman T, Merkin SS, Goldwater D, Cole SW. Intergenerational mentoring, eudaimonic well-being and gene regulation in older adults: a pilot study. *Psychoneuroendocrinology.* (2019) 111:104468. doi: 10.1016/j.psyneuen.2019.104468
9. Carlson MC, Erickson KI, Kramer AF, Voss MW, Bolea N, Mielke M, et al. Evidence for neurocognitive plasticity in at-risk older adults: the experience corps program. *J Gerontol A Biol Sci Med Sci.* (2009) 64:1275–82. doi: 10.1093/gerona/glp117
10. Carlson MC, Kuo JH, Chuang YF, Varma VR, Harris G, Albert MS, et al. Impact of the Baltimore experience corps trial on cortical and hippocampal volumes. *Alzheimers Dement.* (2015) 11:1340–8. doi: 10.1016/j.jalz.2014.12.005
11. Carlson MC, Saczynski JS, Rebok GW, Seeman T, Glass TA, McGill S, et al. Exploring the effects of an "everyday" activity program on executive function and memory in older adults: experience corps. *Gerontologist.* (2008) 48:793–801. doi: 10.1093/geront/48.6.793
12. Chippendale T, Boltz M. Living legends: effectiveness of a program to enhance sense of purpose and meaning in life among community-dwelling older adults. *Am J Occup Ther.* (2015) 69:6904270010. doi: 10.5014/ajot.2015.014894
13. Gruenewald TL, Tanner EK, Fried LP, Carlson MC, Xue QL, Parisi JM, et al. The Baltimore Experience Corps Trial: enhancing generativity via intergenerational activity engagement in later life. *J Gerontol B Psychol Sci Soc Sci.* (2016) 71:661–70. doi: 10.1093/geronb/gbv005

14. Herrmann DS, Sipsas-Herrmann A, Stafford M, Herrmann NC. Benefits and risks of intergenerational program participation by senior citizens. *Educ Gerontol.* (2005) 31:123–38. doi: 10.1080/03601270590891522
15. Park JH, Lee K, Dabelko-Schoeny H. A comprehensive evaluation of a lifelong learning program: program 60. *Int J Aging Hum Dev.* (2016) 84:88–106. doi: 10.1177/0091415016668352
16. Yuen HK, Huang P, Burik JK, Smith TG. Impact of participating in volunteer activities for residents living in long-term-care facilities. *Am J Occup Ther.* (2008) 62:71–6. doi: 10.5014/ajot.62.1.71
17. Nicholson NR, Jr., Shellman J. Decreasing social isolation in older adults: effects of an empowerment intervention offered through the CARELINK program. *Res Gerontol Nurs.* (2013) 6:89–97. doi: 10.3928/19404921-20130110-01
18. Rook KS, Sorkin DH. Fostering social ties through a volunteer role: implications for older-adults' psychological health. *Int J Aging Hum Dev.* (2003) 57:313–37. doi: 10.2190/NBBN-EU3H-4Q1N-UXHR
19. Morrow-Howell N, Hong S-I, McCrary S, Blinne W. Changes in activity among older volunteers. *Res Aging.* (2012) 34:174–96. doi: 10.1177/0164027511419371
20. Parisi JM, Kuo J, Rebok GW, Xue QL, Fried LP, Gruenewald TL, et al. Increases in lifestyle activities as a result of experience corps participation. *J Urban Health.* (2015) 92:55–66. doi: 10.1007/s11524-014-9918-z
21. Strand KA, Francis SL, Margrett JA, Franke WD, Peterson MJ. Community-based exergaming program increases physical activity and perceived wellness in older adults. *J Aging Phys Act.* (2014) 22:364–71. doi: 10.1123/japa.22.3.364
22. Tan EJ, Rebok GW, Yu Q, Frangakis CE, Carlson MC, Wang T, et al. The long-term relationship between high-intensity volunteering and physical activity in older African American women. *J Gerontol B Psychol Sci Soc Sci.* (2009) 64:304–11. doi: 10.1093/geronb/gbn023
23. Tan EJ, Xue QL, Li T, Carlson MC, Fried LP. Volunteering: a physical activity intervention for older adults—the experience corps program in Baltimore. *J Urban Health.* (2006) 83:954–69. doi: 10.1007/s11524-006-9060-7
24. Varma VR, Tan EJ, Gross AL, Harris G, Romani W, Fried LP, et al. Effect of community volunteering on physical activity: a randomized controlled trial. *Am J Prev Med.* (2016) 50:106–10. doi: 10.1016/j.amepre.2015.06.015
25. Nelson ME, Rejeski WJ, Blair SN, Duncan PW, Judge JO, King AC, et al. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. *Circulation.* (2007) 116:1094−105. doi: 10.1161/CIRCULATIONAHA.107.185650
26. Mobily KE, Rubenstein LM, Lemke JH, OHara MW, Wallace RB. Walking and depression in a cohort of older adults: the Iowa 65+ rural health study. *J Aging Phys Act.* (1996) 4:119–35. doi: 10.1123/japa.4.2.119
27. Ory MG, Towne SD, Won J, Forjuoh SN, Lee C. Social and environmental predictors of walking among older adults. *BMC Geriatrics.* (2016) 16:155. doi: 10.1186/s12877-016-0327-x
28. Hakim AA, Petrovitch H, Burchfiel CM, Ross GW, Rodriguez BL, White LR, et al. Effects of walking on mortality among nonsmoking retired men. *N Engl J Med.* (1998) 338:94–9. doi: 10.1056/NEJM199801083380204
29. Heesch KC, Burton NW, Brown WJ. Concurrent and prospective associations between physical activity, walking and mental health in older women. *J Epidemiol Community Health.* (2011) 65:807–13. doi: 10.1136/jech.2009.103077
30. Julien D, Gauvin L, Richard L, Kestens Y, Payette H. The role of social participation and walking in depression among older adults: results from the VoisiNuAge study. *Can J Aging.* (2013) 32:1–12. doi: 10.1017/S071498081300007X
31. Centers for Disease Control and Prevention. *BRFSS survey Data and Documentation*. (2018). Available online at: https://www.cdc.gov/brfss/annual_data/annual_2018.html
32. Lawton MP. Environment and other determinants of well-being in older people. *Gerontologist.* (1983) 23:349–57. doi: 10.1093/geront/23.4.349
33. King AC, Sallis JF, Frank LD, Saelens BE, Cain K, Conway TL, et al. Aging in neighborhoods differing in walkability and income: associations with physical activity and obesity in older adults. *Soc Sci Med.* (2011) 73:1525–33. doi: 10.1016/j.socscimed.2011.08.032
34. Christman ZJ, Wilson-Genderson M, Heid A, Pruchno R. The effects of neighborhood built environment on walking for leisure and for purpose among older people. *Gerontologist.* (2019) doi: 10.1093/geront/gnz093
35. Beard JR, Blaney S, Cerda M, Frye V, Lovasi GS, Ompad D, et al. Neighborhood characteristics and disability in older adults. *J Gerontol B Psychol Sci Soc Sci.* (2009) 64:252–7. doi: 10.1093/geronb/gbn018
36. Freedman VA, Grafova IB, Schoeni RF, Rogowski J. Neighborhoods and disability in later life. *Soc Sci Med.* (2008) 66:2253–67. doi: 10.1016/j.socscimed.2008.01.013
37. Berke EM, Gottlieb LM, Moudon AV, Larson EB. Protective association between neighborhood walkability and depression in older men. *J Am Geriatr Soc.* (2007) 55:526–33. doi: 10.1111/j.1532-5415.2007.01108.x
38. Parra DC, Gomez LF, Sarmiento OL, Buchner D, Brownson R, Schimd T, et al. Perceived and objective neighborhood environment attributes and health related quality of life among the elderly in Bogota, Colombia. *Soc Sci Med.* (2010) 70:1070–6. doi: 10.1016/j.socscimed.2009.12.024
39. Sugiyama T, Thompson CW, Alves S. Associations between neighborhood open space attributes and quality of life for older people in Britain. *Environ Behav.* (2009) 41:3–21. doi: 10.1177/0013916507311688
40. Richard L, Gauvin L, Kestens Y, Shatenstein B, Payette H, Daniel M, et al. Neighborhood resources and social participation among older adults: results from the VoisiNuage study. *J Aging Health.* (2013) 25:296–318. doi: 10.1177/0898264312468487
41. Haak M, Fange A, Horstmann V, Iwarsson S. Two dimensions of participation in very old age and their relations to home and neighborhood environments. *Am J Occup Ther.* (2008) 62:77–86. doi: 10.5014/ajot.62.1.77
42. McLeroy KR, Bibeau D, Steckler A, Glanz K. An ecological perspective on health promotion programs. *Health Educ Q.* (1988) 15:351–77. doi: 10.1177/109019818801500401
43. Sabharwal S, Wilson H, Reilly P, Gupte CM. Heterogeneity of the definition of elderly age in current orthopaedic research. *Springerplus.* (2015) 4:516. doi: 10.1186/s40064-015-1307-x
44. US Census Bureau. *2014-2018 American Community Survey 5-year estimates*. (2018). Available online at: https://data.census.gov/cedsci/advanced
45. US Census Bureau. *2000: DEC Summary File 1*. (2000). Available online at: https://data.census.gov/cedsci/advanced
46. Zhong S, Lee C, Foster M, Bian J. Intergenerational communities: a systematic literature review of intergenerational interactions and older adults' health-related outcomes. *Soc Sci Med.* (2020) 264:113374. doi: 10.1016/j.socscimed.2020.113374
47. International Physical Activity Questionnaires. *Downloadable questionnaires: IPAQ_Elderly_English_self-admin_short*. (2015). Available online at: https://sites.google.com/site/theipaq/questionnaire_links
48. Cerin E, Saelens BE, Sallis JF, Frank LD. Neighborhood environment walkability scale: validity and development of a short form. *Med Sci Sports Exerc.* (2006) 38:1682–91. doi: 10.1249/01.mss.0000227639.83607.4d
49. Saelens BE, Sallis JF. Neighborhood Environment Walkability Survey (NEWS) & Neighborhood Environment Walkability Survey – Abbreviated (NEWS-A) (2002). Available online at: https://activelivingresearch.org/neighborhood-environment-walkability-survey-news-neighborhood-environment-walkability-survey-%E2%80%93.
50. Chudyk AM, McKay HA, Winters M, Sims-Gould J, Ashe MC. Neighborhood walkability, physical activity, and walking for transportation: a cross-sectional study of older adults living on low income. *BMC Geriatr.* (2017) 17:82. doi: 10.1186/s12877-017-0469-5
51. Oliver LN, Schuurman N, Hall AW. Comparing circular and network buffers to examine the influence of land use on walking for leisure and errands. *Int J Health Geogr.* (2007) 6:41. doi: 10.1186/1476-072X-6-41
52. Hinckson E, Cerin E, Mavoa S, Smith M, Badland H, Stewart T, et al. Associations of the perceived and objective neighborhood environment with physical activity and sedentary time in New Zealand adolescents. *Int J Behav Nutr Phys Act.* (2017) 14:145. doi: 10.1186/s12966-017-0597-5
53. Forsyth A, Van Riper D, Larson N, Wall M, Neumark-Sztainer D. Creating a replicable, valid cross-platform buffering technique: the sausage network buffer for measuring food and physical activity built environments. *Int J Health Geogr.* (2012) 11:14. doi: 10.1186/1476-072X-11-14

54. Kim JH, Lee C, Sohn W. Urban natural environments, obesity, and health-related quality of life among Hispanic children living in inner-city neighborhoods. *Int J Environ Res Public Health.* (2016) 13:121. doi: 10.3390/ijerph13010121
55. Lee C, Moudon AV. The 3Ds+R: quantifying land use and urban form correlates of walking. *Transp Res D Transp Environ.* (2006) 11:204–15. doi: 10.1016/j.trd.2006.02.003
56. Carr LJ, Dunsiger SI, Marcus BH. Walk score as a global estimate of neighborhood walkability. *Am J Prev Med.* (2010) 39:460–3. doi: 10.1016/j.amepre.2010.07.007
57. Duncan DT, Aldstadt J, Whalen J, Melly SJ, Gortmaker SL. Validation of walk score for estimating neighborhood walkability: an analysis of four US metropolitan areas. *Int J Environ Res Public Health.* (2011) 8:4160–79. doi: 10.3390/ijerph8114160
58. Hirsch JA, Winters M, Clarke PJ, Ste-Marie N, McKay HA. The influence of walkability on broader mobility for Canadian middle aged and older adults: an examination of walk score and the Mobility over Varied Environments Scale (MOVES). *Prev Med.* (2017) 95:S60–7. doi: 10.1016/j.ypmed.2016.09.036
59. Behavioral Risk Factor Surveillance System. *BRFSS Questionnaire*. (2018). Available online at: https://www.cdc.gov/brfss/questionnaires/index.html
60. US Census Bureau. *The American Community Survey*. (2017). Available online at: https://www.census.gov/programs-surveys/acs/methodology/questionnaire-archive.2017.html
61. Frank L, Saelens BE, Powell KE, Chapman JE. Stepping towards causation: do built environments or neighborhood and travel preferences explain physical activity, driving, and obesity? *Soc Sci Med.* (2007) 65:1898–914. doi: 10.1016/j.socscimed.2007.05.053
62. Doescher MP, Lee C, Berke EM, Adachi-Mejia AM, Lee CK, Stewart O, et al. The built environment and utilitarian walking in small US towns. *Prev Med.* (2014) 69:80–6. doi: 10.1016/j.ypmed.2014.08.027
63. Towne SD, Jr., Won J, Lee S, Ory MG, Forjuoh SN, et al. Using walk score and neighborhood perceptions to assess walking among middle-aged and older adults. *J Community Health.* (2016) 41:977–88. doi: 10.1007/s10900-016-0180-z
64. Koohsari MJ, McCormack GR, Nakaya T, Shibata A, Ishii K, Yasunaga A, et al. Walking-friendly built environments and objectively measured physical function in older adults. *J Sport Health Sci.* (2020). doi: 10.1016/j.jshs.2020.02.002
65. Liao Y, Lin CY, Lai TF, Chen YJ, Kim B, Park JH. Walk score® and its associations with older adults' health behaviors and outcomes. *Int J Environ Res Public Health.* (2019) 16:622. doi: 10.3390/ijerph16040622

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 22 December 2020
doi: 10.3389/fpubh.2020.564533

Everyday Walking Among Older Adults and the Neighborhood Built Environment: A Comparison Between Two Cities in North America

Florian Herbolsheimer[1], Atiya Mahmood[1]*, Yvonne L. Michael[2] and Habib Chaudhury[1]

[1] Department of Gerontology, Simon Fraser University, Vancouver, BC, Canada, [2] Dornsife School of Public Health, Drexel University, Philadelphia, PA, United States

OPEN ACCESS

Edited by:
Anna Patricia Lane,
Singapore University of Technology and Design, Singapore

Reviewed by:
Patricia M. Alt,
Towson University, United States
Shubing Cai,
University of Rochester, United States

***Correspondence:**
Atiya Mahmood
amahmood@sfu.ca

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: 21 May 2020
Accepted: 23 November 2020
Published: 22 December 2020

Citation:
Herbolsheimer F, Mahmood A, Michael YL and Chaudhury H (2020) Everyday Walking Among Older Adults and the Neighborhood Built Environment: A Comparison Between Two Cities in North America. Front. Public Health 8:564533. doi: 10.3389/fpubh.2020.564533

A walkable neighborhood becomes particularly important for older adults for whom physical activity and active transportation are critical for healthy aging-in-place. For many older adults, regular walking takes place in the neighborhood and is the primary mode of mobility. This study took place in eight neighborhoods in Metro Portland (USA) and Metro Vancouver (Canada), examining older adults' walking behavior and neighborhood built environmental features. Older adults reported walking for recreation and transport in a cross-sectional telephone survey. Information on physical activity was combined with audits of 355 street segments using the Senior Walking Environmental Audit Tool-Revised (SWEAT-R). Multi-level regression models examined the relationship between built environmental characteristics and walking for transport or recreation. Older adults [$N = 434$, mean age: 71.6 ($SD = 8.1$)] walked more for transport in high-density neighborhoods and in Metro Vancouver compared to Metro Portland ($M = 12.8$ vs. $M = 2.2$ min/day; $p < 0.001$). No relationship was found between population density and walking for recreation. Older adults spent more time walking for transport if pedestrian crossing were present ($p = 0.037$) and if parks or outdoor fitness amenities were available ($p = 0.022$). The immediate neighborhood built environment supports walking for transport in older adults. Comparing two similar metropolitan areas highlighted that high population density is necessary, yet not a sufficient condition for walking in the neighborhood.

Keywords: physical activity, built environment, walking, neighborhood, older adults

INTRODUCTION

The literature widely supports the health benefits for older adults who engage in regular physical activity [e.g., (1, 2)]. Thereby, walking is the most popular form of physical activity among older adults (3, 4). The neighborhood built environment plays a significant role in walking for recreation or transport, which generally takes place outdoors and in nearby settings (e.g., parks, shopping malls, trails, neighborhood streets) (5).

As postulated by social-ecological models, walking is affected by multiple levels of influence, including the built environment (6, 7). Therefore, walking needs to be analyzed from a multi-level perspective bringing together individual characteristics and physical environmental features. Older adults with declined functioning are more likely to be more affected than other age groups by the neighborhood built environmental features as being supportive or restrictive (8).

It has been suggested that older adults walk more often in high-dense residential areas (9). Residential density and the walkability of the built environment, such as easy access to destinations and services, pedestrian-oriented street elements and street patterns, and connectivity, are associated with physical activity and walking (10). By distinguishing different types of walking behavior, a review revealed strong relationships between walking for transport and walkability, urbanization, land use mix, accessibility, and the presence of amenities (11). Walking for recreation was closely associated with walkability, aesthetics/green spaces, and air quality.

However, most research on the built environment and walking has not fully accounted for the wide variation in built-environmental characteristics. Most studies relied on single-countries, primarily the U.S. and other high-income countries with limited variability in density resulting in an underestimation of potential effects. As a result, reviews of the neighborhood built environment and older adult's walking activity reveal inconsistent findings (11). Studies adopting a similar research design in Japan and Taiwan have found no association between public transport and walking for transport in older adults (12, 13), whereas public transport was positively related to walking for transport in Belgium, the U.S., and China (14–16). Other studies reported that walkable neighborhoods, notably higher density environments, were associated with walking for transport in older adults (15, 17, 18), but not in other studies (13, 19, 20).

Therefore, an international comparison approach is crucial because unique built environmental conditions related to issues such as local topography, urban planning, social preferences, etc. are likely to modify the relationship between walking and the neighborhood built environment. An exception is the International Physical Activity and the Environment Network (IPEN) study across 11 countries. Land-use mix and sidewalks showed the most consistent associations with moderate-to-vigorous physical activity (21). However, single study sites are hard to compare because they differ in population densities. The findings of the IPEN study can only partially be transferred to an older adult population as it represents a younger population with a mean age of forty-two.

The present study applies a country-comparative perspective analyzing the neighborhood-built environment and walking in older adults. Districts in both counties were selected based on the population's density and income. Combining a survey and a street-level built environmental audit, we examined walking behavior of older adults in terms of: (1) the differences between the U.S. and Canadian metropolitan areas, (2) its associations with population density, and (3) its associations with neighborhood built environmental factors within and across study sites.

MATERIALS AND METHODS

This study was part of a larger three-phase, mixed-methods research project consisting of a qualitative photovoice method (22) a neighborhood environmental audit using the Senior Walking Environmental Audit Tool-Revised (SWEAT-R) (23, 24), and a telephone survey (25). The study was conducted in the metropolitan areas of Vancouver, British Columbia (B.C.), Canada and Portland, Oregon (OR), United States. The topography, climate, and urban planning decisions had broad similarities due to the two cities' locations in North America's Pacific Northwest. Given these similarities, we wanted to explore if physical activity was also similar among the older adult populations in comparable built environments. Data collection took place in four neighborhoods in the Metro Vancouver and four neighborhoods in Metro Portland. Census tract data were used to select eight neighborhoods based on neighborhood density and income levels to ensure variation in the physical environment features essential for physical activity (23). The following analyses utilize a cross-sectional telephone survey conducted in a random sample of older adults from the eight neighborhoods and combine this information with street audits of the corresponding neighborhoods. The study was approved by the Simon Fraser University Ethics review committee (Number 38156).

Study Population

A detailed description of the study is published elsewhere (25). In short: 434 older adults completed the telephone survey, among whom 393 reported being physically active in their neighborhood or outdoor places. Eligibility criteria for participants were: (a) at least 60 years of age at the time of the survey, (b) living in one of the selected neighborhoods, and (c) being able to understand English. These older adults resided across eight neighborhoods: Mount Tabor, OR ($n = 56$), Clackamas, OR ($n = 50$), Lake Oswego, OR ($n = 61$), Milwaukie, OR ($n = 64$), Vancouver, BC ($n = 53$), Burnaby, BC ($n = 51$), South Surrey, BC ($n = 50$) and Maple Ridge, BC ($n = 49$).

MEASURES

Walking

Recreational walking and walking for transport was operationalized in two ways in the following analyses: (1) as a dichotomous outcome (currently physically active or not), and (2) time spent per day for a specific activity was operationalized as a continuous measure. To assesses whether or not participants were physically active, we asked if the participants engaged in a list of physical activities (i.e., gardening, housework, walking for transport, walking for recreation, etc.) in the previous 4 weeks (yes/no). In a second question, the participants provided information on the type and the frequency of up to three most common physical activity (or activities) they have engaged every week (metric score). The frequency and duration were multiplied and divided by seven days to calculate the average daily walking activity (in minutes/day). The following analyses only applied walking for recreation (e.g., walk in the park) and walking for transport (e.g., walking to a bank or grocery store). Extreme outliers (>4 SD) were identified and set to the value of the 4th standard deviation ($n_{\text{recreation}} = 2$; $n_{\text{transport}} = 4$). Given the absence of an objective, or a gold standard measure of walking, we evaluated both walking measures (i.e., metric walking measure in minutes per day and dichotomous walking measure in yes/no) in our analyses to compare them and evaluate the robustness of the results based on differently operationalized walking activities.

Seniors Walking Environment Assessment Tool-Revised (SWEAT-R)

The SWEAT-R was developed as a tool to collect data on the physical environment to understand its association with physical activity. It is organized into four domains, which are (a) functionality, (b) safety, (c) aesthetics, and (d) destinations, and has been shown a valid tool with high inter-rater reliability (23, 24). In the current study, SWEAT-R data were collected along with a sample of street segments (defined as the street section between two intersections) in each neighborhood, excluding highways. Correlates of walking, such as street connectivity and land-use, were addressed by including low and high residential density neighborhoods in this study. These segments in the eight neighborhoods were randomly selected, with a range from 16 to a maximum of 58 audited segments per neighborhood. In total, 158 segments were observed across the four Portland metropolitan neighborhoods, and 197 segments were audited across the four Vancouver metropolitan neighborhoods.

Four research assistants (two per region) received training before data collection. Training led by research investigators encompassed both classroom and field components. Training manuals with detailed explanations for each item in SWEAT-R were provided, and the second observation form was discussed in detail. For each street segment, the research assistant collected data on 168 environmental characteristics. If items were present in fewer than 2 percent of all segments, they were deleted from subsequent analyses ($n = 63$). Factor scores were calculated for each of the four dimensions based on the remaining items and resulted in 35 factors. Five factors were excluded from the following analyses as they did not vary significantly across the eight districts. To identify the most relevant factors, we calculated correlation analyses with Bonferroni-adjusted significance levels between walking and the SWEAT-R extracted factors and accepted factors that reached a significance level of $p < 0.001$. Finally, 10 factors remained significant in the correlation analyses, of which four reached significance in the multi-level models.

Covariates

Background characteristics included sex, age, self-rated health, the average of the maximum temperature in the last 4 weeks (in degrees Celsius), duration of residency (in years), and country of residence were considered as potential confounders that have been used in previous studies (12, 13, 26). Self-rated health was measured with one item from the 12-item Short-Form Health Survey: "In general would you say your health is" including poor, fair, good, very good, and excellent (27). The duration of residence was assessed by asking, "How many years have you lived in your current neighborhood?" Moving within the neighborhood counted to the total years. Local weather stations provided average values for temperature in degrees Celsius (°C) for each of the 28 days before the completion of the physical activity questionnaire. For each participant, the average temperature was calculated. Additionally, sex and age (in years) were assessed.

Statistical Analysis

Data were analyzed using STATA 15.0 (StataCorp L.P., College Station, TX). Baseline demographic and health characteristics are presented stratified by country and the density of neighborhoods. Differences in mean were tested using a one-way analysis of variance (ANOVA), and frequencies were tested using the Pearson Chi-square Test. First, a linear regression was conducted to compare the effect of the neighborhood density and the location (the USA vs. Canada) and test for an interaction between country and population density. Second, using the Intraclass Correlation Coefficient (ICC) (variance due to neighborhood/total variance), the neighborhood accounted for 13% of the time spent walking for transport and 6% for recreational walking. That justified using a mixed modeling approach to analyze walking for transport, including neighborhood as a random effect (Vajargah and Nikbakht, 2015). Generalized linear mixed models with gamma log link transformation (with the value of one added to all scores to eliminate zeros) and multi-level logistic regression models were used to study associations between the neighborhood characteristics and walking activity. Each environmental attribute (based on the street audits) was analyzed in a separate model. All models were adjusted for age and sex, self-reported health, mean maximum temperature over the last 4 weeks, and the duration of residency in the neighborhood. Likert-type variables with <5% item non-response were imputed using mean values from valid records.

RESULTS

The characteristics of the study sample are presented stratified by density and country in **Table 1**. Respondents ($N = 434$) were, on average 71.6 ($SD = 8.1$) years old, mostly female (64.7%), highly educated (44.0%), and had an average total annual household income of $47,300 ($SD = 22{,}300$). Overall, the participants walked more often for recreation than for transport (74.2 vs. 49.3%) in the previous 4 weeks, which is reflected by an average of 5.4 min per day ($SD = 12.2$) for transport and 13.4 min per day ($SD = 16.5$) for recreational purposes. Comparing districts in Metro Portland and Metro Vancouver with high density and low density, significant differences were found for education attainment, mean temperature, duration of residency in the neighborhood and both walking measures. *Post-hoc*-tests revealed that older adults walked significantly longer for recreation when comparing low-density neighborhoods between Metro Vancouver and Metro Portland ($M = 20.0$ vs. $M = 7.6$; $p < 0.001$). Walking for transport was significantly higher in

TABLE 1 | Sample characteristics of respondents, neighborhood and physical activity study ($n = 434$), Vancouver, British Columbia, Canada and Portland, Oregon, United States of America.

	Overall		**Vancouver**				**Portland**					
			High density ($n = 104$)		**Low density ($n = 99$)**		**High density ($n = 120$)**		**Low density ($n = 111$)**		**χ^2/F**	***p*-value**
Age (years), M (SD)	71.6	(8.1)	72.0	(7.9)	71.1	(7.7)	70.8	(8.3)	72.4	(8.3)	1.0	0.387
Female, (%)		64.7	66.3		56.6		64.2		71.2		5.4	0.147
Married, (%)		52.3	47.1		63.6		52.5		46.7		7.5	0.056
Education, (%)												
High school or less		24.2	23.1		34.3		18.3		22.5			
Some post-secondary		31.8	22.1		30.3		37.5		36.0			
Completed college/university		44.0	54.8		35.4		44.2		41.5		15.7	0.015
Total annual household income (thousand $), M (SD)	47.3	(22.3)	46.7	(21.6)	49.4	(22.5)	51.2	(21.6)	43.0	(22.9)	2.2	0.084
Duration of residence (years), M (SD)	21.9	(15.4)	19.3	(12.6)	16.4	(12.8)	26.2	(16.1)	24.7	(17.2)	10.2	<0.001
Walking for transport, (%)		49.3	78.8		59.6		39.2		23.4		75.2	<0.001
Walking for recreation, (%)		74.2	77.9		77.8		75.0		66.7		4.7	0.193
Walking for transport[a] (minutes/day), M (SD)	5.4	(12.2)	12.8	(18.0)	6.2	(11.9)	2.2	(7.0)	1.2	(4.7)	23.0	<0.001
Walking for recreation (minutes/day)[b], M (SD)	13.4	(16.5)	15.6	(17.7)	20.0	(20.4)	11.3	(13.6)	7.6	(10.9)	12.1	<0.001
Mean temperature (°C), M (SD)	10.0	(3.0)	10.0	(4.3)	10.3	(2.6)	9.3	(1.2)	10.4	(3.0)	3.3	0.021
Self-rated health[c], M (SD)	3.7	(1.0)	3.6	(0.9)	3.8	(1.0)	3.8	(1.0)	3.8	(1.0)	1.2	0.314

[a] *Ranges from 0 to 63.4.*
[b] *Ranges from 0 to 81.7.*
[c] *Possible range from 1 to 5, higher values indicate better health.*

the high-density neighborhoods of metro Vancouver compared to high-density neighborhoods in Portland ($M = 12.8$ vs. $M = 2.2$; $p < 0.001$).

Figure 1 illustrates these variations in walking for transport across the eight neighborhoods of our study. Walking for transport ranged from 0.6 min per day in Lake Oswego to 15.1 min in the Vancouver neighborhood. It showed that Canadians walked more often for transport (Maple Ridge, Burnaby, South Surrey, and Vancouver neighborhood). Older adults also walked more for transport in high-density neighborhoods (Milwaukie, Burnaby, Mount Tabor, and Vancouver neighborhood) across the two metro areas. Accordingly, the linear regression showed that older adults in Metro Vancouver walked on average 10.1 more min per day for transport compared to those in Metro Portland (**Table 2**). Overall, there was also more walking for transport in high-density neighborhoods compared to the low-density neighborhood. The interaction between density and country reached significance ($p = 0.008$), which means that older adults walked most for transport in high-density Canadian neighborhoods.

Descriptive Results From SWEAT-R Observations in Districts With a High Population Density

Descriptive audit data revealed an additional source of information about the variations between the high-density districts in Metro Vancouver (Burnaby, Vancouver) and Metro Portland (Milwaukie, Mount Tabor). Descriptive results summarized in **Table 3** are based on a subset of SWEAT-R items that exhibited the highest degree of difference in observer responses. Each item score denotes the percentage of segments on which it was observed within a given neighborhood and the significance of percentage differences.

The building types differed between the two Metro Vancouver and the two Metro Portland neighborhoods with high population density: In Portland, single-family detached houses are more prevalent, while in Vancouver, multi-family housing is far more common. The SWEAT-R documented that commercial destinations like grocery stores, barber shops, health clinics, and pharmacies were rare in high-density Metro Portland neighborhoods with only 0.0–3.6% of the audited streets having these destinations. In comparison, these destinations

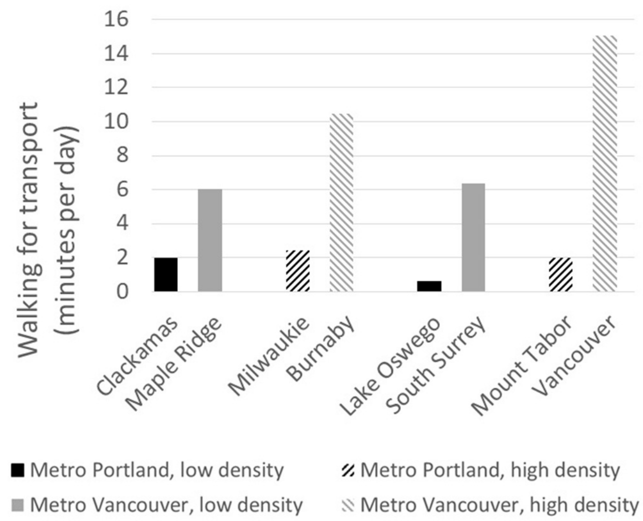


FIGURE 1 | Mean walking for transport time in eight neighborhoods.

TABLE 2 | Country of residence, population density, and walking activity ($n = 393$).

	Walking for transport		Recreational walking	
	B	***p*-value**	***B***	***p*-value**
Main effects				
USA (Ref. Canada)	−10.1	<0.001	−5.6	0.065
Low-dense district (Ref. High-dense)	−7.0	<0.001	4.1	0.065
Interactions effect				
Low-dense* USA	5.9	0.008	−7.1	0.020

*Adjusted for age, sex, self-rated health, average maximum temperature, duration of residency. *stands for the interaction terms which is the multiplication of both variables.*

were more often present in each of the Metro Vancouver neighborhoods (1.8–17.9%).

Differences in sidewalk availability were observed between the high-density neighborhoods of Metro Vancouver and Metro Portland. A higher proportion of segments with sidewalks, as well as continuous sidewalks on both sides of the street, were more often present in Vancouver neighborhoods compared to Portland neighborhoods. Parks and outdoor fitness venues were more present in the Vancouver neighborhoods in comparison to the neighborhoods in Portland. Parks were more often present in the Vancouver low-income district (Burnaby) when comparing it with the Portland low-income district (Milwaukie) (15.6 vs. 0.0; $p = 0.028$), and outdoor recreational areas were also found to be three times more often present in the Vancouver neighborhoods. Street conditions that either slowed down the car traffic (e.g., bumps or grooves) or enabled pedestrians to cross the street safely (e.g., indented crossing areas) were significantly more prevalent in Vancouver neighborhoods, with these conditions most common in Burnaby.

Associations of Audited Environmental Attributes With Walking Activity

In the last step, multi-level models were applied to identify the association between built environmental characteristics (based on the audits) and walking for transport (based on the survey). The multi-level models identified four significant environmental factors (**Table 4**): Building types, the presence of public spaces (i.e., parks and outdoor fitness), brick sidewalks, and safety (i.e., pedestrian crossings) were significantly (all $p \leq 0.050$) positively associated with walking for transport in the linear mixed-model. Applying a multi-level logistic regression model, two built neighborhood characteristics remained significant: building types (OR = 1.81; $p = 0.034$) and street crossing areas for pedestrians (OR = 5.15; $p = 0.001$). The results were consistent with a dominance analysis (28) identifying the safety from traffic aspects (street crossing, traffic calming, the safety of intersection) as the essential aspects for walking for transport and neighborhood density and the presence of undeveloped land as the least relevant (**Supplementary Material**). None of the environmental attributes was significantly associated with walking for recreation.

DISCUSSION

The study is unique as it compares equivalent neighborhoods with comparable socioeconomic composition and population density in an international context. The study revealed that time spent walking for transport in the two North American metropolitan areas is highly variable as older adults walked more for transport in high-density districts in Metro Vancouver compared to individuals in high-density districts in Metro Portland. Population density served as one important prerequisite but did not necessarily lead to walking for transport. The interplay of high-density neighborhoods with safe street crossings and nearby nature might motivate older adults to choose walking for transport.

In line with the existing literature, strong evidence was found for residential density and parks and walking for transport within the neighborhood (29). Outdoor recreational facilities that are easy to access and located within walking distance from home have been found to promote physical activity of community-dwelling older adults (30). The finding for residential density is especially relevant, given current policy decisions in U.S. cities to increase density to address the shortage of housing (31). Given research supporting the importance of increased density for higher levels of physical activity across the lifespan, these policies are also consistent with improving health behaviors. The positive association between safety from traffic and walking for transport is consistent with an earlier meta-analysis and several studies (15, 32, 33). That points to the need to advocate for policy and regulatory actions aimed at improving pedestrian safety.

A recent review revealed no environmental characteristics associated with walking regardless of the walking type (e.g., total, for transport, for recreation) among older adults (11). Our study did not find any significant associations

TABLE 3 | Characteristics of street segments in high-density neighborhoods (n = 187 segments), Vancouver, British Columbia, Canada and Portland, Oregon, United States of America.

Units (% of segments)	Burnaby (CA) (n = 56)	Milwaukie (USA) (n = 58)	χ^2	p-value	Vancouver (CA) (n = 45)	Monut Tabor (USA) (n = 28)	χ^2	p-value
Functionality								
Building types								
Single-family homes (detached)	42.2	96.4	21.8	<0.001	21.4	96.6	66.8	<0.001
Low-rise multi-family housing (<5 stories)	37.8	14.3	4.6	0.031	30.4	5.2	12.5	0.001
High-rise multi-family housing (5 or more stories)	37.8	3.6	10.9	0.001	16.1	0.0	10.1	0.001
Grocery store	11.1	0.0	3.3	0.068	5.4	1.7	1.1	0.292
Pharmacy/drug store	6.7	0.0	1.9	0.163	1.8	0.0	1.0	0.307
Health clinics, medical facilities	13.3	3.6	1.9	0.168	3.6	1.7	0.4	0.538
Beauty/barber shop	6.7	0.0	1.9	0.163	5.4	0.0	3.2	0.074
Service facilities (e.g., insurance offices, dry cleaners)	13.3	0.0	4.1	0.044	17.9	0.0	11.4	0.001
Sidewalks								
Presence of sidewalks	93.3	14.3	46.3	<0.001	100.0	89.7	6.1	0.013
Continuous sidewalks on both sides (if present)	71.1	0.0	35.5	<0.001	58.9	56.9	0.0	0.826
Public spaces								
Park/playground	15.6	0.0	4.8	0.028	17.9	10.3	1.3	0.248
Outdoor fitness/recreation area	33.3	7.1	6.6	0.010	35.7	10.3	10.4	0.001
Safety and Comfort								
Crossing area with ramps or curb cuts	91.1	25.0	33.5	<0.001	73.2	34.5	17.2	<0.001
Grooves or bumps	75.6	21.4	20.4	<0.001	58.9	10.3	29.9	<0.001
Intended crossing area for pedestrians	11.1	7.1	0.3	0.576	8.9	3.5	1.5	0.223
Signs for pedestrians/children/etc.	37.8	10.7	6.4	0.012	28.6	1.7	16.2	<0.001
Signs for school speed zone	8.9	3.6	0.8	0.382	4.4	3.5	0.1	0.813

N refers to the number of audited street segments in each neighborhood.

between neighborhood characteristics and walking for recreation. This is in line with previous research that neighborhood characteristics served as more critical predictors for walking for transport rather than recreational walking among older adults (11, 34, 35) and among the entire population (36). The weak association might reflect that walking for recreation often takes place outside the immediate neighborhood as living in less-walkable neighborhoods might make persons seek more desirable places outside their own neighborhood (37).

No relationship was found between the population income and walking for transport or recreational walking when comparing low and high-income districts. This in accordance with previous research that identified differences between low and high-income districts when it came to moderate-to-vigorous physical activity but found no effect on walking (38).

We found a weak association between sidewalk characteristics and walking. We had expected the pedestrian infrastructure-specifically sidewalks-to be an essential neighborhood feature because it was one out of five attributes in a review of qualitative studies related to physical activity in older adults (39). In the IPEN study, which comprises of a younger population, the presence of sidewalk was one of the most consistent associations with moderate-to-vigorous physical activity (21). In contrast, no association was observed between walking in older adults and the percentage of sidewalks in a randomized controlled trial in Portland (40). While sidewalks were rarely present in Portland, they were more often available in Vancouver, which, however, did not translate to more time spending for walking for transport.

In contrast to prior research, we did not find that older adults who live within walking distance of shopping areas and public transit were more physically active than individuals who lived further away (29, 41–43). Nearby destinations did not reach significance even though commercial destinations and shops were more frequent in the Canadian neighborhoods in comparison to the American neighborhoods. Comparing similar neighborhoods that are equivalent in terms of population density and income might have leveled-out differences in nearby destinations.

We observed different walking for transport patterns in our study, although the metropolitan areas of Vancouver and Portland are located in the same geographic region (Pacific Northwest of North America) with comparable cultural backgrounds and similar demographic characteristics (in terms of age, sex, health status, and physical limitations) and the same population density and income. Among other factors such as attitude to physical activity, built environmental differences might have resulted in diverse opportunity structures for walking in the neighborhood and made Canadians became even more

TABLE 4 | Association of environmental attributes with walking for transport, neighborhood and physical activity study ($n = 434$), Vancouver, British Columbia, Canada and Portland, Oregon, United States of America.

Environmental attribute	Walking for transport					
	Linear model[a]			Logit model		
	B	(95% CI)	p-value	OR	(95% CI)	p-value
Buildings						
Mixed-use houses	−1.44	(−3.95, 1.08)	0.263	0.05	(0.00, 1.15)	0.061
Buildings types[b]	0.42	(0.03, 0.81)	0.037	1.81	(1.05, 3.13)	0.034
Undeveloped land	−0.66	(−1.26, −0.06)	0.031	0.50	(0.19, 1.30)	0.154
Sidewalks						
Brick sidewalks	0.54	(0.15, 0.93)	0.006	1.92	(0.95, 3.87)	0.068
Public spaces						
Benches	0.76	(−0.13, 1.64)	0.093	2.37	(0.64, 8.82)	0.198
Green open space[c]	0.88	(0.13, 1.63)	0.022	3.01	(0.97, 9.35)	0.057
Safety from traffic						
Intersection[d]	0.48	(−0.04, 1.0)	0.069	1.66	(0.75, 3.67)	0.212
Street crossing[e]	0.91	(0.06, 1.76)	0.037	5.15	(2.02, 13.15)	0.001
Traffic-calming[f]	0.93	(−0.17, 2.02)	0.098	3.14	(0.58, 16.92)	0.183

OR, odds ratio; B, unstandardized coefficient; [a]Multilevel linear mixed model with gamma log transformation; [b]Few single family house, low rise multi-family house, high-rise multi-family house [c]parks, outdoor fitness [d]ramps or curb cuts [e]Intended crossing area for pedestrians, signs for pedestrians, signs for school speed zone; [f]sidewalk extension, median strip; All models were adjusted for respondents' age, sex, self-rated health, duration of residency, country of residence, and mean maximum temperature.

physically active in 2005 compared to 1994 (44). In contrast, walking declined significantly in the United States among persons 65 and older while walking increased slightly in the general population (45).

This study has a few notable strengths in advancing our understanding of neighborhood influences on walking in older adults. Using data from two cities and eight neighborhoods matched for mean household income and population density, this study aimed to contribute to the understanding of how specific neighborhood environmental features are related to everyday walking levels. Single country and country-adjusted analyses cannot provide information on differences in country-level environments walking associations if population and neighborhood characteristics vary. Consequently, this study was also able to estimate the extent to which between-site differences explain differences in walking for transport patterns. The use of an environmental audit performed by two raters in several randomly chosen segments in each district made the study unique and less dependent on the participants' perception of the built environment. Studies have shown that physically active persons also tend to report more activity-friendly features and perceive their neighborhood to be more favorable in terms of physical activity supporting characteristics (46).

Although the study addresses a series of methodological issues, there are a few limitations. First, cross-sectional data limit the causal inferences about the neighborhood environment and walking behavior. Second, the study was conducted in a specific geographic region of North America, which might restrict the comparability to the two countries at large and other world regions. Another limitation was that the physical activity questionnaire only assessed up to the three most common activities, which might have led to an underestimate of activities. To address this issue, we presented results twofold: (1) as a metric measure based on the three most common physical activities using linear regression, and (2) as a dichotomous measure based on a different survey question using logistic regression. We demonstrated that the results were stable. Furthermore, we did not adjust for additional relevant confounding variables such as car ownership, race/ ethnicity, and residential self-selection. Last, walking measure was based on self-reports, which overestimate activity compared to objective measures and might be biased by other individual characteristics like cognitive function (47). However, these biases should work in each neighborhood in the same way and are less likely to affect the association between the built environment and walking behavior.

CONCLUSIONS

Supporting walking in older adults is critical to the development of healthy cities. Public policies on urban infrastructure development shape individual transportation choices by setting the conditions of personal cost, benefits, and opportunities. A safe and pedestrian-friendly neighborhood might positively influence walking for transport behavior. This research indicates that it is essential to consider a combination of physical planning characteristics to foster everyday walking behavior in older adults effectively. There is a need for policy and regulatory actions that consider increasing housing density and other contributing factors, such as appropriately designed street crossing, the presence of parks, etc. Future research can further examine, among other topics, countries, and jurisdictions that have notably different city planning and urban design contexts and associated potential variability in walking behaviors in older adults.

DATA AVAILABILITY STATEMENT

We usually do not state this about the data because of the university ethics consideration. We prefer "Sharing of raw data would be contingent on approval from the university research ethics office."

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Simon Fraser University Office of Research

Ethics. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

HC, AM, and YM contributed to the conception and design of the study. HC and FH organized the database. FH performed the statistical analysis and wrote the first draft of the manuscript. FH, AM, HC, and YM wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

FUNDING

This study was funded by the Canadian Institutes of Health Research (CIHR); Florian Herbolsheimer was funded by the German Research Foundation—No.:398948032.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.564533/full#supplementary-material

REFERENCES

1. Hamer M, Lavoie KL, Bacon SL. Taking up physical activity in later life and healthy ageing: the english longitudinal study of ageing. *Br J Sports Med.* (2014) 48:239–43. doi: 10.1136/bjsports-2013-092993
2. Strath S, Swartz A, Parker S, Miller N, Cieslik L. Walking and metabolic syndrome in older adults. *J Phys Activ Health*. (2007) 4:398–411. doi: 10.1123/jpah.4.4.398
3. Armstrong GK, Morgan K. Stability and change in levels of habitual physical activity in later life. *Age Ageing*. (1998) 27(Suppl. 3):17–23. doi: 10.1093/ageing/27.suppl_3.17
4. Cunningham GO, Michael YL. Concepts guiding the study of the impact of the built environment on physical activity for older adults: a review of the literature. *Am J Health Promot*. (2004) 18:435–43. doi: 10.4278/0890-1171-18.6.435
5. Eyler AA, Brownson RC, Bacak SJ, Housemann RA. The epidemiology of walking for physical activity in the United States. *Med Sci Sports Exerc*. (2003) 35:1529–36. doi: 10.1249/01.MSS.0000084622.39122.0C
6. Ding D. Ecological models: application to physical activity. In: Gellman MD, Turner JR, editors. *Encyclopedia of Behavioral Medicine*. (2013) New York, NY: Springer. p. 645–7.
7. Sallis JF, Owen N, Fisher EB. Ecological models of health behavior. In: Glanz K, Rimer BK, Viswanath K, editors. *Health Behavior and Health Education: Theory, Research, and Practice*. Jossey-Bass (2008). p. 465–485.
8. Lawton MP. *Environment and Aging*. 2nd ed. Albany, NY: Center for the Study of Aging (1986).
9. Troped PJ, Starnes HA, Puett RC, Tamura K, Cromley EK, James P, et al. Relationships between the built environment and walking and weight status among older women in three U.S. States. *J Aging Phys Act*. (2014) 22:114–25. doi: 10.1123/japa.2012-0137
10. Barnett DW, Barnett A, Nathan A, Van Cauwenberg J, Cerin E. Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act*. (2017) 14:103. doi: 10.1186/s12966-017-0558-z
11. Yun HY. Environmental factors associated with older adult's walking behaviors: a systematic review of quantitative studies. *Sustainability*. (2019) 11:3253. doi: 10.3390/su11123253
12. Inoue S, Ohya Y, Odagiri Y, Takamiya T, Kamada M, Okada S, et al. Perceived neighborhood environment and walking for specific purposes among elderly Japanese. *J Epidemiol*. (2011) 21:481–90. doi: 10.2188/jea.JE20110044
13. Liao Y, Huang P-H, Hsiang C-Y, Huang J-H, Hsueh M-C, Park J-H. Associations of older Taiwanese adults' personal attributes and perceptions of the neighborhood environment concerning walking for recreation and transportation. *Int J Environ Res Public Health*. (2017) 14:1594. doi: 10.3390/ijerph14121594
14. Cerin E, Lee K, Barnett A, Sit CH, Cheung M, Chan W, et al. Walking for transportation in Hong Kong Chinese urban elders: a cross-sectional study on what destinations matter and when. *Int J Behav Nutr Phys Act*. (2013) 10:78. doi: 10.1186/1479-5868-10-78
15. Ding D, Sallis JF, Norman GJ, Frank LD, Saelens B, Kerr J, et al. Neighborhood environment and physical activity among older adults: do the relationships differ by driving status? *J Aging Phys Act*. (2014) 22:421–31. doi: 10.1123/JAPA.2012-0332
16. Van Cauwenberg J, Clarys P, De Bourdeaudhuij I, Van Holle V, Verté D, De Witte N, et al. Physical environmental factors related to walking and cycling in older adults: the Belgian aging studies. *BMC Public Health*. (2012) 12:142. doi: 10.1186/1471-2458-12-142
17. Nyunt MSZ, Shuvo FK, Eng JY, Yap KB, Scherer S, Hee LM, et al. Objective and subjective measures of neighborhood environment (NE): relationships with transportation physical activity among older persons. *Int J Behav Nutr Phys Act*. (2015) 12:108. doi: 10.1186/s12966-015-0276-3
18. Shigematsu R, Sallis JF, Conway TL, Saelens BE, Frank LD, Cain KL, et al. Age differences in the relation of perceived neighborhood environment to walking. *Med Sci Sports Exerc*. (2009) 41:314–21. doi: 10.1249/MSS.0b013e318185496c
19. Cerin E, Macfarlane D, Sit CHP, Ho SY, Johnston JM, Chou KL, et al. Effects of built environment on walking among Hong Kong older adults. *Hong Kong Med J*. (2013) 19(Suppl. 4):39–41.
20. Weber Corseiul Giehl M, Hallal PC, Weber Corseuil C, Schneider IJ, d'Orsi E. Built environment and walking behavior among Brazilian older adults: a population-based study. *J Phys Act Health*. (2016) 13:617–24. doi: 10.1123/jpah.2015-0355
21. Ding D, Adams MA, Sallis JF, Norman GJ, Hovell MF, Chambers CD, et al. Perceived neighborhood environment and physical activity in 11 countries: do associations differ by country? *Int J Behav Nutr Phys Act*. (2013) 10:UNSP 57. doi: 10.1186/1479-5868-10-57
22. Mahmood A, Chaudhury H, Michael YL, Campo M, Hay K, Sarte A. A photovoice documentation of the role of neighborhood physical and social environments in older adults' physical activity in two metropolitan areas in North America. *Soc Sci Med*. (2012) 74:1180–92. doi: 10.1016/j.socscimed.2011.12.039
23. Chaudhury H, Sarte AFI, Michael YL, Mahmood A, Keast EM, Dogaru C, et al. Use of a systematic observational measure to assess and compare walkability for older adults in Vancouver, British Columbia and Portland, Oregon Neighbourhoods. *J Urban Des*. (2011) 16:433–54. doi: 10.1080/13574809.2011.585847
24. Michael YL, Keast EM, Chaudhury H, Day K, Mahmood A, Sarte AFI. Revising the senior walking environmental assessment tool. *Prev Med*. (2009) 48:247–9. doi: 10.1016/j.ypmed.2008.12.008
25. Chaudhury H, Campo M, Michael Y, Mahmood A. Neighbourhood environment and physical activity in older adults. *Soc Sci Med*. (2016) 149:104–13. doi: 10.1016/j.socscimed.2015.12.011
26. Sugiyama T, Ward Thompson C. Associations between characteristics of neighbourhood open space and older people's walking. *Urban For Urban Green.* (2008) 7:41–51. doi: 10.1016/j.ufug.2007.12.002
27. Ware JE, Kosinski M, Keller SD. A 12-item short-form health survey—construction of scales and preliminary tests of reliability and validity. *Med Care*. (1996) 34:220–33. doi: 10.1097/00005650-199603000-00003
28. Luo W, Azen R. Determining predictor importance in hierarchical linear models using dominance analysis. *J Educ Behav Stat*. (2013) 38:3–31. doi: 10.3102/1076998612458319
29. Cerin E, Nathan A, van Cauwenberg J, Barnett DW, Barnett A. The neighbourhood physical environment and active travel in older adults: a

systematic review and meta-analysis. *Int J Behav Nutr Phys Act*. (2017) 14:15. doi: 10.1186/s12966-017-0471-5

30. Eronen J, von Bonsdorff M, Rantakokko M, Rantanen T. Environmental facilitators for outdoor walking and development of walking difficulty in community-dwelling older adults. *Eur J Ageing*. (2014) 11:67–75. doi: 10.1007/s10433-013-0283-7
31. Mervosh S. *Minneapolis, Tackling Housing Crisis and Inequity, Votes to End Single-Family Zoning*. (2018). Available online at: www.nytimes.com/2018/12/13/us/minneapolis-single-family-zoning.html (accessed October 10, 2019).
32. Duncan MJ, Spence JC, Mummery WK. Perceived environment and physical activity: a meta-analysis of selected environmental characteristics. *Int J Behav Nutr Phys Act*. (2005) 2:11. doi: 10.1186/1479-5868-2-11
33. Gómez LF, Parra DC, Buchner D, Brownson RC, Sarmiento OL, Pinzón JD, et al. Built environment attributes and walking patterns among the elderly population in Bogotá. *Am J Prev Med*. (2010) 38:592–9. doi: 10.1016/j.amepre.2010.02.005
34. Forsyth A, Hearst M, Oakes JM, Schmitz KH. Design and destinations: factors influencing walking and total physical activity. *Urban Stud*. (2008) 45:1973–96. doi: 10.1177/0042098008093386
35. Procter-Gray E, Leveille SG, Hannan MT, Cheng J, Kane K, Li W. Variations in community prevalence and determinants of recreational and utilitarian walking in older age. *J Aging Res*. (2015) 382703: doi: 10.1155/2015/382703
36. Saelens BE, Handy SL. Built environment correlates of walking: a review. *Med Sci Sports Exerc*. (2008) 40:S550–66. doi: 10.1249/MSS.0b013e31817c67a4
37. Cerin E, Sit CHP, Barnett A, Cheung M, Chan W. Walking for recreation and perceptions of the neighborhood environment in older Chinese urban dwellers. *J Urban Health*. (2013) 90:56–66. doi: 10.1007/s11524-012-9704-8
38. Van Holle V, Van Cauwenberg J, Van Dyck D, Deforche B, Van de Weghe N, De Bourdeaudhuij I. Relationship between neighborhood walkability and older adults' physical activity: results from the Belgian environmental physical activity study in seniors (BEPAS Seniors). *Int J Behav Nutr Phys Act*. (2014) 11:110. doi: 10.1186/s12966-014-0110-3
39. Moran M, Van Cauwenberg J, Hercky-Linnewiel R, Cerin E, Deforche B, Plaut P. Understanding the relationships between the physical environment and physical activity in older adults: a systematic review of qualitative studies. *Int J Behav Nutr Phys Act*. (2014) 11:79: doi: 10.1186/1479-5868-11-79
40. Nagel CL, Carlson NE, Bosworth M, Michael YL. The relation between neighborhood built environment and walking activity among older adults. *Am J Epidemiol*. (2008) 168:461–8. doi: 10.1093/aje/kwn158
41. Farkas B, Wagner DJ, Nettel-Aguirre A, Friedenreich C, McCormack GR. A systematized literature review on the associations between neighbourhood built characteristics and walking among Canadian adults. *Health Promot Chronic Dis Prev Can*. (2019) 39:1–14. doi: 10.24095/hpcdp.39.1.01
42. Lin L, Moudon AV. Objective vs. subjective measures of the built environment, which are most effective in capturing associations with walking? *Health Place*. (2010) 16:339–48. doi: 10.1016/j.healthplace.2009.11.002
43. Winters M, Voss C, Ashe MC, Gutteridge K, McKay H, Sims-Gould J. Where do they go and how do they get there? Older adults' travel behaviour in a highly walkable environment. *Soc Sci Med*. (2015) 133:304–12. doi: 10.1016/j.socscimed.2014.07.006
44. Juneau C-E, Potvin L. Trends in leisure-, transport-, and work-related physical activity in Canada 1994-2005. *Prev Med*. (2010) 51:384–6. doi: 10.1016/j.ypmed.2010.09.002
45. Pucher J, Buehler R, Merom D, Bauman A. Walking and cycling in the United States, 2001-2009: evidence from the National Household Travel Surveys. *Am J Public Health*. (2011) 101(Suppl. 1):S310–7. doi: 10.2105/AJPH.2010.300067
46. Wallmann-Sperlich B, Froboese I, Schantz P. Physical activity and the perceived neighbourhood environment—looking at the association the other way around. *Int J Environ Res Public Health*. (2014) 11:8093–111. doi: 10.3390/ijerph110808093
47. Herbolsheimer F, Riepe MW, Peter R. Cognitive function and the agreement between self-reported and accelerometer-accessed physical activity. *BMC Geriatr*. (2018) 18:56. doi: 10.1186/s12877-018-0747-x

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 01 February 2021
doi: 10.3389/fpubh.2021.611895

Neighborhood Walkability as a Predictor of Incident Hypertension in a National Cohort Study

Alana C. Jones[1], Ninad S. Chaudhary[1], Amit Patki[2], Virginia J. Howard[1], George Howard[2], Natalie Colabianchi[3,4], Suzanne E. Judd[2†] and Marguerite R. Irvin[1†]*

[1] Department of Epidemiology, University of Alabama at Birmingham, Birmingham, AL, United States, [2] Department of Biostatistics, University of Alabama at Birmingham, Birmingham, AL, United States, [3] School of Kinesiology, University of Michigan, Ann Arbor, MI, United States, [4] Department of Biostatistics, School of Public Health (M.R.E.), University of Michigan, Ann Arbor, MI, United States

OPEN ACCESS

Edited by:
Xuemei Zhu,
Texas A&M University, United States

Reviewed by:
Clas-Håkan Anders Nygård,
Tampere University, Finland
Patricia M. Alt,
Towson University, United States

***Correspondence:**
Marguerite R. Irvin
irvinr@uab.edu

† These authors have contributed equally to this work and share last authorship

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: 29 September 2020
Accepted: 04 January 2021
Published: 01 February 2021

Citation:
Jones AC, Chaudhary NS, Patki A, Howard VJ, Howard G, Colabianchi N, Judd SE and Irvin MR (2021) Neighborhood Walkability as a Predictor of Incident Hypertension in a National Cohort Study. Front. Public Health 9:611895. doi: 10.3389/fpubh.2021.611895

The built environment (BE) has been associated with health outcomes in prior studies. Few have investigated the association between neighborhood walkability, a component of BE, and hypertension. We examined the association between neighborhood walkability and incident hypertension in the REasons for Geographic and Racial Differences in Stroke (REGARDS) Study. Walkability was measured using Street Smart Walk Score based on participants' residential information at baseline (collected between 2003 and 2007) and was dichotomized as more (score ≥70) and less (score <70) walkable. The primary outcome was incident hypertension defined at the second visit (collected between 2013 and 2017). We derived risk ratios (RR) using modified Poisson regression adjusting for age, race, sex, geographic region, income, alcohol use, smoking, exercise, BMI, dyslipidemia, diabetes, and baseline blood pressure (BP). We further stratified by race, age, and geographic region. Among 6,894 participants, 6.8% lived in more walkable areas and 38% (N = 2,515) had incident hypertension. In adjusted analysis, neighborhood walkability (Walk Score ≥70) was associated with a lower risk of incident hypertension (RR [95%CI]: 0.85[0.74, 0.98], P = 0.02), with similar but non-significant trends in race and age strata. In secondary analyses, living in a more walkable neighborhood was protective against being hypertensive at both study visits (OR [95%CI]: 0.70[0.59, 0.84], P < 0.001). Neighborhood walkability was associated with incident hypertension in the REGARDS cohort, with the relationship consistent across race groups. The results of this study suggest increased neighborhood walkability may be protective for high blood pressure in black and white adults from the general US population.

Keywords: walkability, built environment, hypertension, REGARDS, older adults, neighborhood walkability, neighborhood

INTRODUCTION

A primary risk factor for cardiovascular diseases (CVD), hypertension affects ∼1 in three adults in the US (∼75 million) (1). Regular physical activity (PA, ≥150 min per week) is associated with reduced risk of hypertension and is widely recommended for CVD prevention and all-cause mortality (2–4). Given the strong association between PA and health outcomes, there has been recent interest in how one's immediate surroundings (built environment (BE)) affect individual physical activity level. Neighborhood walkability, a measure of walking friendliness and important component of the BE, has been associated with PA and cardiometabolic risk factors in previous cohort studies (5–9). Particularly, there is a burgeoning interest in understanding the impact of neighborhood walkability on blood pressure and hypertension (10–14). Yet studies of walkability and hypertension in US populations are lacking, even though this association may differ by national and regional context. Moreover, in a cross-sectional analysis of neighborhood characteristics (including walkability) and prevalent hypertension in the US, Mujahid et al. noted that—because of the history of residential segregation—race may confound this relationship (15). Therefore, there is a need to the evaluate the association between walkability and hypertension and also consider the impact of racial and geographic differences.

The purpose of this study was to investigate the association between objectively measured neighborhood walkability and incidence of hypertension in the REasons for Geographic and Racial Differences in Stroke (REGARDS) Study. Given the protective effect of PA on hypertension and stroke risk, as well as the racial disparities in these cardiovascular outcomes, we sought to understand the relationship between walkability and new onset (incident) hypertension in a study population that includes both black and white participants from the continental US. In secondary analyses, we investigated effect modification by age, race, and geographic region and tested associations between walkability and hypertension status across two study visits.

MATERIALS AND METHODS

Study Population

REGARDS is a population-study that was designed to observe racial and geographic differences in stroke incidence in the US, with oversampling in the Southeastern states with high stroke incidence, i.e., Stroke Belt and Stroke Buckle. The cohort is composed of 30,239 white and black adults aged 45 and older. Data was collected via telephone survey and in-home physical assessment at enrollment between 2003 and 2007 (baseline visit). Follow-up data were collected on ∼51% of the original cohort (n = 15,550) using similar methods during a second visit an average of 10 years after enrollment (between 2013 and 2017). The REGARDS study design and objectives have been described elsewhere (16). The study protocol was approved by the institutional review boards of all participating institutions, and all participants provided written informed consent.

Outcome of Interest

The measurement of blood pressure (BP) in the REGARDS study across both study visits has been described (17). Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were defined as the average of two measurements taken by a trained technician using a standard protocol and regularly tested aneroid sphygmomanometer after the participant was seated for 5 min. Incident hypertension was defined as SBP ≥140 and/or DBP ≥90 mmHg and/or treatment with antihypertensive medication at the second study visit among those without hypertension at baseline. The use of anti-hypertensive medication was self-reported.

Walkability Measurement

Street Smart Walk Score® is a validated and widely used walkability instrument that is derived from an algorithm that measures BE in proximity to each participant's residential address (18, 19). The score is based on proximity to walking routes to nearby amenities (e.g., parks, libraries, shopping centers, restaurants). The algorithm, after adjusting for intersection density and average block length, assigns the values from 0 to 100 with higher values reflecting greater walkability (0–49: Car-Dependent, 50–69: Somewhat Walkable, 70–89: Very Walkable, 90–100: Walker's Paradise). In the current study we dichotomized walk score as ≥70 (more walkable) and <70 (less walkable). All participants' addresses at baseline were validated and linked to a walk score. Scores were collected in 2018 as part of an ancillary study in REGARDS.

Covariates

Covariates included baseline sociodemographic factors (age, sex, race, household income, geographic region), health-related behaviors (smoking, alcohol use, exercise frequency), and cardiometabolic traits (body mass index, dyslipidemia, diabetes). Age, sex, and race were self-reported. Race was classified as white or black. Income was self-reported and categorized into five groups: <$20,000, $20,000–$34,999, $35,000–$74,999, ≥$75,000, and refused to answer. Region was defined as Stroke Buckle (coastal plains of North Carolina, South Carolina and Georgia), Stroke Belt (the rest of North Carolina, South Carolina and Georgia, as well as Tennessee, Mississippi, Alabama, Louisiana, and Arkansas), or non-belt (other states of the continental US) (20). Self-reported smoking status was categorized as current smoking (yes or no). Self-reported alcohol use was categorized according to the National Institute on Alcohol Abuse and Alcoholism as heavy (>7 drinks/week for women, >14 drinks/week for men), moderate (≤7 drinks/week for women, ≤14 drinks/week for men), and none (0 drinks/week). Baseline exercise was categorized by self-reported frequency of exercise per week (none, 1 to 3, 4 or more). Body mass index (BMI) was calculated as a ratio of weight (kg) to square of height (m^2). Dyslipidemia was defined as self-reported physician diagnosis of hyperlipidemia or current use of lipid-lowering medication. Diabetes was defined as self-reported current use of hypoglycemic medication, fasting blood glucose ≥126, or non-fasting blood glucose ≥200.

Statistical Analysis

We compared subject characteristics and covariates between more walkable and less walkable areas using Pearson chi-square tests for categorical variables and independent t-tests for continuous variables among participants without baseline hypertension (see **Table 1**) and among all participants who completed a second visit (see **Supplementary Table 1**). In primary analyses (N = 6,894 without baseline hypertension), we determined overall and race-stratified risk ratios between walkability (dichotomized as <70 vs. ≥70 and, separately, considered as a continuous variable) and incident hypertension using modified Poisson regression with robust variance estimation. The risk ratios were unadjusted (Model 1, see **Table 2**) and adjusted for sociodemographic factors (age, sex, race, income, and geographic region), health-related behaviors (smoking status, alcohol use, and exercise frequency), cardiometabolic traits (diabetes, dyslipidemia, and BMI), and baseline blood pressure (SBP and DBP) in Model 2 (see **Table 2**). We further stratified these models by age (45–54, 55–64, ≥65) or geographic region (see **Supplementary Table 2**). We also conducted multivariate linear regression to determine the association between neighborhood walkability and second visit SBP and DBP, adjusting for covariates described above and antihypertensive medications to account for medication effect on blood pressure measurements (**Table 3**).

Assuming that walkability at an individual level may remain relatively stable over time, we assessed the relationship between walkability and hypertension across two study visits ($N =$ 15,550) in secondary analyses. We defined a multinomial outcome where participants who completed both study visits were categorized as hypertensive at both study visits ("always hypertensive"), normotensive at the first visit and hypertensive at the second visit ("incident hypertension"), hypertensive at the first visit and normotensive at the second visit ("blood pressure decline"), and reference category normotensive at both visits ("always normotensive"). We then conducted a multinomial logistic regression and report a crude and adjusted odds ratio for hypertension status across both visits considering age, race, sex, region, income, alcohol use, smoking status, exercise frequency, BMI, dyslipidemia, and diabetes as covariates (see **Supplementary Table 3**). All the analyses were performed using SAS v9.4 (SAS Corp).

RESULTS

Among 6,894 participants without prevalent hypertension, 2,515 developed hypertension by the second visit (see **Figure 1**). A total of 6.8% ($N = 468$) were living in more walkable areas defined as walk score ≥70 at the first visit. **Supplementary Figure 1** shows the distribution of walk scores among the 6,894 participants (mean(sd) 26.1(24.7), median 19). Those who lived in more walkable areas had mean(sd) age of 61.4(8.1) years, were more likely to be black and college graduates (see **Table 1**). Participants in more walkable areas were more likely living in non-belt areas compared to those in less walkable areas. Mean baseline SBP was similar in participants living in more walkable areas and those living in less walkable areas, whereas the mean DBP at baseline was slightly higher for those in more walkable areas. Baseline characteristics of the 15,500 participants who completed the two study visits (including participants with prevalent hypertension) can be found in **Supplementary Table 1**. Like the data presented in **Table 1**, those living in more walkable areas were more likely to be black, be college graduates, and live outside the stroke belt and stroke buckle.

The incidence of hypertension in those living in more walkable (≥70) areas at baseline was lower than those living in less walkable (<70) areas at baseline (31.4% vs. 36.9%, $P = 0.02$). As shown in **Table 2**, the higher risk of incident hypertension was resilient to covariate adjustment (Model 2, RR[95%CI]: 0.85[0.74,0.98]). There was not a significant interaction between race and walkability ($P = 0.75$). The results in the racial strata were consistent with that of the full cohort, although with the smaller race-specific sample sizes, these relationships did not remain significant after full adjustment in Model 2 (see **Table 2**).

After multivariable adjustment, walkability was not significantly associated with second visit SBP and DBP among those without prevalent hypertension (see **Table 3**). Diastolic blood pressure was lower among black participants living in more walkable areas compared to those in less walkable areas in crude analysis. This same trend was observed among whites

TABLE 1 | Baseline characteristics of 6,894 REGARDS participants.

Characteristic Mean (SD)/*N*(%)	Total	More walkable	Less walkable	*P*
N	**6894**	**468**	**6,426**	
Age Mean (SD)	61.7 (8.4)	61.4 (8.1)	61.8 (8.4)	0.41
Females	3,771 (54.7%)	271 (57.9%)	3,500 (54.5%)	0.15
Race				**<0.0001**
White	5,087 (73.8%)	249 (53.2%)	4,838 (75.3%)	
Black	1,807 (26.2%)	219 (46.8%)	1,588(24.7%)	
Education				**0.022**
Less than high school	377 (5.5%)	23 (4.9%)	354 (5.5%)	
High school graduate	1,402 (20.3%)	81 (17.3%)	1,321 (20.6%)	
Some college	1,627 (26.1%)	92 (21.1%)	1,713 (26.5%)	
College graduate or above	3,310 (48.0%)	257 (54.9%)	3,053 (47.5%)	
Income				0.09
<$20,000	674 (9.8%)	61 13.0%)	613 (9.5%)	
$20,000–$34,000	1,292 (18.7%)	75 (16.0%)	1,217 (18.9%)	
$35,000–$74,000	2,407 (34.9%)	167 (35.7%)	2,240 (34.9%)	
$75,000 or more	1,763 (25.6%)	118 (25.2%)	1,645 (25.6%)	
Refused to Answer	758 (11.0%)	47(10.0%)	711 (11.1%)	
Geographic Region				**<0.0001**
Stroke Belt	2,278 (33.0%)	42 (9.0%)	2,236 (34.8%)	
Stroke Buckle	1,460 (21.2%)	27 (5.8%)	1,433 (22.3%)	
Non-Belt	3,156 (45.8%)	399 (85.3%)	2,757 (42.9%)	
Current Smoker	815 (11.8%)	59 (12.6%)	756 (11.8%)	0.59
Heavy Alcohol User (NIAAA)	298 (4.4%)	21 (4.6%)	277 (4.4%)	0.80
Exercise Frequency – None	1,788 (26.3%)	134 (28.8%)	1,654 (26.1%)	0.20
BMI Mean(SD)	27.8 (5.3)	27.6 (5.1)	27.8 (5.3)	0.41
Dyslipidemia	3,410 (51.2%)	213 (47.9%)	3,197 (51.4%)	0.15
Systolic Blood Pressure	118.7(11.2)	118.7(10.2)	118.7(11.3)	0.99
Diastolic Blood Pressure	73.6(7.6)	74.7(7.2)	73.5(7.7)	**0.002**
Diabetes	611 (9.1%)	50 (8.2%)	561 (9.0%)	0.13

Boldface indicates statistical significance ($p < 0.05$) based on Pearson chi-square or independent t tests.

TABLE 2 | Risk ratios for incident hypertension for living in a more walkable neighborhood at baseline.

Outcomes	Events/Total	Model 1[##]	Model 2[##]
Incident Hypertension[a]			
Overall	2,515/6,894	**0.85,(0.74,0.98)**	**0.85,(0.74,0.98)**
Black	836/1,807	**0.80,(0.67,0.95)**	0.88,(0.74,1.06)
White	1,679/5,087	**0.77,(0.62,0.96)**	0.82,(0.66,1.02)

Results presented as [a]risk ratios (95% CI); [##]more walkable (Walk Score 70–100) compared to less walkable (<70, reference group); Model 1: Crude; Model 2: age, race, sex, region, income, alcohol use, smoking status, exercise, BMI, dyslipidemia, diabetes, baseline SBP, baseline DBP. Boldface indicates statistical significance (p < 0.05).

TABLE 3 | Association of walkability category with second visit SBP and second visit DBP.

Outcomes	Model 1[##]	*P*	Model 2[##]	*P*
Systolic Blood Pressure	β(SE)		β(SE)	
Overall	−0.82(0.65)	0.21	−0.38(0.67)	0.57
Black	−1.16(0.99)	0.24	0.16(1.06)	0.88
White	−1.39(0.88)	0.11	−0.64(0.89)	0.47
Diastolic Blood Pressure				
Overall	−0.65(0.41)	0.12	−0.52(0.43)	0.23
Black	**−1.52(0.63)**	**0.02**	−0.23(0.67)	0.74
White	−0.54(0.55)	0.33	−0.60(0.57)	0.29

Results presented as beta estimates (SD); N = 6,894; [##]more walkable (Walk Score 70–100) compared to less walkable (<70, reference group); Model 1: Crude; Model 2: age, race, sex, region, income, alcohol use, smoking status, exercise, BMI, dyslipidemia, diabetes, baseline SBP, baseline DBP, and second visit hypertensive medications. Boldface indicates statistical significance (p < 0.05).

although not significant. The relationships were not statistically significant after multivariable adjustment.

When stratifying the results by geographic region, the protective effect of higher neighborhood walkability for incident hypertension was consistent across strata ($P_{\text{interaction}} = 0.69$), but not statistically significant (see **Supplementary Table 2**). Participants in more walkable areas also had lower risk of incident hypertension across age categories with the strongest protective relationship observed in the youngest age group (45–54 years). However, we did not see modification of the relationship between neighborhood walkability and incident hypertension by age-group ($P_{\text{interaction}} = 0.25$), and the relationship was not significant in any age strata (see **Supplementary Table 2**).

In a secondary analysis of hypertension status across two study visits ($n = 15{,}550$, see **Supplementary Table 3**), living in more walkable areas was associated with a lower odds of being "always hypertensive" vs. "always normotensive" (OR [95% CI]: 0.70[0.59, 0.84]), and these associations persisted in both blacks and whites, separately. Additionally, the results for "incident hypertension" were consistent with the primary model. Finally, neighborhood walkability category was not associated with "blood pressure decline" vs. "always normotensive" as part of this analysis.

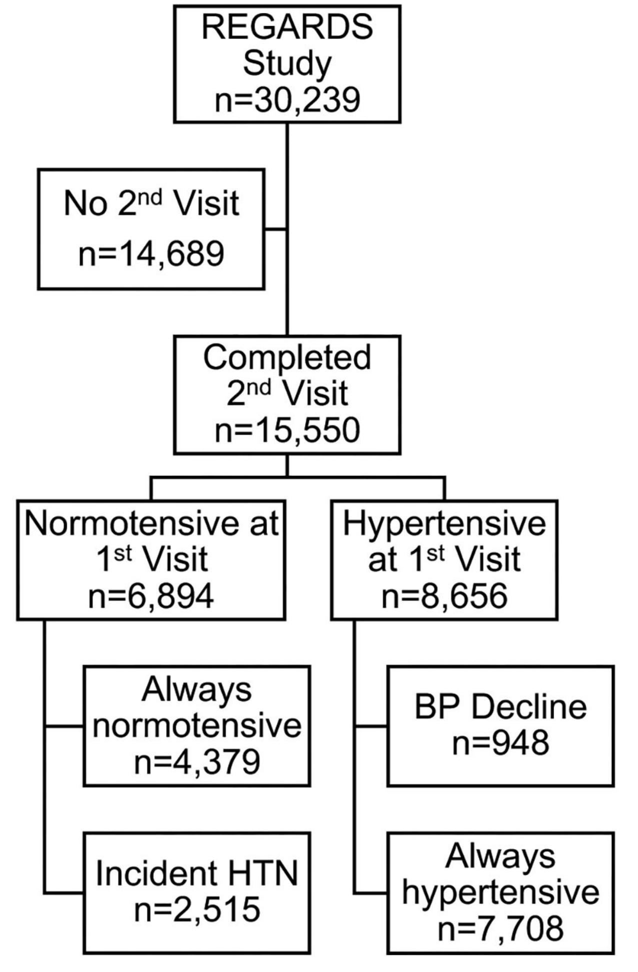


FIGURE 1 | Exclusion cascade to identify REGARDS participants who were normotensive at baseline and later developed hypertension.

DISCUSSION

There is a growing interest in understanding the role of the BE in community member activity levels. Previous studies have linked neighborhood walkability to hypertension and blood pressure. We found in a population of geographically and racially diverse older adults that higher neighborhood walkability was protective for incident hypertension, even in the fully adjusted model including measures of exercise. The association was consistent in both race groups and was not modified by age and geographic region. Further investigation is needed to better understand these relationships and help spur additional investment in walking infrastructure which could help improve community health.

Previous work has asked similar questions on neighborhood walkability and incident hypertension (10–15). Multiple studies in Canadian cohorts have shown that living in a more walkable neighborhood (as measured by Walk Score and other validated walkability indices) predicts a lower risk of developing hypertension, diabetes, and CVD (10–12). Similarly, in a cross-sectional study of middle-aged and older adults in China, higher walkability was associated with lower odds of CVD. While exercise partially mediated this relationship, there was no significant interaction with BE (21). These findings, along with our significant results which remained after adjusting PA, suggest that there may be additional health-promoting factors in more walkable environments that benefit older adults even if they are less likely to be as physically active in those environments as they age.

Comparing these results to our own support the notion that neighborhood walkability may have a consistent protective effect across different sub-groups. However, it is important to note that these associations may differ depending on geography and/or age. For example, a study in an Australian cohort that was similar to REGARDS in terms of age and comorbidities found no significant association between neighborhood walkability (not measured by Walk Score) and incident hypertension (13). Similarly, a longitudinal study of older Taiwanese adults found no associations between Walk Score and exercise or hypertension (22). Yet in Portland, Oregon, higher neighborhood walkability was associated with lower blood pressure after 1 year of follow-up among adults aged 50–75 (20). In our stratified analyses, we found that higher neighborhood walkability was protective for incident hypertension among all regional and age groups (although not statistically significant in smaller strata), with greatest effects among those living outside the stroke belt/buckle and among younger age groups (<65). However, there were no significant interactions between Walk Score and age or region of the country related to stroke risk (belt, buckle, non-belt).

The REGARDS cohort is comprised of a biracial sample of older US individuals and we did not see modification of the relationship between walkability and incident hypertension by race. Additionally, we observed that walkability category was not only protective against incident hypertension among older normotensive adults, but also against persistent hypertension (i.e., "always hypertensive" at both study visits) which was consistent across race groups in a larger secondary analysis. These results could mean that walkability may not be a major contributor to racial disparities in hypertension risk, even though other neighborhood characteristics (e.g., socioeconomic status) have been linked to these disparities (23). These results suggest increased neighborhood walkability is an aspect of the BE that is consistently protective for hypertension across subgroups of older adults in the US.

Strengths and Limitations

Overall, the mechanisms by which aspects of the BE, e.g., walkability, affect health outcomes is complex, and even the measurements we used are not without error. Street Smart Walk Score is limited in its ability to directly determine walking behaviors. The score calculation is based on the density of destinations in a given block, which does not necessarily lend itself to predicting whether people will walk (potentially due to neighborhood safety or effects of housing segregation) so much as it informs us that they are in close proximity to a place where they can walk (24–26). Even with these limitations, the score has been validated as an appropriate measurement of neighborhood walkability in the US (18, 19). In this study, we observed that neighborhood walkability was associated with hypertension risk among those in more walkable areas (Walk Score ≥70). However, in sensitivity analyses exploring other categorizations of the Walk Score— "Walkable" (≥50) vs. "Car-Dependent" (<50)—and as a continuous variable, there was not a significant association. These findings suggest that there may be a non-linear relationship between neighborhood walkability and hypertension, and future studies should continue to evaluate this relationship and potentially more sensitive definitions of walkability.

Although walkability data were based on participants' addresses at baseline (2003–2007), the Walk Scores were calculated in 2018 for a REGARDS ancillary study (5). The software did not allow us to backdate the calculation to agree with the timing of the baseline visit. Additionally, second visit data were collected an average of 10 years after the baseline visit. Therefore, we cannot fully account for how participants' environments changed during the time between the baseline visit and when the Walk Scores were collected (e.g., gentrification), as well as the second visit (e.g., moving to a different neighborhood). Finally, although we attempted to adjust for all potential confounders, including self-reported exercise, we could not rule out the potential for unknown or residual confounding (27). Still, we believe the size and nationwide, biracial composition of the cohort makes this study one of the most comprehensive studies of this walkability metric and incident hypertension to date.

In conclusion, we sought to determine if walkability is a novel risk factor for hypertension, and we found that neighborhood walkability may be protective for incident hypertension among older adults in a large sample from the REGARDS Study. Our study constitutes one of the first to report on the association between neighborhood walkability and incident hypertension in the US and evaluate potential effect modification by race, age, and geographic region. Future studies should address additional nuances in these relationships related to race, age, and region as well as other measures of the BE. Continued understanding of the relationship between the built environment and cardiovascular health could potentially lead to neighborhood improvements which spur cardiovascular disease risk reduction on the community level.

DATA AVAILABILITY STATEMENT

The datasets used and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Alabama-Birmingham Institutional Review Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AJ initiated the study, performed the data analysis, and prepared the Introduction, Results, and Discussion sections of the text. NSC and AP assisted in the development and implementation of the analysis plan and prepared the Methods section of the text. VH and GH were instrumental in the data collection for the REGARDS cohort. GH also provided feedback on the data analysis plan. NC and SJ assisted in the study design, as well as provided the walkability data and their expertise on the metric in REGARDS. MI (corresponding) assisted in the study design, development of the analysis plan, and provided expertise on hypertension in REGARDS. Both SJ and MI provided mentoring and extensive feedback from the inception of this project to subsequent data analysis and manuscript preparation. They contributed equally as last authors. All authors contributed to the article and approved the submitted version.

FUNDING

This work was supported by a cooperative agreement U01 NS041588 co-funded by the National Institute of Neurological Disorders and Stroke (NINDS) and the National Institute on Aging (NIA), National Institutes of Health, Department of Health and Human Services. AJ was also supported by the Medical Scientist Training Program (T32GM008361, National Institute of General Medical Sciences). The content is solely the responsibility of the authors and does not necessarily represent the official views of the NIGMS, NINDS, or the NIA. Representatives of the NINDS were involved in the review of the manuscript but were not directly involved in the collection, management, analysis or interpretation of the data.

ACKNOWLEDGMENTS

The authors thank the other investigators, the staff, and the participants of the REGARDS study for their valuable contributions. A full list of participating REGARDS investigators and institutions can be found at: https://www.uab.edu/soph/regardsstudy/.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.611895/full#supplementary-material

REFERENCES

1. Centers for Disease Control and Prevention. *High Blood Pressure*. Available online at: https://www.cdc.gov/bloodpressure/index.htm (accessed July 20, 2018).
2. Howard VJ, McDonnell MN. Physical activity in primary stroke prevention. *Stroke*. (2015) 46:1735–9. doi: 10.1161/STROKEAHA.115.006317
3. Centers for Disease Control and Prevention. Adult participation in aerobic and muscle-strengthening physical activities. *MMWR Wkly Rep*. (2013) 62:326–9.
4. Diaz KM, Howard VJ, Hutto B, Colabianchi N, Vena JE, Safford MM, et al. Patterns of sedentary behavior and mortality in U.S. middle-aged and older adults: a national cohort study. *Ann Intern Med*. (2017) 167:465–75. doi: 10.7326/M17-0212
5. Twardzik E, Judd S, Bennett A, Hooker S, Howard V, Hutto B, et al. Walk Score and objectively measured physical activity within a national cohort. *J Epidemiol Community Health*. (2019) 73:549–56. doi: 10.1136/jech-2017-210245
6. Braun LM, Rodriguez DA, Evenson KR, Hirsch JA, Moore KA, Diez Roux AV. Walkability and cardiometabolic risk factors: cross-sectional and longitudinal associations from the Multi-Ethnic Study of Atherosclerosis. *Health Place*. (2016) 39:9–17. doi: 10.1016/j.healthplace.2016.02.006
7. Diez Roux AV, Mujahid MS, Hirsch JA, Moore K, Moore LV. The impact of neighborhoods on cardiovascular risk: the MESA Neighborhood Study. *Glob Heart*. (2016) 11:353–63. doi: 10.1016/j.gheart.2016.08.002
8. Meline J, Chaiz B, Pannier B, Ogedegbe G, Trasande L, Athens J, et al. Neighborhood walk score and selected cardiometabolic factors in the French RECORD cohort study. *BMC Public Health*. (2017) 17:960. doi: 10.1186/s12889-017-4962-8
9. Qureshi AI, Adil MM, Miller Z, Suri M, Rahim B, Gilani SI, et al. Walk score and risk of stroke and stroke subtypes among town residents. *J Vasc Interv Neurol*. (2014) 7:26–29.
10. Chiu M, Rezai MR, Maclagan LC, Austin PC, Shah BR, Redelmeier DA, et al. Moving to a highly walkable neighborhood and incidence of hypertension: a propensity-score matched cohort study. *Environ Health Perspect*. (2016) 124:754–60. doi: 10.1289/ehp.1510425
11. Howell NA, Tu JV, Moineddin R, Chen H, Chu A, Hystad P, et al. The probability of diabetes and hypertension by levels of neighborhood walkability and traffic-related air pollution across 15 municipalities in southern Ontario, Canada: a dataset derived from 2,496,458 community-dwelling adults. *Data Brief*. (2019) 27:104439. doi: 10.1016/j.dib.2019.104439
12. Howell NA, Tu JV, Moineddin R, Chu A, Booth GL. Association between neighborhood walkability and predicted 10-year cardiovascular disease risk: the CANHEART (Cardiovascular Health in Ambulatory Care Research Team) cohort. *JAHA*. (2019) 8:e013146. doi: 10.1161/JAHA.119.013146
13. Müller-Riemenschneider F, Pereira G, Villanueva K, Christian H, Knuiman M, Giles-Corti B, et al. Neighborhood walkability and cardiometabolic risk factors in Australian adults: an observational study. *BMC Public Health*. (2013) 13:755. doi: 10.1186/1471-2458-13-755
14. Sarkar C, Webster C, Gallacher J. Neighbourhood walkability and incidence of hypertension: findings from the study of 429,334 UK Biobank participants. *Int J Hyg Environ Health*. (2018) 221:458–68. doi: 10.1016/j.ijheh.2018.01.009
15. Mujahid MS, Diez Roux AV, Morenoff JD, Raghunathan TE, Cooper RS, Ni H, et al. Neighborhood characteristics and hypertension. *Epidemiology*. (2008) 19:590–8. doi: 10.1097/EDE.0b013e3181772cb2
16. Howard VJ, Cushman M, Pulley L, Gomez CR, Go RC, Prineas RJ, et al. The reasons for geographic and racial differences in stroke study: objectives and design. *Neuroepidemiology*. (2005) 25:135–43. doi: 10.1159/000086678
17. Howard G, Cushman M, Moy CS, Oparil S, Muntner P, Lackland DT, et al. Association of clinical and social factors with excess hypertension risk in black compared with white US adults. *JAMA*. (2018) 320:1338–48. doi: 10.1001/jama.2018.13467
18. Duncan DT, Aldstadt J, Whalen J, Melly SJ, Gortmaker SL. Validation of Walk Score for estimating neighborhood walkability: an analysis of four US metropolitan areas. *Int J Environ Res Public Health.* (2011) 8:4160–79. doi: 10.3390/ijerph8114160
19. Duncan DT, Aldstadt J, Whalen J, Melly SJ. Validation of Walk Scores and Transit Scores for estimating neighborhood walkability and transit availability: a small-area analysis. *GeoJournal*. (2013) 78:407–16. doi: 10.1007/s10708-011-9444-4

20. Li F, Harmer P, Cardinal BJ, Vongjaturapat N. Built environment and changes in blood pressure in middle aged and older adults. *Prev Med*. (2009) 48:237–41. doi: 10.1016/j.ypmed.2009.01.005
21. Jia X, Yu Y, Xia W, Masri S, Sami M, Hu Z, et al. Cardiovascular diseases in middle aged and older adults in China: the joint effects and mediation of different types of physical exercise and neighborhood greenness and walkability. *Environ Res*. (2018) 167:175–83. doi: 10.1016/j.envres.2018.07.003
22. Liao Y, Lin CY, Lai TF, Chen YJ, Kim B, Park J-H. Walk Score and its associations with older adults' health behaviors and outcomes. *Int J Environ Res Public Health*. (2019) 16:622. doi: 10.3390/ijerph16040622
23. Usher T, Gaskin DJ, Bower K, Rohde C, Thorpe RJ Jr. Residential segregation and hypertension prevalence in black and white older adults. *J Appl Gerontol*. (2018) 37:177–202. doi: 10.1177/0733464816638788
24. Adkins A, Makarewicz C, Scanze M, Ingram M, Luhr G. Contextualizing walkability: do relationships between built environments and walking vary by socioeconomic context? *J Am Plann Assoc*. (2017) 83:296–314. doi: 10.1080/01944363.2017.1322527
25. Thornton CM, Conway TL, Cain KL, Gavand KA, Saelens BE, Frank LD, et al. Disparities in pedestrian streetscape environments by income and race/ethnicity. *SSM – Popul Health*. (2016) 2:206–16. doi: 10.1016/j.ssmph.2016.03.004
26. Duncan DT, Aldstadt J, Whalen J, White K, Castro MC, Williams DR. Space, race, and poverty: spatial inequalities in walkable neighborhood amenities. *Demogr Res*. (2012) 26:409–48. doi: 10.4054/DemRes.2012.26.17
27. Long DL, Howard G, Long DM, Judd S, Manly JJ, McClure LA, et al. An investigation of selection bias in estimating racial disparity in stroke risk factors. *Am J Epidemiol*. (2019) 188:587–97. doi: 10.1093/aje/kwy253

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 04 February 2021
doi: 10.3389/fpubh.2020.589371

Senior Housing as a Living Environment That Supports Well-Being in Old Age

Outi Hannele Jolanki[1,2]*

[1] *Gerontology Research Center, Faculty of Social Sciences, University of Tampere, Tampere, Finland,* [2] *Department of Social Sciences and Philosophy, Faculty of Humanities and Social Sciences, University of Jyväskylä, Jyväskylä, Finland*

Background: In different parts of the world new models of senior housing have rapidly appeared, which indicates that existing housing and care models are not fulfilling the hopes and needs of current and new generations of older people.

Material and Methods: This qualitative study focuses on one type of communal senior housing complex located in a mid-sized town in Central Finland. The complex was designed to have accessible low-maintenance apartments and common spaces, and to be near easily accessible green spaces, amenities, services, and public transport. The complex has a part-time community coordinator. The minimum age limit is set at 55 years. The data consists of 36 qualitative interviews with residents (21 women, 15 men) aged 66–93, conducted between November 2018 and February 2019. The semi-structured interviews were recorded and transcribed. The data analysis focused on how different aspects of the manmade, natural, and social environment were portrayed in residents' descriptions of day-to-day life. Theoretical framework adopted for the study draws from the ideas of environmental and geographic gerontology. The data was analyzed using positioning analysis which is one form of discourse analysis.

Results: The senior housing in this study fulfilled its promise of providing accessible a physical and social environment which encourages and enables residents to be physically active and independent, yet which also provides social activities and feeling safe. In this respect, the senior housing complex offered an environment which supports well-being and healthy aging. However, the residents' interpretations of what the senior housing complex represented varied. For some of the residents it was first and foremost a social place, which provided opportunities for social contacts and social activities. For some of the residents the most important were maintenance-free apartments and outdoor areas. The question remains as to how social practices, in the form of government policies and market systems can support the development of different kinds of senior housing which are affordable and accessible for all.

Keywords: accessibility, senior housing, social environment, physical environment, aging in place, communal housing, well-being, qualitative analysis

OPEN ACCESS

Edited by:
Katherine Henrietta Leith,
University of South Carolina,
United States

Reviewed by:
Steven A. Cohen,
University of Rhode Island,
United States
Shubing Cai,
University of Rochester, United States

Correspondence:
Outi Hannele Jolanki
outi.jolanki@tuni.fi

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *30 July 2020*
Accepted: *19 November 2020*
Published: *04 February 2021*

Citation:
Jolanki OH (2021) Senior Housing as a Living Environment That Supports Well-Being in Old Age. Front. Public Health 8:589371. doi: 10.3389/fpubh.2020.589371

INTRODUCTION

This study looks at new senior housing models, which are distinct from residential care homes, and aims to answer the research question of how this form of housing can offer the kind of environment that supports the health and well-being of older people. There are now many kinds of senior housing in different parts of the world, but irrespective of cultural and social differences, all these new models share the same goal, that is, to support aging in place and independent living. Some of the models also aim to increase reciprocity and mutual help at the same time. Before I look at the data produced by this study and the data analysis, I will therefore first look more closely at the policy goal of "aging in place" and how it relates to the development of new models for senior housing.

Aging in place (AiP) has become a policy goal around the world. The aim of AiP is to ensure that older people can continue living in their homes and familiar neighborhood without having to move due to a health problems and care needs (1–5). According to the World Health Organization (WHO) it means that by providing appropriate services and assistance it is possible to support older people's desire and ability to maintain relatively independent living arrangements within the community either in their current home or one that is more suitable to their current life situation (2004, p. 9). From this perspective the quality of housing stock, its physical characteristics and accessibility, and its transportation links to a wider community, are all important factors that support aging in place (1). Netherland et al. (6), for instance, argue that neighborhood and community are a crucial part of aging successfully—creating either barriers or supporting resilience and well-being in later life; while Lehning (7) links aging in place to age-friendly community initiatives, that pay attention to a multitude of non-human factors and services within local communities which could support independent living and encourage them to engage with the community. Age-friendly community initiatives vary depending on the policies adopted by local government in different places. It is for this reason why studies (such as the present one) which look at local initiatives in a particular cultural and regional context are important, as they can provide examples which, as Lehning (7) points out, researchers and practitioners can learn from.

The quality and extent of social relationships and participation in social activities affects the well-being and quality of life for elderly people (8–10). The availability of social support, social networks, and social activities can also affect health and functional ability (11, 12). The physical environment and geographical features of one's domestic surroundings can either enable or hinder physical activity. Since physical activity is not only linked to independent mobility, but to a general sense of autonomy and having some control over one's daily life, studies of older people's health and well-being need to look at the physical realities of their living environments (13, 14).

While there is often ambivalence about moving house in later life and relocation decisions arise from a complex set of reasons (15), some older people prefer relocation to staying put in an environment which no longer supports their well-being and accustomed lifestyle (2, 16, 17). The rise of these new models of senior or "in-between" housing (as they are also known), has appeared to fill the gap between ordinary private dwellings and residential care. As such, they are not residential care units or a form of service housing *per se*, although residential care is sometimes available or there may be a separate care unit in the premises. Senior housing models range from a purpose-built retirement villages, senior co-housing, virtual "Village model" to multigenerational co-housing and collaborative senior housing (9, 17–26). These models vary in respect to how they are funded, the age of residents', tenure type, and the role of residents in managing administration and maintenance of the building. What all these models have in common, however, is that they aim to support independent living as much as possible in spite of age-related health problems (26), while at the same time offering social activities, community participation, and mutual support and help (26).

There is some research which shows that residents have a mostly positive view of these new models of senior housing. They appear to increase subjective well-being by allowing the residents to feel that they have some control over the type of environment they live in (21, 23, 25); and they seem to provide new social contacts which not only enable the residents to continue lifelong social activities but even come up with new ones (17, 19, 24, 25, 27). Social contacts are particularly important since they decrease loneliness and increase feelings of safety and security (18, 21). A central concern is whether they are available for older people with poor health and memory problems, or for those with low-income (24, 28). While new senior housing models certainly seem to promote the well-being of residents, they are often an expensive solution that are mainly available only in urban areas in larger cities (18, 20, 24).

In sum, these studies give reason to think that new senior housing options which aim to provide accessible apartments and environments, have amenities and services within walking distance if not on the premises themselves, and offer opportunities for social activities, may provide an environment which promotes the residents' well-being in many ways. The present study analyzed in detail certain elements of senior housing that are often taken for granted, to see if the accommodation in question fulfills its promise of being a living environment that truly supports the well-being of its residents. The senior housing complex looked at here has owner-occupied, social rental housing, and "right of occupancy" housing (*asumisoikeus-asunto* as it is known in Finland and covered in more detail below), which sets it apart from the models featured in previous studies.

The present study looks at one type of senior housing located in a mid-sized town in Central Finland. In Finland majority of older people live independently in private owner-occupied detached houses or apartments. A number of people living in assisted living facilities is low, and for example of people aged 75 or older about 90% live in ordinary private houses or apartments. Many older people live alone and the trend is strengthening (29). In general about 40% of people aged 65 and older live alone, but in urban areas the percentages are even higher with more than 60% living alone. Older people often live in old and inaccessible detached houses or apartment blocks (29), but many plan to move to live closer to services and in apartment blocks. In short, there is clearly need for senior housing which is accessible, affordable, and offers appropriate amenities.

While this is a specifically Nordic context, it is based on the same ideas as many other senior housing models around the world. The complex was designed to have accessible low-maintenance apartments, lots of common spaces where residents could mix, and to be near easily accessible green spaces, amenities, services, and public transport. The aim of this architecture and design is to support an independent lifestyle, but also to facilitate contacts between those living there [cf. (30, 31)]. The residents all belong to a committee chaired by one of their own which meets every month to plan social activities (none of which are compulsory) and to convey the residents' views to the housing association in charge of administration. The block is thus a form of "communal" senior housing, but it is not co-housing since the block has a part-time community coordinator who organizes the activities together with the residents, none of whom are obliged to participate.

The senior housing model studied here is a "hybrid" in many ways: it is located in a semi-urban area close to services and public transport, but with good access to parks and forest areas. The complex consists of three high-rise apartment buildings which are linked on the first floor by hobby rooms, a laundry room, a lounge with kitchen area, and a restaurant. The complex has a mix of private owner-occupied, social rental housing and state-regulated "right of occupancy" housing which means that residents come from a fairly wide cross-section of socioeconomic backgrounds. Right of occupancy housing means that residents pay for only a small percentage of the value of the property plus a monthly fee which gives them a more secure right to live there than in normal rented accommodation. In fact, residents in this kind of housing have the same rights as those who bought their property privately—only more cheaply. The state helps with building right of occupancy housing, but it sets limits to the building costs and monthly fees that residents must pay. As well as the housing available for fully independent residents, a private care company provides 24/7 residential care in one part of the senior housing complex that they have rented out. The minimum age limit in the whole complex is set at 55 years, and at the time of the data collection the three apartment buildings had a total of almost 200 residents.

Research Questions

Our main research question asked what the most meaningful elements were in residents' descriptions of the senior housing complex as a place to live, and more specifically what the elements were that they described most meaningful in making the decision to move there. The aim of the analysis was to examine what the man-made, natural, and social environment meant for the residents in their day-to-day life, and to answer the question of whether this type of senior housing met their expectations and has allowed them to age well. In the following we will show the results of the data analysis. Data extracts have been chosen which not only demonstrate shared and recurrent patterns of positioning but also the less common ways of portraying features of living in the senior housing complex.

Theoretical Background

The concept of healthy aging is relatively complex, but for the study at hand we begin from the definition that for an individual person "healthy aging means having a sense of well-being, the capacity for independent activity, meaningful involvement, supportive environments, and positive attitudes. Being healthy is seen as having the resources for an everyday life that is satisfying to self and others" [(32), p. 101]. The fit between an individual person's capabilities and aspirations and his or her environment is thus essential in healthy aging (33). This study looks at the linkages between healthy aging and housing which means that the analysis needs to look at the physical, social, and mental aspects of health and well-being (34). A healthy environment refers to the natural, manmade, and social environment which supports the physical and social well-being of residents in a community. Housing is indirectly linked to well-being, for example, when one chooses to move to accommodation which is expected to be easily accessible and provide social support. It is directly linked to well-being, however, in terms of its physical and economic aspects—the size and quality of apartments, for instance, and housing tenure type (35). An important point to remember is that a precondition for choosing to relocate is to actually have some alternatives from which to choose. Following Clapham (36) it can thus be argued that housing policy is an important tool for improving the well-being of elderly people, insofar as it can create accessible and affordable housing options which provide a supportive living environment.

In age studies, geographical gerontology has drawn attention to the importance of studying how places affect the well-being of older people (37), but it also shows that with age, the meanings of places change (38). Wiles (39) has developed this notion further in noticing that places are processual and subject to ongoing negotiation; indeed, experiences and interpretations of place may differ, compete, or even conflict with one another. Furthermore, places are interrelated with other places on a different scale and at different times (39). Change is thus a fundamental part of this study, because it is looking at *relocation in later life* and living in a new environment, where people and places "co-constitute each other in an ongoing way through constant change" [(37), p. 218]. The senior housing complex is one form of communal housing and thus it aims to provide a sense of community and serve as *a community* for the residents. Yet, following Agnew's (40) distinction between *spaces* and *places* I point out that it is a matter of the data analysis to find out if the complex represents a community of belonging for the residents, or if it remains as a generic senior housing complex.

MATERIALS AND METHODS

The data consists of qualitative interviews with 40 residents (25 women, 15 men) aged 57–92. Majority of the interviewees were 70 years old or older (33) and majority of the interviewees lived alone (29). Of those living alone 6 were never married, 9 were divorced and 9 were widows. The interviewees housing tenure varied and 19 of them lived in right of occupancy housing, 8 in ordinary owner-occupied housing and 9 in rental housing. The semi-structured interviews were conducted between November 2018 and February 2019 and they were map-assisted, recorded, and then transcribed. At the time they were being interviewed, most of the residents had lived for about a year in the complex, and the interviews were held there, either in the residents' apartments or elsewhere on the premises (e.g., restaurant or hobby room). The authors interviewed them, so they also became acquainted with this living environment. Prior to the interviews they had also visited the senior housing complex in a group when they were introduced to how the place operated and to the actors involved in building and managing it.

In the data analysis, the focus was on how different aspects of the manmade, natural, and social environment were portrayed in residents' descriptions of day-to-day life, and, secondly on whether these portrayals give reason to argue that the living environment supports the residents' well-being. The focus of the study is thus on how the residents perceived housing and living environment as an element relevant for their well-being (34). To this end, concepts from positioning analysis (41) and environmental positioning analysis (42) were employed to analyze how residents describe themselves in relation to previous, current, and future living arrangements. Positioning analysis is one form of discourse analysis which focuses on language use to see if, and how, different features of the living environment are described as meaningful in daily life. This approach means that, irrespective of the research focus, the analyst has to remain open to each participant's own meaning-making activities. Following the theorization of geographical and environmental gerontology, we have used positioning analysis to study how the residents position themselves in relation to their current living environment. This approach brings with it a notion that the analysis has to look at both human and non-human dimensions of the environment, and how the residents position themselves and others as agents with the power to change their everyday life for better or for worse. As an example of positioning oneself in relation to other people is how the residents used the word "we" which sometimes referred to "we the residents" acting together ("we have the coffee time"), or alternatively to oneself and the spouse ("we like to go our own way") as a dyad separate from the residents of the senior complex. The methodological application of environmental positioning proposed by Medeiros et al. (42) is particularly useful in unraveling different meanings of this particular type of senior housing which is founded on predefined ideas of accessibility and ideals of community living. In environmental positioning not just humans but non-human objects can be represented as actors, and the focus of attention is how the residents positioned themselves in relation to the objects. For example, one of the residents portrayed his previous living environment in relation to his health status ("when I got ill…I was left with a house that was too big and expensive") and then the new environment that "drew" him in ("I could have moved somewhere else, but it's the sense of community here which drew me").

In the analysis, the data was first organized by coding it with the NVivo software program, and then the coded text was subjected to discourse analysis to interpret the meanings of text segments within the context of the whole study. The final phase of the analysis was to draw together the results from this, and to interpret whether they confirmed that the senior housing complex provides a supportive environment for the residents. The coding consisted of going through transcribed interviews, systematically assigning a particular code to the language used in each case. The initial focus was on the physical (both man-made and natural) and social environment (in terms of services, social relationships, social activities). This provided the initial codes and sub-codes, but a more nuanced coding was created in the process of going through this data. The residents talked about the meaning of different dimensions of current living environment when they were asked about their reasons for moving, why they chose the housing complex over other choices, and when they were asked if they thought moving was a good decision. Occasionally current living environment was brought up in the context of other questions too.

RESULTS

When the residents talked about the life at the senior block two topics of concern came up in all the interviews, namely, the importance of being able to both have a choice and prepare for the future. Having a choice referred to two rather different things: namely, to relocation but also to everyday life in the housing complex. When talking about relocation, the residents highlighted that it was they who had made the choice to live in the complex; and when talking about everyday life in it, they emphasized the importance of being able to choose the extent to which they engaged in social activities. In this sense all of the residents interviewed positioned themselves as agents who had made a conscious decision to leave their previous home and relocate to a new "communal" living environment, but one in which they were able to choose their level of engagement in social activities. Relocation and a life in the senior complex thus provided a sense of being at least into a certain extent in control of one's life (32).

Environmental positioning entails also relational aspects between past, present and anticipated future (42). The residents often compared the suitability of their previous and current living environment for older people. They positioned senior housing complex as a suitable environment to grow old and a move was thus portrayed as an act to prepare for the future. In this context, future meant "aging"—in terms of its adverse effects—and relocation was portrayed as means to find a supportive environment to help cope with these. In short, residents exercised their agency in choosing to relocate to an environment that would support older people [cf. (37)]. However, in their interviews, residents anticipated the possibility of becoming less physically and cognitively able in the future. This view of the future restricted the range of places that they imagined to be appropriate for them to live in [cf. (40)]. So, when the residents described themselves as aging people, they were portraying old age as a kind of external force which restricted their agency in choosing a place to live.

Physical Environment Enables Physical Activity and Social Encounters

The analysis examined the meanings to residents of various aspects of the physical and social environment in and around the senior housing complex—in terms of how these affected their decision to move there and find the new life there satisfying. Residents emphasized different aspects according to their own background, previous experiences, and housing history. For some, the design of the building and the surrounding physical environment made it easier to maintain their accustomed lifestyle. The following extract illustrates the importance to these residents of having the opportunity to continue certain physical activities and maintain social contacts. In the data extracts, I stands for the interviewer. The square brackets [...] mark text that has been omitted for reasons of confidentiality, or in some cases to abbreviate the text to make it more readable. Without brackets three dots mark either a pause or interruption in the speech itself. Occasionally some information details have also been anonymized and marked in square brackets too [the neighborhood].

Extract 1. Anneli, female, living alone

> *I*: OK, yep, so what was it like, what were your reasons for deciding to move here?
> *Anneli*: Well, both my daughters live in [the neighborhood] with their families. And I decided to move here too when I retired [years] ago, because I had made the decision to no longer drive the car in wintertime. Sometimes it used to take an hour or so to drive here from [previous home]... So, I gave the car up altogether last autumn, and now I just walk from here as they live within a kilometer from here.
> *I*: Right... so, in other words, it seems to have been a good solution then?
> *Anneli*: Yes, it has been. Then there's also the fact that, throughout my life, I've always been involved in all kinds of organizations and associations, and have had a lot of activities. As it is, from here, I can manage very well, since there are six buses to the city every hour. And the bike—I've been biking so much this summer that I don't think I've ever biked as much in all the time I've lived in this city as I do now. Even though there's that huge [delay], I just went the other way around the lake. The road there is nice and level, you can get here just as quickly, there are no uphills, going uphill tends to be difficult at this age.

For some of the residents the location of the senior housing complex was important since they already had connections to the area either because children or other family members were living nearby, or because they had previously lived there themselves. In Anneli's case, the overall accessibility of the environment—in terms of location and local transport—not only made it easier to see her children and ensure that she could continue actively participating in various different organizations, but it also encouraged her to be more physically active overall—with all the cycling she was now doing. Even if they were not explicitly talking about it, residents hinted that age was an important factor in not just making the decision to move, but also in their day-to-day decisions. Anneli, for instance, describes herself as an active person who likes to walk, cycle and take part in different social activities on a daily basis, but nevertheless has some problems with mobility due to her age; and yet, for her, these problems were adequately addressed in her new living environment. Similar positive points about the environment were raised by other residents, when they described it in terms of other residents with more severe health and mobility problems, as we shall see in the next extract.

Extract 2. Martti ja Laura, a couple

> *I*: So, we're interested in what exactly makes this kind of housing good, the factors that influence people to make the decision to move there...
> *Laura*: OK
> *I*: ...and we want to find out more about the day-to-day life in it.
> *Martti*: Well about that, yes, the environment is excellent for your average decrepit person, you know, for people who are not in good health.
> *Laura*: Yes, they've got these excellent exercise...
> *Martti*: Areas nearby.
> *Laura*: ...Yes, exercise areas that the council has built, which—when they were planning this place [the complex]—were going to be up on that hill, but then they brought the equipment down here instead...
> *Martti*: To the lakeside
> *Laura*: ...by the lake, as people in the complex walk along the lakeside path quite a lot. And they don't—most of those with wheeled walkers anyway—don't have the strength to climb that hill.

In this extract Laura and Martti have highlighted the accessibility of certain outdoor facilities for frailer residents who otherwise have difficulty getting around. An interesting feature which crops up time and again in the data is that residents might occasionally portray themselves as old and having various health issues, yet will still draw attention to those in a worse physical condition to themselves. In this extract, for instance, Martti describes himself and his wife as being a bit "decrepit," but he is quick to point out that they are nevertheless *not* one of the folk using wheeled walkers. In Laura and Matti's eyes, the outdoor areas serve the needs of older people with a range of varying abilities. One actor in implementing this is the council, which has equipped the park nearby with the kind of equipment which will make it easier for people living in the area to exercise more often.

As stated earlier, the housing complex was designed as a communal environment that encourages residents to socialize. However, the data analysis showed that for some, there were other aspects that were far more important in making the decision to move and their everyday life. The extract below comes from a part in the conversation where the interviewees—a couple called Seppo and Inkeri—had just stated they did not take part in the communal activities.

Extract 3. Seppo and Inkeri, a couple

> *I*: OK, so are you saying you just haven't gone that much or what exactly?
> *Seppo*: No, we haven't really gone. I'm not so keen on the poetry circle and the [unclear] circle... [laughter]
> *Inkeri*: We, well we're more the kind of people, we like to go our own way. So, when it's the morning, yes it's usually before

> noon, we might… well, we usually go for a good walk—it's four or sometimes even five kilometers. There are good opportunities for walking round here.
> *Seppo*: That's right, and everything is nearby too—except for that mall which was burnt down, but there is another [grocery store] near here, then there's [another store] less than a kilometer away and there are [other stores], so there are all these services, and this building is really good since it's new house and purpose-built for the old people [. . .] Everyone must be over 55 years old. So, all of these things have been taken into account.
> [Inkeri mutters something incomprehensible at this point]
> *Seppo*: Yes, of course there is.
> *I*: You mean outside or indoors?
> *Seppo*: Yeah, there's a gym and everything.

From this extract, it is clear that it is vitally important for this couple to have easy access to outdoor walking areas, as well as amenities and services both inside and outside the complex. The couple portray themselves as independent-minded people who "go their own way" and appreciate their age-specific living environment without pursuing shared communal activities.

The following extract is an example of how a resident's previous living environment (whether an apartment or house), their life history, their health, and financial issues all affect their views of living in the senior housing complex.

Extract 4. Hannu, male, living alone

> *I*: So what made you move here then? This is marketed as a communal senior block, but what really was it then—the central factor as it were—that made you choose this place?
> *Hannu*: Well, these problems with mobility mainly. I mean, before this I was living in a two-story house, and with this mobility… these mobility problems, it just wasn't practical anymore. And it was quite hilly around there; hills—well there are some hills here too—but even small hills can actually cause quite a problem when moving around in this [assistive device]. And yeah, [the house] was unnecessarily big [. . .]. Then, when I got ill [and personal circumstances changed] I was left with a house that was too big and expensive. And of course, there are these services here which also tempted me [. . .]. I could have moved somewhere else, but it's the sense of community here which drew me . . . and the gym and restaurant were also important factors.
> *I*: Right, so it was both the services and this sense of community which drew you. So, what does it mean exactly for you—this sense of community?
> *Hannu*: Well, I guess it means at the very least, saying hello to other people [laughs] when you see them. And being able to bump into each other [. . .] in the communal areas where you can chat if you feel like it [. . .] I've never really got fully into that, but still, it's nice [. . .] that there's this community, it provides some form of security.

As the above extract shows, for some people, the senior housing complex has been a place that makes life easier for those who have problems with their health and mobility. The fact that it has accessible indoor and outdoor areas, basic services like a restaurant and gym, and smaller and cheaper accommodation all weighed heavily in favor of moving there. Hannu's account also shows how having the chance to interact with others on a casual everyday level can also be important to those people who are otherwise not involved in the more organized social activities, so there are opportunities for residents to choose their level of social contact in the community. The data analysis showed, as we see in Hannu's case, that financial issues were an important factor in finding a smaller and cheaper place to live, but they also had an effect on how daily life was experienced in the senior housing complex. The following extract shows how, for some people, the shared spaces and shared facilities were important not just because of their accessibility, but also for financial reasons.

Senior Housing as a Social Environment

The data analysis showed that while the physical and social environments were of equal importance and intertwined in residents' accounts, for some the social environment was more prominent in their accounts of day-to-day life. Social environment refers here to social contacts and activities provided by other people but also services. Services are made possible by decisions and actions of human actors and they entail activities of humans as service providers and users, and thus services are included in social environment in the analysis. In the following extracts, different aspects of social environment that relate to the well-being of residents will be addressed.

Extract 5. Raimo, male, living alone

> *I*: OK, so if we were going to sum it all up, what then are the good sides and the bad sides here?
> *Raimo*: Well, this building is very good, it's so quiet and, well, everything seems to be working. And if you want some company, there's a large shared living room so at a certain period of the day there are people there—not all the time, but anyway—you can sit and watch the big televisions they have there with other people if you want, and be a couch potato.
> *I*: OK, so do you usually go there?
> *Raimo*: Well, um, yes, I go there every now and then, and then there's coffee, we have a "coffee time" and a system where you can buy a cup of coffee [. . .] that costs 50 cents. So, once we've set it up, we can buy our own coffee and so on.
> [. . .]
> *Raimo*: And then, then we have the gyms, they are free, and laundry is free, and then there's the sauna and that's free too—you just book the time you want to go in advance.
> *I*: Right. So, do you book a time?
> *Raimo*: I have my own time, a time that I go. [. . .] Yes, I have my own [sauna] slot.

The extract above is a good example of those interviews where residents highlighted the advantages of the purpose-built facilities and the overall peacefulness of the living environment. It is also representative of those residents did not take a very active part in community life, and yet described some of the shared premises as a continuation of their own apartment. For some, these common spaces clearly allow residents to engage in activities as an organizer, while for others, like Raimo, it's clearly enough to socialize with people as just an observer.

Like Hannu, Raimo seems to view social activities as something you can choose to do from time to time, but only if you feel like it. He describes how watching TV in the living room gives him the chance to be in a group, albeit as a passive "couch potato."

In addition, participating in making and sharing the daily coffee provides an opportunity to be part of social group without there being any more specific activity going on. In this way, Raimo sees himself as a member of the community, one of the "us" involved with organizing activities without feeling that he is the sole or primary organizer. In Finnish culture, an afternoon coffee-break (which usually takes place between 1 and 2 p.m.) is treated as an important part of the day. If you take afternoon coffee with others, it shows that you are at some level willing to engage with the community and socialize with them.

Raimo's extract also draws attention to the important aspect of financial issues. One of the apartment houses in the complex had people living on rental in social housing, or in right of occupancy housing which is considerably cheaper than non-subsidized private housing. Even though financial issues did not come up explicitly in linkage to living environment i.e., nobody positioned themselves as poor or talked about financial issues as a reason to choose this type of living environment financial issues were not unimportant. The free laundry, gym and sauna, as well the availability of a big TV and cheap coffee were mentioned as such resources are not ordinarily available in most apartment buildings, and going to a public gym or sauna is likely to be too expensive for some of the residents. It is also worth mentioning here that sauna, like afternoon coffee, is another very important part of Finnish culture, and each of the complex's three saunas were frequently mentioned by interviewees as being an important part of day-to-day life. The senior housing complex thus provides two symbolically important features of Finnish culture—afternoon coffee and sauna.

While some of the residents, as we have seen, preferred to see themselves more as passive observers in organized events and activities, for others it was a place where they could engage in their personal interests and put their skills to use by creating a program and events for the whole housing complex.

Extract 6. Timo, male, lives alone

> *I*: So that's what you're involved in (residents committee); but what about these coffee breaks and so on, how are you involved in those?
> *Timo*: Yes, all the time [. . .] There's a good [. . .] restaurant. There are good common areas where we can mingle too, and then there's a gym and everything. There's a barber's too—even a chiropodist. You don't really need to leave here except to shop.
> *I*: So do you make use of them then, these other services?
> *Timo*: Yeah, I do use them, I do [. . .]. Yes, I use the barber and the chiropodist and I sometimes go to the gym. And let's see, yes, we have this regular discussion group, and then there is singing. There's like a singing evening, in the neighboring apartment block they have choir singers, and I'm pretty good at too, I'm quite good at singing. So, there's two of us [laughter], who organize the singing evening [laughter].

This is a good example of how residents might highlight quite different aspects of day-to-day life that make them feel good about their living environment. In Timo's case above, it's not just the availability of services and amenities in his living environment that is important, but also the social relationships and activities which take place there. Some residents described the senior block as a place that enabled the residents to bring their own special talents to the social life of the community. In Timo's case it is singing—he portrays himself as a "good singer" and as active in organizing the singing evening. But this is not all; in describing himself as an active member of the community—in the residents committee and as an active user of the services available on site—Timo uses the first person plural. He sees himself clearly as part of a group, a "we" who attend social groups and events together. For some residents like Timo, therefore, the senior housing complex represents a place which can, in many ways, offer "everything."

In the next extract, the perspective is again slightly different, but the interviewee again underlines the importance of services and social contacts.

Extract 7. Rauha, female, living alone

> *Rauha*: [talking about her previous apartment] So it would have been possible to live there during the renovation, but I thought it'd be better not to have to move twice. And then the second thing was to do with how I was going to spend the rest of my life, since you don't have to be alone here. You can go into the living room and there's always, there are always people there, so the loneliness is not so bad, and when you want to be left alone, you can do that too. So there's nothing. . . well, it's basically safe here. And then there's the surroundings, with countryside and the lake nearby.
> *I*: OK, so let's see, did you know about these things before you moved here, and was that what interested you about moving here. . . this sense of community?
> *Rauha*: Yes, yes, that was exactly it.
> *I*: So, it was not just the apartment?
> *Rauha*: No, not really, it was the thing that, well I was thinking I'm still fit enough not to have to go to an actual care home, so this was a sort of in-between option, and there are all kinds of good things about this place. Yes, and if your health deteriorates, then there is [private health care provider]. . . as long as you have enough money, [laughter] you can move there.
> *I*: Yes, that's right-
> *Rauha*: So, if you look at it holistically, it's the idea of living as independently as you can for as long as possible, and there are services here too. . . practically everything you need.

In the above extract, Rauha is describing her living environment in terms of how she sees the rest of her life. Aging and old age were often cited by interviewees as a kind of "outer force" which dictated certain necessary criteria for future accommodation. For many, the senior housing complex fitted the bill insofar as it provides a buffer against social isolation and loneliness in old age, and some form of support should one's physical health require it. Not all residents saw themselves as prone to loneliness or social isolation, but it was more something that they feared might happen if they continued living in ordinary accommodation. Moving to the kind of accommodation they were now in was therefore a preemptive way to tackle this possibility, and to improve one's life in old age. Another crucial factor raised by many residents, and in Rauha, Hannu and Raimo's accounts above, was the matter of not only being able to choose one's social activities but also one's level of engagement in them. Senior housing should offer the possibility of company if desired, so that being alone or with others is a matter of choice rather than obligation.

As well as providing the chance to socialize, another important feature of the social environment raised by residents was that it should have easily accessible services and amenities. In the interviews, one of the most frequently cited of these services was public transport—either the local buses with a stop nearby, or dial-a-ride ones which would pick up and drop off residents right outside their home. In the following, Rauha talks more about these in relation to her own mobility issues.

Extract 8. Rauha

> *Rauha*: I can't really add anything else to that except to say that this is an ideal place since services are close, so you don't really need to go anywhere, but at the nearby mall there is everything anyway.
> *I*: OK
> *Rauha*: And there are buses too, then there's also this [name of dial-a-ride service] minibus, which picks you up and drops you off in front of this building [. . .].
> *I*: Do you use it?
> *Rauha*: Yes, yes, yes, whenever I need to get out, it's so handy since you don't need to walk anywhere. But I do also use the [ordinary] bus quite a lot too, as it's not like I need it [dial-a-ride], but for someone like me with mobility problems, and I do have a [wheeled walker] since my back hurts so much [it's nice]. I sometimes need to sit down when there are no seats around, so that's why I use one, but otherwise I don't need one.

In the majority of interviews, public transport was seen as a crucial resource, especially among those who did not have a car, but it was also important for those that did, who were thinking about a future when they might not. For many, like Rauha, both kinds of bus service allowed her to run errands independently which, if there are no friends or family nearby to assist, is clearly an advantage. For those residents who were single or childless, public transport was also essential for shopping elsewhere. It is interesting here, that Rauha downplays her need for the dial-a-ride option by pointing out that she also uses the normal bus—dial-a-ride is only for special occasions.

One thing this senior housing complex has that does not seem to be available in most other senior housing contexts is a community coordinator. This coordinator works part-time on site, and their salary is paid out of residents' monthly fees. The senior housing complex also has a private care provider who operates a small care home within the premises. Both of these were often mentioned as welcome reassurance of support in the future, even if they weren't services that were currently being used.

Extract 9. Martti ja Laura, a couple (see also extract 2)

> *Martti*: Yes, but I was talking about the community coordinator; she can help with things like if you can't get your internet banking, for instance, to work on your computer. If she can't help, then she will at least look for someone who can. . .
> *Laura*: And she's organized all sorts of things in our common room.
> *Martti*: And if you have papers you need to sort out with the bank, then she'll help you with that.
> [. . .]
> *Laura*: So yes, it really is excellent, and now there is also this [private service provider] here so, and I'm thinking of our situation if we get a bit more worse for wear, then it's just a case of ticking a few more boxes on our agreement contracts to have those services included. There are some people here who really have trouble starting their day so, even now, the people at [private service provider] take them breakfast [. . .], delivered directly to their home, and. . .
> *Martti*: And they make sure they take the right doses of medicine.
> *Laura*: Yes. . . all these kind of things
> *Martti*: They get the medicine from the pharmacist.
> Laura: So then it's quite natural [. . .] at this stage, when you cannot, when you start to lose your marbles, or there is some other reason that you need [. . .] round-the-clock care, that you can just be transferred there.
> *Martti*: And the [private service provider] gives you these safety alarm [. . .] wristbands.
> *Laura*: And for those of us who live here, we get a different price for this service. . .
> *Martti*: . . . for the continuous supervision.
> [. . .]
> *Martti*: And, what's really excellent compared to [previous home location] is the, well, a kind of, safe environment here. Of course, we had neighbors there, and we kind of got on OK, but here there is a broader network of people that give you this greater feeling of safety.

In many of the interviews, the community coordinator cropped up as the person who sorts out residents' various practical problems, especially with the internet, computers, banking or other official business. Another important job for the community coordinator mentioned in the interviews was arranging a range of activities for the residents. In this respect, the coordinator eased the burden of responsibility on those residents who were trying to organize activities, so residents felt encouraged to not only continue organizing activities, but also to engage in a wider range of them than might have been possible without the involvement of the coordinator.

The private care service provider also cropped up in the interviews as a form of support that might be relied on in the future should the need arise; it was thus seen as another potential resource that contributed toward making the living environment feel safer. As we could see in Martti's and Laura's interview above, knowing that the private care was in the same housing complex made them feel that it was quite safe to continue living in individual apartments, as relocation could be done gradually with an intermediate level of care being brought to them in their apartments, for instance, as one level of service.

In the last part of the extract above, Martti compares the "safe environment" of his present home with how he felt in his previous home. This was a theme often brought up by residents in their interviews. This feeling "safe" was expressed in a range of ways depending on what they were previously accustomed to: from Hannu's feeling that residents were able to just say "hi" to each other, to Martti's feeling that residents knew each other a lot better in the senior housing complex than in an ordinary apartment block; while for others, the feelings of safety were linked to the accessibility of amenities and services nearby and on the premises. Another important factor that increased these feelings of safety was knowing that there were resources provided for onsite which residents would be able to benefit from if their mental or physical health deteriorated with age. In most cases, residents had cited this eventuality as being one major reason for wanting to move into senior housing in the first place.

DISCUSSION

The senior housing in this study fulfilled its promise of providing a good example of a physical and social environment which encourages residents to be independent, enables them to continue life in the manner they've been accustomed to, yet which—at the same time—provides a new social network and activities that they can take up should they so choose. In this respect, the senior housing complex offered an environment which supports well-being and healthy aging (32). However, the analysis showed that the residents' interpretations of what the senior housing complex represented varied to such an extent that it was clearly not the same place for them all [cf. (39)]. Our study adds to the previous studies of collaborative housing by showing that the residents in collaborative senior housing may position themselves in relation to other residents but equally often to non-human aspects of the housing complex. While some residents value communal activities for some the primary value of housing lives elsewhere. Since the complex was advertised as a form of *communal* senior housing, there must certainly have been expectations that it would offer more than regular senior housing. Nevertheless, for some it was just that; a physical space, which via accessible and maintenance-free apartments and outdoor areas enabled them to continue their lifestyle and maintain existing social networks and family relations. Common areas and activities were described as being a possibility should they so choose, but not relevant to their own daily life. For others, however, the senior housing complex was first and foremost a social place. The senior housing complex was also portrayed as *a community in the making*—offering opportunities for new social contacts and social activities. These different perspectives were clearly illustrated in the kinds of language used by interviewees. While some residents emphasized that their main social contacts and social life was outside the housing complex, some of the residents talked about *our* common areas and the *we* who would meet, greet, and organize activities together. This use of the first-person plural clearly shows that they positioned themselves as members of a community to which they felt a sense of belonging.

An important novel finding of this study was received by using Agnew's (40) distinction to places and spaces. The senior housing complex was a special *place* for some residents and they felt they were very much part of it. At the same time, there were those who kept their distance and participated either very little or not at all in communal activities. For these residents, the housing complex was a generic living environment suitable for older people; *a space* which served its purpose but could be swapped with any other senior housing. This does not mean that attempts to create communal senior housing which encourages social contact is futile, but is simply a reminder of the fact that seniors are as heterogenous a group as any other in our society, and the people in this group have their own interests, preferences and aims in life. The residents chose to relocate to an environment which they anticipated as being supportive for older people, but they also chose the level of participation in activities within the housing complex. This reminds us that older people are agents in their environments (37), and not all of them want to grow old in old homes but are keen to actively shape their own living environment in later life (40).

Creating a living community is a process (39), and aging changes how we see our living environment, our homes, and the places we live (38). Residents spoke about the future in terms of anticipating deteriorating health and the restrictions this would cause. These "restrictions" determined views of appropriate housing and living environments for older people [cf. (40)]. A common feature in the data was that residents described themselves as aging people, and in so doing, old age was portrayed as an external force which set limits on their agency over determining places to live.

While there were clearly differences in regard to the importance of the communal aspects of the senior housing complex, there was general unanimity about the importance of its physical location: the easy access to amenities and services, the pleasant natural surroundings with the nearby lake and forest paths, and the good public transport. This accessibility also supported physical and social activities seen to be crucial for promoting well-being, as shown in previous studies (43). The accessibility of the physical environment and services allowed for greater mobility, which made it easier for residents (including those with health and mobility problems) to feel they had more control over their day-to-day life [cf. (13, 14)]. Special services—such as the community coordinator and dial-a-ride bus—were other important local initiatives which interestingly added to a sense of simultaneously feeling safe yet also independent. Human and non-human actors and policy practices clearly had a meaning in enhancing the well-being of the residents too, as stated in other studies (1, 7). New feature in some models of senior housing is to have ordinary and service housing within the same complex. In this case, novel finding of the study is that the presence of a private care company and 24/7 care unit on site were seen as a potential resource for the future rather than important on a day-to-day level. Thus, their meaning was more symbolic than practical, but potentially important in the future and adding to a sense of safety. This result shows that integrating service housing units to ordinary senior housing can be an important feature adding to the well-being of the residents.

For many residents, the physical and social environments were intertwined in many ways. The shared first floor, with its common room, restaurant, saunas, gyms and laundry facilitated contact between residents, so the architecture and design of the housing did encourage socializing [cf. (30, 31)]. For those more interested in participating in shared activities the communal senior housing offered a wide range of activities and social possibilities, as described in previous studies (17, 19, 27). A very important novel finding was that the residents' level of engagement in social activities varied from being simply observers to actively organizing events, but knowing that these activities—so meaningful to some residents—were simply there, was often enough to create a sense of belonging in the community, even among the more passive residents. Many residents talked about how the senior housing complex helped decrease feelings of loneliness, while increasing feelings of safety and security [cf. (8, 18, 21)]. Yet another novel finding was that even those who were not "deeply involved" in communal activities mentioned that simply knowing each other increased feelings of safety. The future life of the senior housing complex will prove whether it will have a lasting effect on residents' well-being and whether it will continue to function as a supportive community in the long run [cf. (22)]. For now, the communal senior housing complex, with its accessible environment and nearby amenities and services, offer a supportive environment that adds to the resources of its residents so that they can live a life that is satisfying both for themselves and for others.

The strength of the study is that the data represents views of people of different ages, both men and women, different housing tenures and with different reported health status. In addition, theories coming from geographical gerontology and environmental studies together with detailed analysis of language use and positioning analysis produced results that provide new ways to see the meaning of collaborative senior housing for the residents, as well the meaning and relation of human and non-human aspects in creating living environments that support well-being in later life. The limits of the study come from the fact that the data come from small-scale study that represents rather rare senior housing solution, and a small social and cultural context of one of the Nordic countries. The limits of the study mean that the results cannot be generalized directly to other countries or the analysis cannot be replicated as such. However, these limitations have been acknowledged and addressed and do not make futile the meaning and applicability of the study results.

CONCLUSIONS

New models of senior housing have appeared to fill the gap of so called "in-between" housing. These new models have the potential to offer an age-friendly environment where independent living is possible even with an age-related deterioration in functional abilities. Many of the new housing models aim also to offer social activities, mutual support, and help. However, the residents interviewed here had a range of expectations concerning the housing, just as they acted differently from other residents in their day-to-day life. These concerns do not mean that we should give up on new communal senior housing models, but instead prove the importance of approaching them as processes, which can develop according to how residents interact with their physical and social environment (39).

The senior housing complex analyzed here was in a Nordic country that purportedly has a good level of public social and health care services, with home care and residential care which is supposed to be available for all those in need of them. And yet, the rapid increase in new senior housing models could be an indication that existing housing and care models are not fulfilling the hopes and needs of current and new generations of older people. Therefore, I argue that the model discussed here may work even better in countries with less existing services for older people, and which traditionally rely on private self-care, family care, or housing solutions. While the results of the small-scale qualitative study are not directly generalizable to other countries the results offer a point of comparison, and provide innovative model of senior housing that can be experimented elsewhere to develop senior housing which supports well-being of the residents.

Firstly, this analysis showed that this type of housing has the potential to provide a social environment that supports the health and well-being of older people. Secondly, the hybrid nature of this kind of senior housing—with accessible premises, shared resources, social activities, and an on-site care unit—can provide a socially and economically viable solution for senior housing. However, there are some questions and concerns that need to be addressed—this kind of senior housing is available in a number of different countries, but mainly for only those who already have the health and financial resources to find a new place to live (18, 28). Many such options are rather expensive and available for the most part in only urban areas (20, 24). The question therefore remains as to how social practices, in the form of government policies (on both a national and local level) and market systems can support the development of different kinds of senior housing which are affordable and accessible for all (36). Alternative solutions, like the one studied here, which combine an age-friendly living environment with a communal type of housing, and which also mix tenures, require collaboration between the private, public, and third sectors, not to mention the active participation of the residents themselves (perhaps the most important agents in finding these solutions). Hybrid models require flexibility and innovation from all the actors involved, but as this analysis has hopefully shown, they may well offer a living environment for older people that is truly worth aspiring to.

The rapid growth of different senior housing models signals the need for a variety of in-between housing options for older people, and housing policy is the key to deciding if these exist, and if so, it also decides their location and tenure. Following Clapham (36) it can thus be argued that housing policy is an important tool for improving the well-being of elderly people, insofar as it can create accessible and affordable housing options which provide a supportive living environment.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because the data is in Finnish language. The anonymized data will be made available 2025. Requests to access the datasets should be directed to outi.jolanki@tuni.fi.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Human Sciences Ethics Committee, University of Jyväskylä, Finland. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

OJ has participated in the research group in planning the research project on senior housing, designing the data collection, collecting the data and the administrative task of data preparation for analysis purposed. OJ has planned the study at hand, analyzed the data, and written the final text as well revised the manuscript.

FUNDING

This study was enabled by the resources and funding provided by the Centre of Excellence in Research on Ageing and Care (CoE AgeCare) and Academy of Finland (grant number 312311). The author also wishes to thank Dr. Lina van Aerschot and Dr. Paula Vasara from the University of Jyväskylä, Department of Social Sciences and Health, for their invaluable role in participating in planning the research project on senior housing, designing the data collection, collecting the data, and participating in the administrative tasks of data preparation for analysis purposes.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.589371/full#supplementary-material

REFERENCES

1. Greenfield EA. Using ecological frameworks to advance a field of research, practice, and policy on aging-in-place initiatives. *Gerontologist.* (2012) 52:1–12. doi: 10.1093/geront/gnr108
2. Wiles JL, Leibning A, Guberman N, Reeve J, Allen RES. The meaning of "aging in place" to older people. *Gerontologist.* (2011) 52:357–66. doi: 10.1093/geront/gnr098
3. World Health Organisation. *A Glossary of Terms for Community Health Care and Services for Older Persons.* Geneva: World Health Organisation (2004). Available online at: https://www.who.int/ageing/publications/active_ageing/en/
4. Means R. Safe as a house? Ageing in place and vulnerable older people in the UK. *Social Policy Admin.* (2007) 46:302–20. doi: 10.1111/j.1467-9515.2007.00539.x
5. Mestheneos E. Ageing in place in the European Union. Global ageing. *Iss Action.* (2011) 7:17–24.
6. Netherland J, Finkelstein R, Gardner P. The age-friendly New York City project: an environmental intervention to increase aging resilience. In: Resnick B, Gwyther L, Roberto K, editors. *Resilience in Aging: Concepts, Research, and Outcomes.* New York, NY: Springer (2011). p. 273–87.
7. Lehning AJ. Local and regional governments and age-friendly communities: a case study of the San Francisco Bay area. *J. Ageing Soc Policy.* (2014) 26:102–16. doi: 10.1080/08959420.2014.854140
8. Berg-Warman A, Brodsky J. The supportive community: a new concept for enhancing the quality of life of elderly living in the community. *J Aging Soc Policy.* (2006) 18:69–83. doi: 10.1300/J031v18n02_05
9. Grant BC. Retirement villages: more than enclaves for the aged. *Act Adapt Aging.* (2006) 31:37–55. doi: 10.1300/J016v31n02_03
10. Yang H-Y, Stark SL. The role of environmental features in social engagement among residents living in assisted living facilities. *J Hous Elderly.* (2010) 24:28–43. doi: 10.1080/02763890903547062
11. Gonyea JG, Burnes K. Aging well at home: evaluation of a neighborhood-based pilot project to "Put connection back into community". *J Housing Elderly.* (2013) 27:333–47. doi: 10.1080/02763893.2013.813425
12. Graham CL, Scharlach A, Price Wolf J. The impact of the "village" model on health, well-being, service access, and social engagement of older adults. *Health Educ Behav.* (2014) 41.1(Suppl):91S–7S. doi: 10.1177/1090198114532290
13. Astell-Burt T, Feng X, Kolt GS. Green space is associated with walking and moderate-to-vigorous physical activity (MVPA) in middle-to-older-aged adults: findings from 203 883 Australians in the 45 and up study. *Br J Sports Med.* (2014) 48:404–6. doi: 10.1136/bjsports-2012-092006
14. Portegijs E, Rantakokko M, Mikkola TM, Viljanen A, Rantanen T. Association between physical performance and sense of autonomy in outdoor activities and life-space mobility in community-dwelling older people. *J Am Geriatr Soc.* (2014) 62:615–21. doi: 10.1111/jgs.12763
15. Löfqvist C, Granbom M, Himmelsbach I, Iwarsson S, Oswald F, Haak M. Voices on relocation and aging in place in very old age – a complex and ambivalent matter, *Gerontologist.* (2013) 53:919–27. doi: 10.1093/geront/gnt034
16. Abramsson M, Andersson E. Changing preferences with ageing - housing choices and housing plans of older people. *Housing Theory Soc.* (2016) 33:217–41. doi: 10.1080/14036096.2015.1104385
17. Jolanki O, Vilkko A. The meaning of a "sense of community" in a finnish senior co-housing community. *J Housing Elderly.* (2015) 29:111–25. doi: 10.1080/02763893.2015.989767
18. Baldwin C, Dendle K, McKinlay A. Initiating senior co-housing: People, place, long-term security. *J Housing Elderly.* (2019) 33:358–81. doi: 10.1080/02763893.2019.1583152
19. Bamford G. Cohousing of older people: housing innovation in the Netherlands and Denmark. *Aust J Ageing.* (2005) 24:44–6. doi: 10.1111/j.1741-6612.2005.00065.x
20. Choi JS. Evaluation of community planning and life of senior cohousing projects in northern European countries. *Eur Planning Stud.* (2004) 12:1189–216. doi: 10.1080/0965431042000289296
21. Glass AP. Aging in a community of mutual support: the emergence of an elder intentional cohousing community in the United States. *J Housing Elderly.* (2009) 23:283–303. doi: 10.1080/02763890903326970
22. Glass PA, Vander Plaats RS. A conceptual model for aging better together intentionally. *J Aging Stud.* (2013) 27:428–42. doi: 10.1016/j.jaging.2013.10.001
23. Labit A. Self-managed co-housing in the context of an ageing population in Europe. *Urban Res Prac.* (2015) 8:32–45. doi: 10.1080/17535069.2015.1011425
24. Scharlach AE, Davitt JK, Lehning AJ, Greenfield EA, Graham CL. Does the village model help to foster age-friendly communities? *J Aging Soc Policy.* (2014) 26:181–96. doi: 10.1080/08959420.2014.854664
25. Tyvimaa T, Kemp CL. Finnish seniors' move to a senior house: examining the push and pull factors. *J Housing Elderly.* (2011) 25:50–71. doi: 10.1080/02763893.2011.545742
26. Rowles GD, Bernard M. The meaning and significance of place in old age. In: Rowles GD, Bernard M, editors. Environmental Gerontology. *Making Meaningful Places in Old Age.* New York, NY: Springer (2013). p. 3–24.
27. Glass AP. Resident-managed elder intentional neighborhoods: do they promote social resources for older adults? *J Gerontol Soc Work.* (2016) 59:554–71. doi: 10.1080/01634372.2016.1246501
28. Bernard M, Liddle J, Bartlam B, Scharf T, Sim J. Then and now: evolving community in the context of a retirement village. *Ageing Soc.* (2012) 32:103–29. doi: 10.1017/S0144686X11000079
29. Statistics Finland. *(SVT Tilastokeskus 2018). Asunnot ja Asuinolot [Housing and Housing Conditions].* (2018). Available online at: http://www.stat.fi/til/asas/index.html
30. Giery TF. What buildings do? *Theory Soc.* (2002) 31:35–74. doi: 10.1023/A:1014404201290
31. Nord C. Architectural space as a molding factor of care practices and residential privacy in assisted living. *Ageing Soc.* (2011) 31:935–52. doi: 10.1017/S0144686X10001248

32. Bartlett H, Peel N. Healthy ageing in the community. In: Andrews GJ, Phillips DJ, editors. *Ageing and Place. Perspectives, Policy, Practice*. New York, NY; Oxon: Routledge (2005). p. 98–109.
33. Iwarsson S. Assessing the fit between older people and their physical home environments: an occupational therapy research perspective. In: Wahl HW, Scheidt RJ, Windley PG, editors. *Annual Review of Gerontology and Geriatrics. Aging in Context: Socio-Physical Environments*. New York, NY: Springer (2004). p. 85–109.
34. Sixsmith J, Oswald F, Iwarsson S, Fänge A, Schilling O. Relationships between housing and healthy ageing in very old age. *Gerontologist.* (2007) 47:96–107. doi: 10.1093/geront/47.1.96
35. Clapham D, Foye C, Christian J. The concept of subjective well-being in housing research. *Housing Theory Soc.* (2018) 35:261–80. doi: 10.1080/14036096.2017.1348391
36. Clapham D. Happiness, well-being and housing policy. *Policy Polit.* (2010) 38:253–67. doi: 10.1332/030557310X488457
37. Cutchin MP. Active relationships of ageing people and place. In: Skinner MW, Andrews GJ, Cutchin MP, editors. *Geographical Gerontology. Perspectives, Concepts, Approaches*. London; New York, NY: Routledge (2018). p. 216–28.
38. Wahl HW, Lang F. Aging in the context of adult life course: integrating physical and social environmental research perspectives. *Ann Rev Gerontol Geriatr*. (2004) 23:1–33. doi: 10.1891/0198_8794.23.1.1
39. Wiles J. Conceptualizing place in the care of older people: the contributions of geographical gerontology. *J Clin Nursing.* (2005) 14:100–8. doi: 10.1111/j.1365-2702.2005.01281.x
40. Agnew J. Space and place. In: Agnew J, Livingstone D, editors. *The SAGE Handbook of Geographical Knowledge.* London: Sage (2011). p. 316–30.
41. Harré R, Moghaddam F. *The Self and Others: Positioning Individuals and Groups in Personal, Political and Cultural Contexts*. Westport, CT: Prager (2003)
42. de Medeiros K, Rubinstein RL, Doyle PJ. A place of one's own: reinterpreting the meaning of home among childless older women. In: Rowles G, Bernard M, editors. *Environmental Gerontology. Making Meaningful Places in Old Age*. New York, NY: Springer (2013). p. 79–102.
43. Thoits PA. Mechanism linking social ties and support to physiological and mental health. *J Health Social Behav*. (2011) 52:145–61. doi: 10.1177/0022146510395592

Conflict of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

MINI REVIEW
published: 11 March 2021
doi: 10.3389/fpubh.2021.578832

Check for updates

Use of Connected Technologies to Assess Barriers and Stressors for Age and Disability-Friendly Communities

Preeti Zanwar[1,2,3]*, *Jinwoo Kim*[4], *Jaeyoon Kim*[5], *Michael Manser*[6], *Youngjib Ham*[5], *Theodora Chaspari*[7] and *Changbum Ryan Ahn*[1,5]

[1] *Center for Population Health and Aging, School of Public Health, Texas A&M University, College Station, TX, United States,* [2] *Center for Health Systems and Design, Colleges of Architecture and Medicine, Texas A&M University, College Station, TX, United States,* [3] *Network on Life Course and Health Dynamics and Disparities, University of Southern California, Los Angeles, CA, United States,* [4] *Department of Multidisciplinary Engineering, College of Engineering, Texas A&M University, College Station, TX, United States,* [5] *Department of Construction Science, College of Architecture, Texas A&M University, College Station, TX, United States,* [6] *Texas A&M Transportation Institute, Texas A&M University System, College Station, TX, United States,* [7] *Department of Computer Science and Engineering, College of Engineering, Texas A&M University, College Station, TX, United States*

Background: The benefits of engaging in outdoor physical activity are numerous for older adults. However, previous work on outdoor monitoring of physical activities did not sufficiently identify how older adults characterize and respond to diverse elements of urban built environments, including structural characteristics, safety attributes, and aesthetics.

Objective: To synthesize emerging multidisciplinary trends on the use of connected technologies to assess environmental barriers and stressors among older adults and for persons with disability.

Methods: A multidisciplinary overview and literature synthesis.

Results: First, we review measurement and monitoring of outdoor physical activity in community environments and during transport using wearable sensing technologies, their contextualization and using smartphone-based applications. We describe physiological responses (e.g., gait patterns, electrodermal activity, brain activity, and heart rate), stressors and physical barriers during outdoor physical activity. Second, we review the use of visual data (e.g., Google street images, Street score) and machine learning algorithms to assess physical (e.g., walkability) and emotional stressors (e.g., stress) in community environments and their impact on human perception. Third, we synthesize the challenges and limitations of using real-time smartphone-based data on driving behavior, incompatibility with software data platforms, and the potential for such data to be confounded by environmental signals in older adults. Lastly, we summarize alternative modes of transport for older adults and for persons with disability.

Conclusion: Environmental design for connected technologies, interventions to promote independence and mobility, and to reduce barriers and stressors, likely requires smart connected age and disability-friendly communities and cities.

Keywords: stressors, connected technologies, wearable sensors, computer vision, transport technologies, alternative transport modes, age-friendly communities, disability-friendly communities

Edited by:
Erja Portegijs,
University of Jyväskylä, Finland

Reviewed by:
Steven A. Cohen,
University of Rhode Island,
United States
Sinan Zhong,
Texas A&M University College Station,
United States

***Correspondence:**
Preeti Zanwar
Preeti.Zanwar@alumni.uth.edu

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *01 July 2020*
Accepted: *20 January 2021*
Published: *11 March 2021*

Citation:
Zanwar P, Kim J, Kim J, Manser M, Ham Y, Chaspari T and Ahn CR (2021) Use of Connected Technologies to Assess Barriers and Stressors for Age and Disability-Friendly Communities. Front. Public Health 9:578832. doi: 10.3389/fpubh.2021.578832

INTRODUCTION

Nearly one-fourth percent of the United States (U.S.) population is an older adult; one-fifth have a disability (1). The population of the older adults in the U.S. is projected to increase to 94.7 million by 2060 (1). About 90% of the older population would prefer to age in their homes and communities instead of institutional settings (1). Outdoor physical activity has multitudinous advantages for older adults (2). Physical activity can help reduce the risk of mental health problems and physical disease, such as depression, obesity, cancer, and cardiovascular diseases (2). Maintenance of safe mobility is essential for successful aging in communities and a major challenge faced by older adults. Those with limitations cease driving and depend on their caregivers, informal supports and services, or other alternative modes of transport to stay connected and mobile. For older adults to stay mobile, it is essential their physical and service environment is stressor and barrier free. Therefore, monitoring of outdoor physical activities is an area of high priority and a need (3).

While benefits of engaging with environment are numerous, such built environments can impose numerous barriers and stressors for older adults and for persons with disabilities to age-in-place. Prior studies/reviews have been conducted various demographic groups, such as older adults (4, 5), premenopausal women (6), children (7), and obese adults (8) to examine the relationship between urban elements (e.g., transportation systems, neighborhood disorders, land use) and their behaviors (9). However, prior studies could not sufficiently identify how older adults respond to diverse elements of urban built environments, including structural characteristics, safety attributes, and aesthetics. No prior review has explored the variety of stressors and barriers that can hinder healthy aging in one's preferred environments. Our review was aimed to fill this gap. The rational was 2-fold: (i) to assess the use of physiological responses to identify how older adults react to their ascribed environments during outdoor physical activity using physiologic responses, and to identify the (ii) needs of communities to adapt to the needs of older adult's so they can age-in-place.

We know connected technologies have numerous benefits and potential to allow older adults and those with disabilities to facilitate safe mobility, reduce falls and allow for partaking in outdoor physical activity. Traditional technologies have become outdated and emerging technologies are rapidly evolving. The purpose of this mini-review was to synthesize and describe the use of three emerging connected technologies to mitigate barriers and stressors to environmental stimuli for older adults and those with disabilities from a multidisciplinary perspective (e.g., from population health and aging, to health systems and design, to life-course health dynamics and disparities, to computer science and multidisciplinary engineering, to construction, architecture and transportation science), with the motivation for older adults and those with disabilities of all ages to successfully age in their neighborhoods and in their community and in their city environments. We defined connected or smart technology as embedded technology with sensors, processors, camera, and location services that would allow connection and communication with its environment *via* internet of things and provide data that could be accessed and analyzed *via* a platform. Additionally, the review provides challenges of collection, processing and analysis of mobile, real-time connected data from smartphones in various populations, including older adults, and how such data can be aggregated and visualized.

METHODS

We conducted a literature review with no date restriction on connected technologies for older adults and for those with disability. We focused on three key connected technologies to assess stressors and barriers in community environments: (1) wearable sensing technologies; (2) computer vision techniques; and (3) transport needs, technologies and options for alternative transport modes. We used the following keywords "wearable sensing," "physiological signals," "physical activity or disorders," "urban built environment," "environmental barriers or stressors or stimuli," "human perception of images," "street-level scene," "convolutional neural networks," "mobile transport technologies," "older adult modes of transport."

RESULTS

Our results are summarized below as three separate topics.

Assessing Barriers and Stressors in Community Environments Through Wearable Sensing Technologies

Outdoor physical activities can be described as sleep/wake or as active/sedentary behavior (10, 11). These activities can be quantified by intensity of physical activity (12) or activity energy expenditure (13) or activities of daily living such as walking, running, sitting, stepping (14), and by using various transportation modes such bus, bicycle, car, and subway (15). The ambulatory monitoring of these measures requires comfortable, inexpensive, and accurate equipment, such as wearable devices.

The various confounding factors presented in the captured real-life data further require the contextualization of the corresponding signals, which can be achieved through location tracking with Global Positioning System coordinates (16). With recent advancements in sensing technologies, products such as Actigraph unit (4), Actical (7), Sensewear (8), and GENEActiv (17) can be drawn upon in an integrated electronic device (14). The device contains an Inertial Measurement Unit (IMU), ambient light sensor, sound detector, skin temperature sensor, and heat flux (9–11, 13). Wearable devices are generally worn on one's wrist or chest over a prolonged period of time.

Additionally, the sensors can be integrated with a smartphone-based application such as the Daynamica (15) and Discovery Tool to provide transparent data with the subjective user input *via* survey (18). For example, the Daynamica has been used to deliver personalized and context-aware interventions to app users in several research projects such as investigating the association among travel options, built and natural environments, and mood states in transport environments (15).

The physiological responses of older adult pedestrians can be reflective of human experience toward a surrounding environment, providing us unique insights into the elements of the urban built environments (e.g., neighborhood disorders and environmental barriers) (19–23). Various types of physiological response data including gait patterns, electrodermal activity (EDA), heart rate and brain activity (22, 24–26) have been have been investigated from collected physiological signals in virtual environments (27–29) naturalistic ambulatory settings and daily life locations, such as neighborhoods, downtown, urban parks, and university campuses (18, 20, 22, 23, 30–35). See **Table 1** for a full list of references (18–32, 36–55). The physiological response data have been examined to recognize stress during walking trips and/or stressors of the surrounding environment on personal characteristics such as age (32, 38), gender (20), and degree of disability (37). The researchers investigated how specific populations including older adults and those visually impaired respond to the elements of urban built environment during walking trips.

In general, the gait pattern has been shown to correlate with physical barriers of urban built environments such as sidewalk defects, curbs, slopes, and holes (19–23, 43–52) (See **Table 1**). Signals, such as electrodermal activity (18, 21–25, 27–31, 36–42), electrocardiography or photoplethysmography (18, 20–23, 28, 36–40, 52, 53) and brain activity (26, 32, 40, 54, 55), have been separately used to understand psychological states toward stressors in relation to negative environmental stimuli (e.g., broken houses, barking dogs, and steep stairs) and the mood of walking paths such as urban busy and quiet areas (23, 30–32). Despite the premise and potential of ambulatory monitoring approaches to overcome the subjectivity related to traditional approaches (e.g., self-reporting and surveys), physiological data collected in real-life environments are confounded by various factors (e.g., weather conditions, physical movement, and the discomfort of wearing sensors) (20, 23–27). Additional testing and evaluation of such approaches is expected to provide a basis for developing a monitoring indicator of the elements of urban built environments to promote mobility for specific demographic groups (e.g., older adults, and those with disabilities).

Assessing Barriers and Stressors in Community Environments Through Computer Vision Techniques

To understand the source of physical and emotional distress, visual data such as street-level images are effective (20, 21, 53–55). A physical appearance of urban built environments *via* street-level images can be assessed based on human perception (59). Another tool, a visual perception survey, has been utilized to assess infrastructure defects or neighborhood disorders that can negatively affect behaviors in built environments. Such a survey tool can be leveraged for assessing stressors related to older adults' mobility and the associated physical and emotional distress through computer vision techniques. Although human perception of images is subjective (60, 61), leveraging a large amount of data obtained from a web-survey in online photo-sharing ensures the robustness of using visual data to assess human perception. An example is Photo.net started in 1997 by Philip Greenspun at MIT to study the aesthetics score of images based on peer ratings (62). This peer-rating system could be used to understand stressors in community environments and to analyze their impact on human perception. In this context, scene understanding algorithms building on the computer vision techniques have been examined. An example is the prediction of the perceived safety of a street-level scene, called "Streetscore" created as a training dataset using a machine learning model (59). Another example is the random selection and ranking of several

TABLE 1 | Summary of stressors in community environments through wearable sensing technologies and computer vision techniques for adults and for those with disability.

Author (year)	Location (Country)	Measures	Stressors
Wilhelm et al. (36); Chaspari et al. (24); Chaspari et al. (25); Saitis and Kalimeri (37); Osborne and Jones (27); Tilley et al. (38); Chrisinger and King (18); Yadav et al. (39); Can et al. (40); Hackman et al. (28); Hedblom et al. (29); Kim et al. (21); Lee et al. (41); Ojha et al. (42); Ahn et al. (22); Kim et al. (23); Lee et al. (30, 31)	United States, United Kingdom, Iceland, Switzerland	Electrodermal activity	Mild electric shocks in the virtual environments of urban parks and forests; graffiti; garbage; litter on street; lack of curb ramp; side slopes; vertical displacement; sidewalk obstructions; unpaved sidewalk; sound level; illuminance; dust in the air; relative humidity; broken house; barking dogs; uneven sidewalk; no sidewalks; tree limb; and a storage for gas container
Jebelli et al. (43); Jebelli et al. (44); Kim et al. (19); Yang et al. (45); Kim et al. (46); Yang et al. (47); Duchowny et al. (48); Kim et al. (49); Ahn et al. (26); Kim et al. (20), Kim et al. (21); Twardzik et al. (50); Yang et al. (51); Ahn et al. (22); Kim et al. (23); Bisadi et al. (52)	United States	Gait patterns	Sidewalk condition; presence of holes, sidewalk slopes, bumps, a curb cut; broken house; barking dogs; uneven sidewalk; no sidewalks; tree limb; and a storage for gas container
Wilhelm et al. (36); Goto et al. (53); Chrisinger and King (18); Can et al. (40); Hackman et al. (28); Kim et al. (20), Kim et al. (21); Ahn et al. (22); Kim et al. (23); Bisadi et al. (52)	United States, Switzerland	Electrocardiography or Photoplethysmography	Graffiti; garbage; litter on street; broken house; barking dogs; uneven sidewalks; no sidewalks; tree limb; and a storage for gas container
Li et al. (54); Jebelli et al. (55); Ahn et al. (26); Can et al. (40); Neale et al. (32)	United States, United Kingdom	Brain activity	The mood of walking paths (e.g., urban greens, urban busy, and urban quite)
Ham and Kim (56); Ham and Kim (57); Kim and Ham (58); Kim et al. (20); Kim et al. (21), Naik et al. (59)	United States	Image scores	Residential windows; graffiti; cracks on roads; vegetation; abandoned cars; garbage on the street or sidewalks; intense land uses; and traffic

Google Street-view images from New York, Boston, Linz, and Salzburg through a pairwise comparison (63).

In case studies, large amounts of data, on 4,109 multiple generic images were extracted for semantic scene classification and ranked through 208,738 pairwise comparisons operated by 7,782 participants (64). A trained using Support Vector Regression was used to create dataset of predicted perceived safety scores based on the Google Street-view and using a human- machine scoring framework (61, 65). The performance of the predictor was evaluated by comparing it to pairwise comparison. This research showed the potential to assess a human safety perception of the street- level scene using the computer vision techniques. However, challenges remained and included the predictor potentially failing when unusual visual elements such as atypical architecture were represented in images. Pairwise comparisons from the perspective of older adults can assess urban built environments that can cause physical and emotional distress. Additionally, vector algorithms and participatory sensing-based geospatial localization can evaluate objects in urban built environments (56, 58).

In order to scale up the computational methods to map the perceived safety to the city level and/or to the global scale, convolutional neural network models have been utilized, albeit with some challenges (57, 66). For example the dataset, called "Place Pulse 2.0, containing 110,988 images with 1.17 million pairwise comparisons, and scored by 81,630 online volunteers (59) answered six perceptual dimensions: safe, depressing, boring, lively, wealthy, and beautiful. This dataset was used to train two related convolutional neural networks: (1) Street score-CNN (SS-CNN) and (2) Ranking SS- CNN (RSS-CNN). The SS-CNN was designed for binary classification to predict which image will win against another in a pairwise comparison, but this network did not consider the total ranking over all the images in the dataset. The RSS-CNN included an additional ranking sub- network resulting in the minimization of loss on pairwise classification and total ranking over the dataset but had challenges on identifying exactly what objects in scenes create the human perception.

Assessing Barriers and Stressors in Community Environments Through Transport Technologies, Needs, and Alternative Transport Modes

The early research on utility of transport technologies, focused on understanding driving patterns of teen drivers and how to use technology-based feedback. Such feedback included, identification of risky driving behavior (e.g., hard braking, severe turns), of mobility patterns (e.g., where and when teens drove them vehicles), and of (e.g., crashes) with the aim to eventually improve driving performance and safety (67–69). The continual evolution of low-cost, small size computing platforms has created significant opportunities to develop and deploy mobile transportation technologies and has allowed for a greater understanding of mobility patterns, and transportation needs of older adults and those with disabilities. There has been at least one demonstration effort to adapt this technology to improve older driver behaviors and safety. Manser developed smartphone-based software to collect driving behavior data in real-time and to provide behavioral and safety relevant cues that targeted motoric, cognitive, and perceptual challenges experienced by older drivers (70).

The results from the demonstration project suggests smartphone technologies can be suitably adapted to address several challenges for older drivers. However, there is a need to address individual differences to a greater degree.

Additionally, there have been significant advances in using large data pools to identify, understand, and modify driver behaviors. This data is most commonly collected by sensor sets in modern vehicles, transmitted to vehicle manufacturers, and then aggregated for use by the manufacturer or a third party (e.g., Otonomo, Wejo). The full utility of this data is being explored. Early uses include facilitating municipality and state agencies' ability to identify crash hot spots and deploy engineering-based countermeasures to modify vehicle operational parameters for optimized driver/vehicle interactions, and to assess the safety impacts of infrastructure-based infrastructure-based safety countermeasures.

The transport technologies pose two specific limitations and opportunities in their ability to address the user design needs, mobility patterns and transportation needs of older drivers and for persons with disabilities. First, mobile transportation technologies, such as smartphones require calibration to vehicles, can present data quality issues due to poorly secured mounting and can often run on specific smartphone platforms. Second, these physical considerations for secured mounting can limit the extent with which the technologies can be deployed and the scope to which they can benefit drivers.

In contrast, large data pools are collecting information from millions of vehicles across the U.S. every day. This is resulting in massive quantities of data without the need to consider any physical data limitations. Although, this may seem like a suitable solution; nevertheless, large data pools explicitly omit personally identifiable information (PII) or data that may lead to PII (e.g., location tracking near client homes). Additionally, large data pools do not provide questionnaires, surveys, and focus groups for a more complete understanding of the issues associated with older drivers and/or drivers with disabilities (71, 72). When considering the limitations for each approach for the aforementioned vulnerable populations it is evident no single solution is best for addressing the critical research questions to improve driver behavior and safety. There is reason for optimism. There are some preliminary, albeit undocumented, efforts to aggregate, mine and process multiple sources of connected (e.g., smartphone, vehicle, infrastructure, and environment). Such efforts include use of multi-sensor fusion techniques (73), aggregation of spatiotemporal data using machine learning algorithms, and use of artificial intelligence for block-chain enabled intelligent internet of things (loT) architecture to reach inference by minimizing and/or eliminating the limitations of individual data sources (74–76).

In older adults and/or in those with complex conditions [e.g., those with physical/cognitive disability, loss of driving privileges require alternative transportation options to reduce caregiver

TABLE 2 | Transport technologies, options and alternatives modes of service for older adults and for those with disability.

Author (year)	Mode of transportation	Examples	Benefits / Services	Limitations
Lee et al. (77); Walker et al. (78)	Next generation cars with ubiquitous or pervasive healthcare technologies	U-Cars with augmented reality	Context aware and processing capabilities, greater penetration of navigation and telematics systems, 3D visualization, wire and collision sensing technologies, driver assistance can automate driving task	More research is needed on usability, preferences, design, accessibility for older adults, will require 5G network, internet of things (IoT) platform and digital city infrastructure
Taylor et al. (79); Dickerson et al. (80)	Informal Supports/Caregivers	Family members; adult grand children	Provide real-time monitoring for daily activities and routes; fully instrumented residential neighborhoods	Caregivers may have other obligations such as work, family and may not be available
Saskatoon Council on Aging (81)	Public Ground Transport	Access bus, Train, Subways, Wheelchair Taxis	Some can be free or discounted for older adults, low-cost; specific seat accommodations for wheelchair users; some buses can "kneel" closer to ground, requires older adults to be relatively mobile	Fixed routes, services may not be available all times or during holidays; distance to public station to access services may be an issue; escort may not be available
Paratransit Services (82)	Paratransit	Specially Equipped Shuttles, Vans, Microbuses, Commercial Taxi's	For older adults and those with disabilities, pick-up at doorstep, escort services available to carry items and to ensure safely return to home; available at reduced fares by public transport for area aging agencies, may be operated both publicly or privately	May be more available in urban than rural areas, low-income older adults may not be able to afford
Senior Ride Sharing (83); Vivoda et al. (84); Rosenbloom et al. (85)	Ride Sharing (Fee-for-Hire)	Uber, Lyft, E-hail, SilverRide, GoGoGrandparent	Operate *via* apps from smartphones; pick up and drop off location set by user at their time, can call driver of rideshare; older adult or disability specific services available with large companies (e.g., UberAssist); higher service for higher pay available (e.g., Lyft); inclusive, safe and low-cost with older adult specific training (e.g., SilverRide), GoGoGrandparent)	Expensive (Uber and Lyft), access in rural areas difficult due to not enough drivers; have to reserve 24 h in advance (e.g., SilverRide)
Choi et al. (86)	Supplemental Transportation Programs (STPs)	Grassroots and community based informal senior transportation services	Low-cost; highly responsive to individual needs, local transportation services,	May not be available in rural towns
Senior Ride Sharing (83)	Medicaid Non-Emergency Medical Transportation (NEMT)	Rides might be by taxi, car, van, public bus, or a subway	For those with Medicaid eligibility, will cover cost of non-emergency transport to and from medical services and appointments, do not need to have a working vehicle available in the household; good option for those unable to travel or have a physical, cognitive, mental, or developmental limitation	Will not cover non-emergency non-medical transport, which is what older adults may need for the majority of the time
Social Transportation (87)	Social Transportation	Papa	Companionship and transportation for seniors and those with disabilities; door-to-door transportation to doctor's office, drug store, grocery store, with safety and compassion as key focus.	May not be available in all cities
Harper et al. (88); Meyer et al. (89); Bergmann et al. (90)	Autonomous Vehicles (AV's)	Tesla Autopilot, Nissan ProPilot Assist, Mercedes-Benz Distronic Plus, General Motors Super Cruise	Increase in mobility for older adults with and without restrictive medical conditions, such as those with disabilities; allows for more vehicle miles traveled; higher comfort of traveling at lower prices, can increase accessibility	Challenges with moral decision making

burden and to maintain independence and mobility (5, 71, 72)]. Community living younger and older adults and those with disabilities need access to transportation for timely medical and preventive care (71, 72). These vulnerable populations have transport needs to stay mobile in their communities for their well-being and for improved quality-of-life. Alternative options are needed for other transport modes beyond driving. These alternates transport modes are public ground transport (bus, subway, train), paratransit (vans/shuttles), fee-for-hire transportation (e.g., Lyft, Uber, E-hail, SilverRide, GoGoGrandParent), supplemental transportation programs (STPs), Medicaid non-emergency medical transportation, social transportation, and autonomous vehicles; see **Table 2** (77–90).

DISCUSSION

Our review synthesizing emerging trends on connected technologies, such as wearable sensors, computer vision techniques, and for transport technologies to mitigate barriers and stressors to environmental stimuli to assist safe mobility for age and disability-friendly communities. Given limited reviews exist on new generation technologies, this review is timely and novel, as it synthesizes findings from multidisciplinary perspectives.

We conducted a comprehensive review on stressors and identified numerous challenges and confounders involving connected technologies and for connected data. Challenges for user studies involving older adult population include high subjectivity of self-reports, challenges with wearable technologies, and confounding factors on the signals related to their health conditions. Additional testing and evaluation of such approaches is expected to provide a basis for developing an indicator to monitor elements of the urban built environment for specific demographic groups (e.g., younger and older adults and those with disabilities) with the goal to promote older adult's mobility. Future research on assessing stressors using vision data would involve exploring involve exploring the determinants of perceptual factors of distress in community environments. In addition, there is a need for building scene-centric databases with scene categories in the context of environmental stressors causing physical and emotional distress.

We acknowledge several limitations. Despite conducting a thorough review of literature, we may have missed other relevant findings. Additional limitations may be related to location (e.g., country) and populations (e.g., age group and gender). These can minimize the generalizability of our results in different social, cultural, population, and environmental contexts.

CONCLUSION

Environmental design for connected technologies and interventions to promote independence/mobility and to reduce barriers and stressors likely requires smart connected age and disability-friendly communities and cities (1, 5, 32, 71, 72, 91). Additionally, retaining older adults in a community who otherwise might leave to institutional settings can be an important economic policy and city development strategy.

AUTHOR CONTRIBUTIONS

PZ, JiK, JaK, MM, YH, TC, and CRA conception of mini-review, literature review, and for important intellectual content. PZ synthesized the first draft, it's revisions, and the final draft. CRA was responsible for securing funds. PZ, JiK, JaK, YH, and TC assisted with subsequent revisions. All authors contributed to the topics for this mini-review and approved the final version.

FUNDING

This work was supported by Texas A&M University President's Research Excellence, Interdisciplinary X-Grants (Round 2) to CRA (Team Lead), Chanam Lee, TC, YH, MM, and PZ.

ACKNOWLEDGMENTS

We thank Chanam Lee, Professor of Landscape Architecture and Urban Planning and founding director of Design Research for Active Living (DrAL) at Texas A&M University and Changbum Ryan Ahn, Associate Professor of the Department of Construction Science at Texas A&M University for suggestions on the topic focus and with the feedback on the preliminary version of the abstract. We are grateful to Margaret Foster, Professor and Systematic Review Coordinator at the Medical Sciences Library at Texas A&M University Libraries for helpful suggestions on the revision of the mini-review. The preliminary version of this paper was presented at the 2020 virtual Alzheimer's Association International Conference (AAIC).

REFERENCES

1. US Department of Health, and Human Services. *Administration for Community Living. Profile of Older Americans.* (2018). Available online at: https://acl.gov/aging-and-disability-in-america/data-and-research/profile-older-americans (accessed January 30, 2021).
2. Manferdelli G, La Torre A, Codella R. Outdoor physical activity bears multiple benefits to health and society. *J Sports Med Phys Fitness*. (2019) 59:868–79. doi: 10.23736/S0022-4707.18.08771-6
3. Gao W, Emaminejad S, Nyein HYY, Challa S, Chen K, Peck A, et al. Fully integrated wearable sensor arrays for multiplexed *in situ* perspiration analysis. *Nature*. (2016) 529:509–14. doi: 10.1038/nature16521
4. Barreira TV, Brouillette RM, Foil HC, Keller JN, Tudor-Locke C. Comparison of older adults' steps per day using an NL-1000 pedometer and two GT3X+ accelerometer filters. *J Aging Phys Activ*. (2013) 21:402–16. doi: 10.1123/japa.21.4.402
5. Zanwar P, McGrew G, Heyn PC, Raji M. Assistive technology megatrends to support persons with Alzheimer's disease and related dementias age in habitat:

challenges for usability, engineering, and public policy. In: *Proceedings of the Workshop on Human-Habitat for Health (H3): Human-Habitat Multimodal Interaction for Promoting Health and Well-Being in the Internet of Things Era H3'18*. New York, NY: ACM (2018). doi: 10.1145/3279963.3279971

6. Stiles VH, Griew PJ, Rowlands AV. Use of accelerometry to classify activity beneficial to bone in premenopausal women. *Med Sci Sports Exerc*. (2013) 669 45:2353–61. doi: 10.1249/MSS.0b013e31829ba765
7. Pfeiffer KA, Mciver KL, Dowda M, Almeida MJCA, Pate RR. Validation and 671 calibration of the actical accelerometer in preschool children. *Med Sci Sports Exerc*. (2006) 38:152–7. doi: 10.1249/01.mss.0000183219.44127.e7
8. Shuger SL, Barry VW, Sui X, McClain A, Hand GA, Wilcox S, et al. Electronic feedback in a diet- and physical activity-based lifestyle intervention for weight loss: a randomized controlled trial. *Int J Behav Nutr Phys Activ*. (2011) 8:41. doi: 10.1186/1479-5868-8-41
9. Schepps MA, Shiroma EJ, Kamada M, Harris TB, Lee I-M. Day length is 677 associated with physical activity and sedentary behavior among older women. *Sci Rep*. (2018) 8:6602. doi: 10.1038/s41598-018-25145-w
10. Baron KG, Reid KJ, Kim T, Van Horn L, Attarian H, Wolfe L, et al. 679 Circadian timing and alignment in healthy adults: associations with BMI, 680 body fat, caloric intake and physical activity. *Int J Obes*. (2017) 41:203–9. doi: 10.1038/ijo.2016.194
11. Gibbs BB, Aaby D, Siddique J, Reis JP, Sternfeld B, Whitaker K, et al. Bidirectional 10-year associations of accelerometer-measured sedentary behavior and activity categories with weight among middle-aged adults. *Int J Obes*. (2020) 44:559–67. doi: 10.1038/s41366-019-0443-8
12. Leppänen MH, Nyström CD, Henriksson P, Pomeroy J, Ruiz JR, Ortega FB, et al. Physical activity intensity, sedentary behavior, body composition and physical fitness in 4-year-old children: results from the ministop trial. *Int J Obes*. (2016) 40:1126–33. doi: 10.1038/ijo.2016.54
13. Delisle Nyström C, Pomeroy J, Henriksson P, Forsum E, Ortega FB, Maddison R, et al. Evaluation of the wrist-worn ActiGraph wGT3x-BT for estimating activity energy expenditure in preschool children. *Eur J Clin Nutr*. (2017) 71:1212–7. doi: 10.1038/ejcn.2017.114
14. Lowe SA, ÓLaighin G. Monitoring human health behavior in one's living environment: a technological review. *Med Eng Phys*. (2014) 36:147–68. doi: 10.1016/j.medengphy.2013.11.010
15. Glasgow TE, Le HTK, Scott Geller E, Fan Y, Hankey S. How transport modes, the built and natural environments, and activities influence mood: a GPS smartphone app study. *J Environ Psychol*. (2019) 66:101345. doi: 10.1016/j.jenvp.2019.101345
16. Gough C, Weber H, George S, Maeder A, Lewis L. Location monitoring of physical activity and participation in community dwelling older people: a scoping review. *Disabil Rehabil*. (2019) 43:270–83. doi: 10.1080/09638288.2019.1618928
17. Chan L, Ciol MA, Shumway-Cook A, Yorkston KM, Dudgeon BJ, Asch SM, et al. A Longitudinal evaluation of persons with disabilities: does a longitudinal definition help define who receives necessary care? *Arch Phys Med Rehabil*. (2008) 89:1023–30. doi: 10.1016/j.apmr.2007.10.045
18. Chrisinger BW, King AC. Stress experiences in neighborhood and social environments (SENSE): a pilot study to integrate the quantified self with citizen science to improve the built environment and health. *Int J Health Geogr*. (2018) 17:17. doi: 10.1186/s12942-018-0140-1
19. Kim H, Ahn CR, Yang K. A people-centric sensing approach to detecting sidewalk defects. *Adv Eng Inform*. (2016) 30:660–71. doi: 10.1016/j.aei.2016.09.001
20. Kim H, Ham Y, Kim H. Localizing local vulnerabilities in urban areas using crowdsourced visual data from participatory sensing. In: *2019 ASCE International Conference of Computing in Civil Engineering*. Atlanta, GA (2019). doi: 10.1061/9780784482438.066
21. Kim J, Kim H, Ham Y. Mapping local vulnerabilities into a 3D city model through social sensing and the CAVE system toward digital twin city. In: *2019 ASCE International Conference of Computing in Civil Engineering*. Atlanta, GA (2019). doi: 10.1061/9780784482445.058
22. Ahn C, Ham Y, Kim J, Kim J. A Digital twin city model for age-friendly communities: capturing environmental distress from multimodal sensory data. In: *Proceedings of the 53rd Hawaii International Conference on System Sciences*. Maui: Hawaii (2020). doi: 10.24251/HICSS.2020.206
23. Kim J, Yadav M, Chaspari T, Ahn CR. Saliency detection analysis of collective physiological responses of pedestrians to evaluate neighborhood-built environments. *Adv Eng Inform*. (2020) 43:101035. doi: 10.1016/j.aei.2020.101035
24. Chaspari T, Tsiartas A, Stein LI, Cermak SA, Narayanan SS. Sparse representation of electrodermal activity with knowledge-driven dictionaries. *IEEE Trans Biomed Eng*. (2015) 62:960–71. doi: 10.1109/TBME.2014.2376960
25. Chaspari T, Tsiartas A, Duker LIS, Cermak SA, Narayanan SS. EDA-gram: designing electrodermal activity fingerprints for visualization and feature extraction. In: *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. Orlando, FL: IEEE (2016). p. 403–6. doi: 10.1109/EMBC.2016.7590725
26. Ahn CR, Lee S, Sun C, Jebelli H, Yang K, Choi B. Wearable sensing technology applications in construction safety and health. *J Construct Eng Manage*. (2019) 145:03119007. doi: 10.1061/(ASCE)CO.1943-7862.0001708
27. Osborne T, Jones PI. Biosensing and geography: a mixed methods approach. *Appl Geogr*. (2017) 87:160–9. doi: 10.1016/j.apgeog.2017.08.006
28. Hackman DA, Robert SA, Grübel J, Weibel RP, Anagnostou E, Hölscher C, et al. Neighborhood environments influence emotion and physiological reactivity. *Sci Rep*. (2019) 9:9498. doi: 10.1038/s41598-019-45876-8
29. Hedblom M, Gunnarsson B, Iravani B, Knez I, Schaefer M, Thorsson P, et al. Reduction of physiological stress by urban green space in a multisensory virtual experiment. *Sci Rep*. (2019) 9:10113. doi: 10.1038/s41598-019-46099-7
30. Lee G, Choi B, Jebelli H, Ahn CR, Lee S. Wearable biosensor and collective sensing–based approach for detecting older adults' environmental barriers. *J Comput Civil Eng*. (2020) 34:04020002. doi: 10.1061/(ASCE)CP.1943-5487.0000879
31. Lee G, Choi B, Ahn CR, Lee S. Wearable biosensor and hotspot analysis–based framework to detect stress hotspots for advancing elderly's mobility. *J Manage Eng*. (2020) 36:04020010. doi: 10.1061/(ASCE)ME.1943-5479.0000753
32. Neale C, Aspinall P, Roe J, Tilley S, Mavros P, Cinderby S, et al. The impact of walking in different urban environments on brain activity in older people. *Cities Health*. (2019) 4:94–106. doi: 10.1080/23748834.2019.1619893
33. Kim J, Yadav M, Ahn CR, Chaspari T. Saliency detection analysis of 885 pedestrians' physiological responses to assess adverse built environment features. In: *ASCE International Conference on Computing in Civil Engineering*. Reston, VA: American Society of Civil Engineers (2019). doi: 10.1061/9780784482445.012
34. Neal MB, DeLaTorre A. *The Case for Age-Friendly Communities. Grantmakers in Aging*. (2016). Available online at: https://www.giaging.org/documents/889160302_Case_for_AFC.pdf (accessed February 20, 2021).
35. Kim J, Ahn CR, Nam Y. The influence of built environment features on crowdsourced physiological responses of pedestrians in neighborhoods. *Comput Environ Urban Syst*. (2019) 75:161–9. doi: 10.1016/j.compenvurbsys.2019.02.003
36. Wilhelm FH, Pfaltz MC, Grossman P, Roth WT. Distinguishing emotional from physical activation in ambulatory psychophysiological monitoring. *Biomed Sci Instrument*. (2006) 42:458–63.
37. Saitis C., Kalimeri K. Identifying urban mobility challenges for the visually impaired with mobile monitoring of multimodal biosignals. In: Antona M, Stephanidis C, editors. *Universal Access in Human-Computer Interaction. Users and Context Diversity. UAHCI 2016. Lecture Notes in Computer Science, vol. 9739*. Cham: Springer (2016). p. 616–27. doi: 10.1007/978-3-319-40238-3
38. Tilley S, Neale C, Patuano A, Cinderby S. Older people's experiences of mobility and mood in an urban environment: a mixed methods approach using electroencephalography (EEG) and interviews. *Int J Environ Res Public Health*. (2017) 14:151. doi: 10.3390/ijerph14020151
39. Yadav M, Chaspari T, Kim J, Ahn CR. Capturing and quantifying emotional distress in the built environment. In: *Proceedings of the Workshop on Human-Habitat for Health (H3): Human-Habitat Multimodal Interaction for Promoting Health and Well-Being in the Internet of Things Era H3'18*. New York, NY: ACM (2018). doi: 10.1145/3279963.3279967
40. Can YS, Arnrich B, Ersoy C. Stress detection in daily life scenarios using smart phones and wearable sensors: a survey. *J Biomed Informat*. (2019) 92:103139.doi: 10.1016/j.jbi.2019.103139
41. Lee G, Choi B, Jebelli H, Ahn CR, Lee S. Reference signal-based method to remove respiration noise in electrodermal activity (EDA) collected from

the field. In: *Computing in Civil Engineering 2019: Data, Sensing, and Analytics*. Reston, VA: American Society of Civil Engineers (2019). p. 17–25. doi: 10.1061/9780784482438.003

42. Ojha VK, Griego D, Kuliga S, Bielik M, Buš P, Schaeben C, et al. Machine learning approaches to understand the influence of urban environments on human's physiological response. *Informat Sci.* (2019) 474:154–69. doi: 10.1016/j.ins.2018.09.061
43. Jebelli H, Ahn CR, Stentz TL. Fall risk analysis of construction workers using inertial measurement units: validating the usefulness of the postural stability metrics in construction. *Saf Sci.* (2016) 84:161–70. doi: 10.1016/j.ssci.2015.12.012
44. Jebelli H, Changbum R, Stentz TL. Comprehensive fall-risk assessment of construction workers using inertial measurement units: validation of the gait-stability metric to assess the fall risk of iron workers. *J Comput Civil Eng.* (2016) 30:04015034. doi: 10.1061/(ASCE)CP.1943-5487.0000511
45. Yang K, Ahn CR, Vuran MC, Aria SS. Semi-supervised near-miss fall detection for ironworkers with a wearable inertial measurement unit. *Automat Construct.* (2016) 68:194–202. doi: 10.1016/j.autcon.2016.04.007
46. Kim H, Ahn CR, Yang K. Identifying safety hazards using collective bodily responses of workers. *J Construct Eng Manage.* (2017) 143:04016090. doi: 10.1061/(ASCE)CO.1943-7862.0001220
47. Yang K, Ahn CR, Vuran MC, Kim H. Collective sensing of workers' gait patterns to identify fall hazards in construction. *Automat Construct.* (2017) 82:166–78. doi: 10.1016/j.autcon.2017.04.010
48. Duchowny K, Clarke P, Gallagher NA, Adams R, Rosso AL, Alexander NB. Using mobile, wearable, technology to understand the role of built environment demand for outdoor mobility. *Environ Behav.* (2018) 51:671–88. doi: 10.1177/0013916517749256
49. Kim H, Ahn CR, Stentz TL, Jebelli H. Assessing the effects of slippery steel beam coatings to ironworkers' gait stability. *Appl Ergonom.* (2018) 68:72–9. doi: 10.1016/j.apergo.2017.11.003
50. Twardzik E, Duchowny K, Gallagher A, Alexander N, Strasburg D, Colabianchi N, et al. What features of the built environment matter most for mobility? Using wearable sensors to capture real-time outdoor environment demand on gait performance. *Gait Post.* (2019) 68:437–42. doi: 10.1016/j.gaitpost.2018.12.028
51. Yang K, Ahn CR, Kim H. Validating ambulatory gait assessment technique for hazard sensing in construction environments. *Automat Construct.* (2019) 98:302–9. doi: 10.1016/j.autcon.2018.09.017
52. Bisadi M, Kim H, Ahn CR, Nam Y. Effects of physical disorders in neighborhoods on pedestrians' physiological responses. *Comput Civil Eng.* (2017) 183–190. doi: 10.1061/9780784480847.023
53. Goto S, Park BJ, Tsunetsugu Y, Herrup K, Miyazaki Y. The effect of garden designs on mood and heart output in older adults residing in an assisted living facility. *HERD.* (2013) 6:27–42. doi: 10.1177/193758671300600204
54. Li X, Hijazi I, Koenig R, Lv Z, Zhong C, Schmitt G. Assessing essential qualities of urban space with emotional and visual data based on gis technique. *ISPRS Int J Geo Informat.* (2016) 5:218. doi: 10.3390/ijgi5110218
55. Jebelli H, Hwang S, Lee S. EEG signal-processing framework to obtain high-quality brain waves from an off-the-shelf wearable EEG device. *J Comput Civil Eng.* (2017) 32:04017070. doi: 10.1061/(ASCE)CP.1943-5487.0000719
56. Kim H, Ham Y. Evaluating Deterioration levels of utility poles using participatory sensing and fuzzy inference. In: *ASCE Construction Research Congress*. Tempe, AZ (2020). doi: 10.1061/9780784482865.087
57. Ham Y, Kim J. Participatory sensing and digital twin city: updating virtual city models for enhanced risk-informed decision-making. *J Manag Eng.* (2020) 36:04020005-1–12. doi: 10.1061/(ASCE)ME.1943-5479.0000748
58. Kim H, Ham Y. Participatory sensing-based geospatial localization of distant objects for disaster preparedness in urban built environments. *Automat Construct.* (2019) 107:102960. doi: 10.1016/j.autcon.2019.102960
59. Naik N, Philipoom J, Raskar R, Hidalgo C. Streetscore-predicting the perceived safety of one million streetscapes. In: *IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops*. Washington, DC: IEEE Computer Society (2014). p. 793–9. doi: 10.1109/CVPRW.2014.121
60. Wang W, He Q. A survey on emotional semantic image retrieval. In: *Proceedings - International Conference on Image Processing.* Los Alamitos, CA: ICIP (2008) p. 117–20.
61. Yao Y, Liang Z, Yuan Z, Liu P, Bie Y, Zhang J, et al. A human-machine adversarial scoring framework for urban perception assessment using street-view images. *Int J Geogr Inf Sci.* (2019) 33:2363–84. doi: 10.1080/13658816.2019.1643024
62. Photo.net. *Photo.net - Where Photographers Inspire Each Other*. Available online at: https://www.photo.net/ (accessed January 30, 2021).
63. Salesses P, Schechtner K, Hidalgo CA. The collaborative image of the city: mapping the inequality of urban perception. *PLoS ONE.* (2013) 8:e68400. doi: 10.1371/journal.pone.0068400
64. Xiao J, Hays J, Ehinger KA, Oliva A, Torralba A. SUN database: large-scale scene recognition from abbey to zoo. In: *Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition.* San Francisco, CA (2010) p. 3485–92. doi: 10.1109/CVPR.2010.5539970
65. Schölkopf B, Smola AJ, Williamson RC, Bartlett PL. New support vector algorithms. *Neural Computation.* (2000) 12:1207–45. doi: 10.1162/089976600300015565
66. Dubey A, Naik N, Parikh D, Raskar R, Hidalgo CA. Deep learning the city : quantifying urban perception at a global scale. *Lect Notes Comput Sci.* (2016) 9905 LNCS:196–212. doi: 10.1007/978-3-319-46448-0_12
67. Creaser J, Edwards C, Manser M, Cooper J, Swanson B, Donath M. *Teen Driver Support System (TDSS) Field Operational Test*. Minneapolis, MN: University of Minnesota Center for Transportation Studies (2015).
68. Lerner N, Jenness J, Singer J, Klaur K, Lee SS, et al. *An Exploration of Vehicle-Based Monitoring of Novice Teen Drivers.* Washington, DC: National Highway Traffic Safety Administration. Technical paper number DOT HS 811 333 (2010).
69. Manser M, Edwards C, Lerner N, Jenness J, Huey R. *Evaluation of a Prototype Safer Teen Car: Final Report.* Washington, DC: National Highway Traffic Safety Administration. Technical paper number DOT HS 811 784 (2013).
70. Manser M. *Development of a Smartphone-Based Older Driver Support System*. Advancing Transportation Leadership and Safety (ATLAS Center). College Station, TX: Texas A&M Transportation Institute (2015).
71. Gimm G, Blodgett E, Zanwar P. Examining access to care for younger vs. older dual-eligible adults living in the community. *Disabil Health J.* (2016) 9:431–8. doi: 10.1016/j.dhjo.2015.12.004
72. Gimm G, Wood E, Zanwar P. Access to preventive services for working-age adults with physical limitations. *Arch Phys Med Rehabil.* (2017) 98:2442–8. doi: 10.1016/j.apmr.2017.05.017
73. ElFaouzi NE, Leung H, Kurian A. Data fusion in intelligent transportation systems: progress and challenges – a survey. *Informat Fusion.* (2011) 1:4–10. doi: 10.1016/j.inffus.2010.06.001
74. Weerasekera R, Sridharan M, Ranjitkar P. Implications of spatiotemporal data aggregation on short-term traffic prediction using machine learning algorithms. *J Adv Transport.* (2020) 2020:7057519. doi: 10.1155/2020/7057519
75. Miles JC, Walker AJ. The potential application of artificial intelligence in transport. *IEE Proc Intell Transport Syst.* (2006) 3:183–98. doi: 10.1049/ip-its:20060014
76. Singh SK, Rathore S, Park H. Block loT intelligence: a blockchain-enabled intelligent loT architecture with artificial intelligence. *Fut Generat Comput Syst.* (2020) 110:721–43. doi: 10.1016/j.future.2019.09.002
77. Lee JY, Rhee G. Context-aware 3D visualization and collaboration services for ubiquitous cars using augmented reality. *Int J Adv Manufact Technol.* (2008) 37:431–42. doi: 10.1007/s00170-007-0996-x
78. Walker GH, Stanton NA, Young MS. Where is computing driving cars? *Int J Hum Comput Interact.* (2009) 13:203–29. doi: 10.1207/S15327590IJHC1302_7
79. Taylor BD, Tripodes S. The effects of driving cessation on the elderly 856 with dementia and their caregivers. *Accid Anal Prev.* (2001) 33:519–28. doi: 10.1016/S0001-4575(00)00065-8
80. Dickerson AE, Molnar L, Bedard M, Eby DE, Classen S, Polgar J. Transportation and Aging: an updated research agenda for advancing safe mobility. *J Appl Gerontology.* (2019) 38:1643–60. doi: 10.1177/0733464817739154
81. Saskatoon Council on Aging. *Age-Friendly Saskatoon Initiative Findings Report*. Available online at: https://extranet.who.int/agefriendlyworld/wp-content/uploads/2018/05/Saskatoon-Age-friendly-Saskatoon-Initiative-Findings-Report-FULL_Dec.22-2011.pdf (accessed February 12, 2021).

82. Paratransit Services. *Maintain Mobility & Independence*. (2020). Available at: https://seniordriving.aaa.com/maintain-mobility-independence/other-ways-get-around/paratransit-services/ (accessed January 30, 2021).
83. Senior Ride Sharing. *Uber, Lyft, SilverRide, GoGoGrandparent*. (2020). Available at: https://www.seniorsmatter.com/ridesharing-transportation-for-seniors/2491978 (accessed January 30, 2021).
84. Vivoda JM, Harmon AC, Babulal GM, Zikmund-Fisher BJ. E-hail (Rideshare) knowledge, use, reliance, and future expectations among $_{867}$ older adults. *Transp Res F Traffic Psychol Behav*. (2018) 55:426–34. doi: 10.1016/j.trf.2018.03.020
85. Rosenbloom, S. Meeting transportation needs in an aging-friendly community. *Am Soc Aging*. (2009) 2:33–43. 870.
86. Choi NG, DiNitto DM. Depressive symptoms among older adults who do not drive: association with mobility resources and perceived transportation barriers. *Gerontologist*. (2016) 56:432–43. doi: 10.1093/geront/gnu116
87. Papa. *Ride safely and effectively*. Available online at: https://www.joinpapa.com/activities/transportation-for-seniors (accessed January 30, 2021).
88. Harper CD, Hendrickson CT, Mangones S, Samaras C. Estimating potential increases in travel with autonomous vehicles for the non-driving, elderly and people with travel-restrictive medical conditions. *Transport Res C Emerge Technol*. (2016) 72:1–9. doi: 10.1016/j.trc.2016.09.003
89. Meyer J, Becker H, Bosch BM, Axhausen W. Autonomous vehicles: the next jump in accessibilities? *Res Transport Econom*. (2017) 62:80–91. doi: 10.1016/j.retrec.2017.03.005
90. Bergmann LT, Schlicht L, Meixner C, Konig P, Gordon P, Boshammer S, et al. Autonomous vehicles require socio-political acceptance-an empirical and philosophical perspective on the problem of moral decision making. *Front Behav Neurosci*. (2018) 12:31. doi: 10.3389/fnbeh.2018.00031
91. Towne SD, Won J, Lee S, Ory MG, Forjuoh SN, Wang S, et al. Using walk score^{TM} and neighborhood perceptions to assess walking among middle-aged and older adults. *J Community Health*. (2016) 41:977–88. doi: 10.1007/s10900-016-0180-z

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

The reviewer SZ declared a shared affiliation, though no other collaboration, with the authors to the handling Editor.

frontiers in Public Health

ORIGINAL RESEARCH
published: 22 April 2021
doi: 10.3389/fpubh.2021.650861

"Our Home Is a Muddy Structure": Perceptions of Housing and Health Risks Among Older Adults in Contrasting Neighborhoods in Ghana

Dominic A. Alaazi[1], Tania Stafinski[1], Joshua Evans[2], Stephen Hodgins[1], Martin Oteng-Ababio[3] and Devidas Menon[1]*

[1] School of Public Health, University of Alberta, Edmonton, AB, Canada, [2] Earth and Atmospheric Sciences, Faculty of Science, University of Alberta, Edmonton, AB, Canada, [3] Department of Geography and Resource Development, University of Ghana, Accra, Ghana

OPEN ACCESS

Edited by:
Anna Patricia Lane, Singapore University of Technology and Design, Singapore

Reviewed by:
John Weeks, San Diego State University, United States
Laura Balis, University of Wyoming, United States

***Correspondence:**
Dominic A. Alaazi
alaazi@ualberta.ca

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *08 January 2021*
Accepted: *19 March 2021*
Published: *22 April 2021*

Citation:
Alaazi DA, Stafinski T, Evans J, Hodgins S, Oteng-Ababio M and Menon D (2021) "Our Home Is a Muddy Structure": Perceptions of Housing and Health Risks Among Older Adults in Contrasting Neighborhoods in Ghana. Front. Public Health 9:650861. doi: 10.3389/fpubh.2021.650861

Aging occurs in a variety of social and physical environmental settings that affect health. However, despite their rapidly growing populations, public health research in sub-Saharan Africa has yet to address the role of residential environments in the health and well-being of older adults. In this study, we utilized an ethnographic research methodology to explore barriers and facilitators to health among older adults residing in two contrasting neighborhoods in Accra, Ghana. Our specific objective was to identify patterns of health risks among older adults in the two neighborhoods. Data were collected through qualitative interviews with a purposive sample of health workers ($n = 5$), community leaders ($n = 2$), and older adults residing in a slum and non-slum neighborhood ($n = 30$). Our thematic data analysis revealed that, despite different underlying drivers, health barriers across the slum and non-slum were largely similar. The harmful effects of these health barriers – poor built environments, housing precariousness, unsanitary living conditions, defective public services, and social incivilities – were mitigated by several facilitators to health, including affordable housing and social supports in the slum and better housing and appealing doors in the non-slum. Our study contributes to a more nuanced understanding of the ways in which aging and urban environments intersect to influence population health in resource poor settings. In particular, rather than the commonly referenced dichotomy of poor and non-poor settlements in discourses of neighborhood health, our findings point to convergence of health vulnerabilities that are broadly linked to urban poverty and governmental neglect of the elderly.

Keywords: aging, Ghana, health, neighborhoods, older adults, slums

INTRODUCTION

The population of older adults is increasing globally; by 2050, the number of people aged 65 and older will reach 1.5 billion, up from 524 million in 2010 (1). The majority of this population will reside in urban areas of the developing world, where sharp increases in morbidity and mortality from non-communicable diseases have been recorded (2). In Ghana, recent gains in life expectancy underlie an unprecedented increase in the population of older adults, estimated to rise from 1.4 million in 2010 to ∼6.3 million in 2050 (3). These demographic changes have catapulted aging issues onto national and global policy agendas, the majority of which now present programs and interventions to support aging-in-place at home and in neighborhood settings (4).

The focus on neighborhoods is important, given that older adults are less mobile and their duration of exposure to community environments is comparatively longer (5, 6). The health effects of adverse neighborhood conditions are therefore more salient for older populations than for younger demographics (7, 8).

The nature and quality of neighborhood built environments, including their spatial organization, land use patterns, and aesthetics, can be critical determinants of health among older adults. For example, poor location and visibility of road signage may accentuate cognition problems and discourage service utilization among older adults (7). Visible signs of environmental dereliction (e.g., dilapidated housing and disintegrated sidewalks) can intimidate older adults and cause them to refrain from outdoor activities (9).

Evidence from the United States suggests a positive relationship between the availability of pedestrian infrastructure and older adults' likelihood of walking (10). Neighborhoods with poor street connectivity and crumbling sidewalks can also restrict physical activity and contribute to disability and depressive symptoms in older adults (11).

Exposure to neighborhood social disorder, such as crime, excessive noise, graffiti, and street litter, has been found to be independently associated with reductions in physical activity, rising obesity prevalence, declines in physical functioning, and the onset of depressive symptoms among older adults. Fear of crime is an independent predictor for mobility declines (12), overweight (13), physical and functional disability (11, 14, 15), and depression in older adults (16). Among a sample of US older adults, Eisenstein and colleagues (13) found a strong association between fear of crime and risk of high BMI.

Not only can quantifiable physical and social features of neighborhoods affect health and well-being; so too can such symbolic constructs as place meaning, place identity, and sense of place. In their study examining sense of community, Zhang and Zhang (17) found a positive correlation between strong sense of community and subjective well-being among Chinese older adults. Similarly, Kitchen and colleagues (18) reported a strong association between sense of community belonging and mental health of older adults, after adjusting for geography and socioeconomic status.

While this body of literature has helped to advance public health knowledge of neighborhood effects on older adults' health, it is noticeably limited in geographical and methodological scope. First, with the exception of a few from Asia and Latin America [e.g., (19–21)], the literature examining relations between neighborhoods and older adults' health has largely neglected low and middle-income regions, such as sub-Saharan Africa (SSA), where much of the expected increase in older populations will occur. Second, this literature relies mostly on analyses of selected variables from large quantitative datasets that do not account for the full range of complex relationships between older adults and their neighborhood environments (16, 22). To build on the current literature and address these gaps, we utilized the person-environment (P-E) hypothesis and an ethnographic research methodology to explore health barriers and facilitators among a sample of older adults residing in two environmentally contrasting neighborhoods in Accra, Ghana. Our specific objective was to explain patterns of health risks among older populations in the city. The focus on urban neighborhoods is important and timely, given the rapid urbanization of older adults in the country (3). In the sections that follow, we discuss the P-E hypothesis and the methods used before presenting and discussing our findings.

THE PERSON-ENVIRONMENT HYPOTHESIS

The P-E hypothesis conceptualizes health in old age as a direct outcome of (mis) fit between environmental press (demands of the socio-physical environment) and personal competence (the ability to cope with environmental demands) (23). Environmental press can be positive, negative, or neutral, and may range from pedestrian infrastructure affecting neighborhood walkability to neighborhood aesthetics, crime, and land-use patterns affecting physical function and mental health (24). Personal competence refers to such individual qualities as biological endowments, cognitive skills, and intelligence, which can either be high or low. In the P-E schema, a harmonious balance between press and competence would result in positive adaptation and well-being, while a misfit often leads to maladaptation and poor health outcomes.

The P-E hypothesis dominated research in environmental gerontology throughout the 1970s and 1980s, and has been influential in driving recent studies examining aging-in-place as a viable alternative to institutional care for older adults (25, 26). Other recent application of the hypothesis includes studies investigating relations between neighborhood safety and psychological health (27), and between neighborhood socio-physical environment and life satisfaction among older adults (28).

METHODS

Research Settings

Data collection was undertaken in the Nima slum and the Adabraka-Asylum Down non-slum neighborhoods in Accra, Ghana's capital city. Historically, Nima emerged in the early 1930s as a legal but unplanned settlement, or what Majale (29) termed a "pirate settlement." The site of the neighborhood was originally acquired as a transitional grazing ground for cattle meant for sale in the rapidly expanding city of Accra (30, 31). By the 1940s, Nima had become the centre of haphazard housing development, by mostly migrant workers seeking employment in a nearby military base to the northeast and a wealthy European neighborhood to the

FIGURE 1 | A section of Nima, Accra.

south of the settlement (32). Nima was not incorporated into Accra's metropolitan boundaries or subject to urban planning regulations until the 1950s, when the neighborhood was already a mature slum (31). This neighborhood is today the largest Ghanaian urban slum, with limited access roads and comparatively poor housing and sanitation infrastructure (32, 33) (**Figure 1**).

Nima is also highly congested and inhabited predominantly by people of the Islamic faith. In 2010, the neighborhood had a population of ∼81,000, distributed across a land area of only 1.6 km^2 (34, 35).

Established in 1910, Adabraka-Asylum Down is a planned, middle-income neighborhood, located 2km from downtown Accra (36, 37). Compared to Nima, the Adabraka-Asylum Down neighborhood has an interconnected network of streets and a functional drainage system (38), although its southern border is flood-prone due to inappropriate and often unapproved upstream land-use activities (39). The neighborhood's location near the city's central business district (CBD) also makes it a bustling hub for commercial activities (40). The socio-environmental characteristics of the slum and non-slum offered a useful contrast for a comparative analysis of barriers and facilitators to health among older adults (**Figure 2**).

FIGURE 2 | A section of Adabraka, Accra.

Design and Recruitment

An ethnographic methodology informed the research design and data collection process. Ethnography is concerned with "what people *do* as well as what they *say*" [(41), p. 552]. By immersing in the cultural worlds of others, ethnographers can gain insider perspectives on the organization of human societies. Ethnographic approaches involving qualitative interviews, focus groups, and (non) participant observations have grown increasingly popular among researchers examining neighborhood health (22, 42). Following approval from the ethics review committees of the University of Alberta and the University of Ghana, two phases of data collection were completed in the summer of 2018. The first phase involved semi-structured interviews with a purposive sample of older adults residing in the slum and non-slum neighborhoods. The individuals selected for participation were those aged 60 years or older, as officially adopted in Ghana's National Aging Policy [(43), p. 37]. Participants were also those deemed capable of providing rich information and who expressed interest in participating in the study. An open-ended interview guide informed by the neighborhood-health literature and the person-environment hypothesis guided the conduct of these interviews. The guide solicited participants' perceptions of neighborhood health barriers and facilitators, in particular the socio-environmental factors influencing their health and well-being. These interviews lasted ∼1 to 1.5 h long and were conducted in the homes of participants. Each participant was given a GHC 20 gift certificate.

The second phase involved semi-structured interviews with health workers and community leaders. The health workers were physicians and public health nurses serving residents of the two neighborhoods, while the community leaders were elected local government representatives. These participants responded to questions about the living conditions of older adults in the two neighborhoods and the health challenges confronting them. The interviews with health workers were conducted at the healthcare facilities where they worked, while those with community leaders occurred in the communities. Each participant provided a written consent prior to the interviews. All interviews were conducted face-to-face, in English, audio-recorded, and transcribed verbatim by a professional transcriptionist before analysis. The first author conducted all interviews. Data saturation was reached when subsequent interviews became informationally redundant (44), after integrating responses across all three categories of participants. Fieldnotes, based on researcher reflections and observations, were recorded throughout the entire data collection period.

Data Analysis

Aided by NVivo 12 (45), the data analysis process was thematic, simultaneously inductive and deductive, and involved using the data management functions of the software to condense the data into nodes, categories, and subsequently themes, reflecting older adults' perception of health barriers and facilitators. The hybridization of data-driven (inductive) and theory-driven (deductive) approaches to thematic analysis is an emerging paradigm in qualitative research that supports a more nuanced understanding and interpretation of research data (46).

The inductive analysis followed Green et al.'s (47) 4-steps analytical framework of data immersion, coding, creating categories, and identifying themes (p. 547). Data immersion was undertaken throughout the period of data collection, and continued thereafter through repeated reading of the interview transcripts. This iterative analytic strategy allowed for modification of the interview guide in response to emerging data gaps in the field. Through the process of immersion, we were able to develop familiarity with the data and create a codebook of emerging nodes, or groups of meaningful statements. In the second step, the transcripts were imported into NVivo 12 coded inductively using the codebook developed previously. The coding process involved sorting individual words, phrases, and paragraphs in the transcripts into nodes. The third step involved exploring relationships between nodes, sorting nodes, and merging nodes into categories that illuminated particular aspects of the research objectives. In the final step, the categories were merged into themes that reflected patterns of barriers and facilitators to health in the slum and non-slum. The formation and interpretation of the emerging themes followed a deductive process that relied on the explanatory power of the *person-environment hypothesis*.

Data triangulation, reflexive memos, and an engaged advisory committee afforded opportunities for methodological rigor (48). Data triangulation was achieved by interviewing multiple stakeholders, including older adults, community leaders, and health workers. The reflexive memos were based on documentation of how our positionalities as non-community members influenced our emerging understanding of the data. Multiple debriefing sessions with a multidisciplinary advisory committee provided additional opportunities for methodological rigor.

RESULTS

Sample Characteristics

The sample consisted of 15 community-residing older adults in each neighborhood, a community leader from each, and 3 and 2 health workers from the slum and non-slum, respectively. The older adults in the sample were, on average, 70.5 years old and had been living in their current neighborhood for 48.2 years prior to the study (**Table 1**). These participants were predominantly male (63.3%), Christian (70%), and regular income earners (66.7%). There were a few notable differences in sample characteristics between the slum and non-slum. For example, compared to the non-slum, there were more males and Muslims in the slum sample. The higher proportion of Muslims in the slum sample reflected the neighborhood's predominantly Muslim population.

TABLE 1 | Demographic characteristics of older adult participants.

Variables	Total ($N = 30$)	Slum ($n = 15$)	Non-slum ($n = 15$)
Age, mean (SD)	70.5 (7.4)	70.7 (8.0)	70.3 (7.0)
Years stayed, mean (SD)	48.2 (18.5)	47.1 (19.3)	49.3 (18.4)
Gender, *n* (%)			
Male	19 (63.3)	11 (73.3)	8 (53.3)
Female	11 (36.7)	4 (26.7)	7 (46.7)
Religion, *n* (%)			
Christian	21 (70.0)	6 (40.0)	15 (100.0)
Muslim	9 (30.0)	9 (60.0)	–
Living arrangements, *n* (%)			
Alone	3 (10.0)	1 (6.7)	2 (13.3)
With family	27 (90.0)	14 (93.3)	13 (86.7)
Homeownership, *n* (%)			
Own/family property	21 (70.0)	9 (60.0)	12 (80.0)
Tenant	9 (30.0)	6 (40.0)	3 (20.0)
Have regular income, *n* (%)			
Yes	20 (66.7)	7 (46.7)	13 (86.7)
No	10 (33.3)	8 (53.3)	2 (13.3)

Health Barriers

Poor Built Environments

Open drains containing stagnant water and liquid waste were widespread in the slum, creating suitable breeding grounds for mosquitos, and subsequently malaria infections. Health workers in the slum identified malaria and fever as common causes of morbidity among older adults presenting at their facilities. While open drains were less common in the non-slum, its built environment presented similar kinds of health risks. A significant portion of this neighborhood lies within the floodplain of the Odawna River, where flooding resulting from unregulated upstream residential development was frequent. Perennial flooding along the river bank was a source of health and safety concerns among older non-slum dwellers. A particular health threat posed by the floods was the transmission of flood-related infectious diseases, such as cholera, malaria, and pneumonia.

> It is a slum, to a large extent…(with) dirty gutters, littered streets, and open water sources for mosquitos. The refuse is everywhere…The environment is not healthy. (So)…Commonly…the usual infections, whether urinary tract infections, malaria, or pneumonias. – HWNI002 (Slum health worker).

> The challenges I face here is this flood issue…The water level was seven feet in our rooms. It affected me. I was sick. I had pneumonia…because they excrete themselves in the gutter. All the water that comes here is full of human excreta. – AAP15 (Male non-slum participant).

The open drains and uneven surfaces in the slum also posed significant safety hazards to its older residents. A parallel safety hazard in the non-slum was the dilapidation of buildings along the banks of the Odawna River, where the physical impacts of the flood waters were most severe.

Recreational walking in the slum was severely impeded by its lack of streets and sidewalks. This difficulty was exacerbated by competing demands for open space from pedestrians, traders, motorists, and domestic animals within the slum's vast expanse of closely built houses and tenements. The lack of access roads and paved sidewalks impeded the free flow of traffic and prevented older adults from undertaking outdoor physical activities, such as walking and running. In contrast, the non-slum neighborhood was spatially planned and had an interconnected network of roads. Nevertheless, the streets and sidewalks of the non-slum were occupied by traders who colonized these spaces for displaying their goods, making them inaccessible for recreational walking in much the same way as the slum.

> So, instead of us to have pavements to walk on, you would see that traders have taken over the pavements and we all have to jam up on the road. So, pedestrians don't have their way. We mix with [moving] vehicles and motorbikes. . . If I want to board a vehicle now, in fact you would see how cautious I would be. I have to make sure that I walk slowly and be dodging some vehicles and so forth. – NIP001 (Male slum participant).

> We need (the) pavements. They should clear the road. Even you can see opposite the house there. They (traders) are back on the pavement. If you go to Adabraka, by the Adabraka Market, they've all built something on the sidewalk. – AAP015 (Male non-slum participant).

The fear of falling into open gutters or colliding with moving vehicles was reported to have played a role in confining large numbers of slum and non-slum older adults to their immediate home environments. This problem was especially salient for those using wheelchairs and walking aids.

Housing Precariousness

The majority of slum residents experienced poor ventilation due to poor housing construction methods, which relied mostly on flimsy building materials (e.g., mud bricks, overaged corrugated iron sheets, plywood, etc.). As such, most slum buildings were structurally weak and substandard, producing living conditions that were largely unsuitable for older adults. A female slum participant described her home as "a muddy structure (with) not a single concrete block" (NIP010). A health worker added that the housing situation in the slum negatively "impacts the elderly, some (of whom) get pneumonia because they are not getting proper ventilation" (HWNI003). The slum housing also provided insufficient living space, as a single bedroom unit typically accommodated as many as 10 occupants.

Although a planned neighborhood, the non-slum had an aging housing stock dating far back to the colonial era. A significant proportion of homes in this neighborhood was therefore reported to be in a state of disrepair, with essentially similar kinds of health risks as the slum – e.g., damp and moldy housing conditions, visible signs of infestations, etc.

> We live in a congested house that does not provide me with much freedom. As I am telling you, I have three children with a wife – five of us – we are living in a single room and a small porch. I don't think anybody would be happy in that accommodation. It affects my health. How many beds can we have in a (single) room? To be healthy, you have to sleep well. And that is what I don't have here. We wake up very tired. – NIP002 (Male slum participant).

> As for the house and my room, you know, the building is old. What I am experiencing is weak windows, weak doors. You know, in the olden days, they used wood to do the flooring. Adabraka is sitting on water. So when there is much rain, sometimes the water from underground enters through the patches and come into the room. This morning, behind there, you could see that the place is a little bit wet. – AA001 (Female non-slum participant).

For older slum dwellers, the challenges of living in overcrowded and poorly ventilated housing included sleep deprivation. In the non-slum, some participants attributed their respiratory health problems to the cold, damp, and moldy housing conditions in which they lived.

Private sector-led gentrification of the housing stock in the non-slum exacerbated the housing precariousness facing its older residents. The redevelopment and conversion of the affordable housing stock into shops, condominiums, and hostels contributed to rent hikes and growing homelessness among older adults residing in the non-slum.

> Some (older adults) are even squatters. And as I'm talking to you, I have somebody who is sleeping outside who is 60 years. So it is to do with the money for the accommodation. After pension, because their (pension) money is so small and the (rent) increments have come, by the time you realize, the person is sleeping outside. – CLAA001 (Non-slum community leader).

According to the health workers, housing instability and homelessness were a pathway to health-damaging exposures, including hunger, sleep deprivation, physical insecurity, and mental health problems among older adults.

Unsanitary Living Conditions

In both neighborhoods, participants reported facing unsanitary conditions, including a complete absence of toilets in some homes. This problem was noticeably more severe in the slum, where the majority of residents used public toilets and practiced open defecation. Traveling to and queueing at public toilets was both time-consuming and physically grueling for older adults, especially those with impaired mobility or compromised bowel and urine control.

> As there is no toilet in the house, I have to use the public toilet. But sometimes, there are long queues at the public toilet, and it is a problem if you need to use the toilet now, now, (and) now. And using the public toilet is expensive. – NIP015 (Male slum participant).

> So, you see, when you walk around, all this gives us sickness, because the rubbish is everywhere, especially these plastic (bags). Some people defecate in it, then leave it anywhere. There are some places where they don't have toilets. – AAP005 (Male non-slum participant).

Study participants reported fecal contamination in both neighborhoods, due to widespread open defecation practices. They associated contact with raw sewage with a variety of health hazards, including cholera and other enteric illnesses.

> A lot of houses in this community have no toilets. So, open defecation is a huge problem. So, the moment the rains come, then you start to get cholera. gastroenteritis, diarrhea, and vomiting. – HWNI001 (Slum health worker).

> It always brings sickness. Even 1 day, I had to be rushed to the hospital because of this cholera outbreak. It affected me, so they had to rush me to the Adabraka Polyclinic. And I went on admission there for about 4 days before I came back. – AAP011 (Female non-slum participant).

The slum's sanitation problem was exacerbated by indiscriminate disposal of solid waste, usually into open gutters and streets. Accordingly, more slum than non-slum participants reported vulnerability to environmental afflictions arising from such practices.

> People (in Nima) put trash in the gutter. We don't care about the environment at all. Somebody can carry his whole dustbin and go and put in the gutter. When you put trash inside the gutter, water accumulates there, what is the result? It would breed mosquitoes. The mosquitoes bring malaria. Sometimes, I get malaria. – NIP005 (Female slum participant).

The turbid drains and pungent ambiance were also a source of health concern to the slum participants. A participant vented: "I don"t like dirty things. So, always, I am annoyed, especially when I'm going to the (food) market." – NIP010 (Female slum participant). Another added: "My BP (blood pressure) is not agreeing with that breeze, (and) it can give me sickness." – NIP014 (Male slum participant).

Defective Public Services and Amenities

Deficiencies in access to potable water and waste collection services were significant concerns in both neighborhoods. The slum participants expressed grave concern over the environmental health risks posed by piles of uncollected refuse around their homes. They blamed the situation on poor performance of the Accra Metropolitan Assembly (AMA), the agency responsible for the city's waste collection services. While the non-slum participants were equally dissatisfied with the services of the AMA, they were largely able to address the service deficiencies by hiring private pay-for-service operators.

> We sweep our houses and the refuse is supposed to be sent to a dumping site. But our dumping inside here, there is no time you will get there and see an empty container. Anytime you go there, it is full. Because when they bring the container, those around there see it first, and they rush there. – NIP009 (Male slum participant).

> Years back, it's the AMA that cleans the drainage (of) the rubbish. Now, they are forcing us to clear the rubbish from the drainage. Why do we pay property rate? We pay property rate for these services. We pay property rate. So something has got to be done. – AAP015 (Male non-slum participant).

While private pay-for-service waste management operations contributed to a more appealing outdoors in the non-slum, such arrangements were limited in much of the slum. Consequently, the slum participants reported more rodent infestation of their homes and surroundings.

Both neighborhoods also experienced acute water shortages, despite the presence of water supply infrastructure, including community pipes. As such, residents had to trek long distances in search of water, a task many older adults were unable to perform.

> I'm very, very worried about the water. The water is a problem, because nowadays I can't carry (water). My neck, I have a problem. My chest too has a problem. I can say my spinal cord, something like that. So, to carry water is hard. So as for water, it's difficult for me. Water problem is difficult for me. – NIP014 (Male slum participant).

> Most of the time, they put the water off, and you have to carry a bucket, go to other places before you get small water and come, and then use it to do what you have to do, which at times pains all of us. – AAP013 (Female non-slum participant).

Older adults who lacked family support had to either pay as high as 40 pesewas/liter for water from private suppliers or forego such necessities as washing, cleaning, and bathing.

Social Incivilities

Crime and noise pollution were prevalent in both the slum and non-slum. Located just 5 km apart, the two neighborhoods reportedly had similar crime rates. The slum was perceived as harboring some of the Ghanaian police most wanted criminals. Although arm robbery and drug-related crimes were also common in the non-slum, most of these crimes were said to be spillovers from the slum.

> Thieves, arm robbers, most of them are from Nima. When we came here in those days, oh, anytime you hear of thieves (it was in Nima). Even thieves (would) move from Nima to other places to steal and come. – NIP009 (Male slum participant).

> The only problem, I will say, is due to those people from Nima and other places who have been patrolling in the nights collecting people's phones and their money. There was a time even they snatched my phone. – AAP014 (Male non-slum participant).

Older adults adapted to neighborhood crime by restricting their movement to daytime and within short distances from their homes. The slum's reputation as an abode for criminals also affected access to employment and public services for its residents. The residents were reportedly blacklisted by employers and service providers, and as such could not, for example, "go to hospital" and expect proper care without having to "forge someone's house number" in another neighborhood. – NIP004 (Female slum participant).

Although the city has bylaws regulating noisemaking, such regulations were generally unenforced. The resulting human and vehicular noise pollution served as a source of discomfort to older adults in both neighborhoods.

> There's some house here. Every day, the younger people around that area have an (entertainment) program. Sometimes, those smokers, they have some program, and they would come and be playing music at high volume in the night. They don't sleep – midnight, the area people can't sleep. They complain bitterly. – CLNI001 (Slum community leader).

> They make noise, especially the churches. The small, small churches, they make noise. And if they are making their outdooring and their weddings, they disturb. As for me, I want a quiet place. – AAP004 (Female non-slum participant).

For older adults, noise pollution was emotionally and psychologically unsettling, as it disrupted their sleep and mental concentration. A slum participant identified "fright," "unusual heartbeat," and "sleep problems" as some of the health effects of excessive noise in her neighborhood. – NIP007 (Female slum participant). Another felt that his hypertension was exacerbated by the noise pollution and sleep disruption he experienced in the slum: "That's why I have hypertension, because in the night, sometimes you hear some shout. You'll be frightened and then wake up." – NIP011 (Male slum participant). Several others mentioned the impact of noise pollution on their mental health: "You cannot have peace of mind and you cannot have good sleep. If I don't have enough rest, you see that in the day I am disturbed." – NIP001 (Male slum participant).

Health Facilitators

Affordable Housing

The slum provided shelter to a large number of older adults who, for financial reasons, could not rent mainstream housing elsewhere at the prevailing market rate. Accordingly, the slum participants described their substandard shelter as a relief from exorbitant rentals and possible homelessness. They described the cost of renting in the slum to be comparatively lower and more affordable.

> I like Nima, because this is where I can get cheaper accommodation to live. So, I prefer here because there is nowhere I can get a room to rent at the cost that I am paying here. Accommodation is (somewhat) cheaper in Nima. The landlord doesn't even care if you don't pay. – NIP002 (Male slum participant).

In some instances, the magnanimity of landlords exempted indigent older adults from rent payments. According to participants, it was common practice for older slum dwellers to reside in rent-free housing.

> If the person is in the house for a long time before he gets old, (and) can't do anything and he has no any children around him, some of the landlords used to lift that (rent) burden on them. – CLNI001 (Slum community leader).

Others were allowed free overnight stays in various Mosques across the slum. The availability of affordable and rent-free accommodation in the slum provided a safety net against elderly homelessness and its related health hazards, including physical and mental stress.

Neighborhood Appeal

As a spatially planned and well-demarcated neighborhood, the non-slum outdoors were aesthetically more appealing than those of most low and middle-income neighborhoods in the city. Participants, therefore, described the non-slum as "a very nice place" and one to "feel proud of staying in." – AAP014 (Male non-slum participant). The neighborhood enjoyed an additional reputation as a political enclave, having previously hosted some of the most influential figures in Ghanaian politics, including a former president, a sitting traditional ruler, and a multitude of current and former government ministers: "Our former president, J.J Rawlings, stayed here before. Quarshigah stayed here." – AAP010 (Male non-slum participant). The neighborhood's aesthetic appeal and rich political history together invoked a sense of pride and prestige, which were perceived to have ultimately benefitted the mental and psychosocial well-being of its older residents. It was also a major transportation hub, with transport networks reaching almost all parts of the city. A participant noted: "(If) I want to go somewhere, it's easy for me to get car." – AAP004 (Female non-slum participant).

Social Supports and Neighborliness

In both neighborhoods, participants expressed satisfaction with the cordiality and social supports accorded by family, friends, religious bodies, and neighbors. They enjoyed financial and material support, as well as assistance with undertaking mundane chores.

> For about 5 years now, I have not been to the Mosque. But they come to visit me, praying for me. We chat sometimes. When it comes to fasting time (Sallah festivities), they bring me food. Somebody would just come, "Oh take this 5 cedis. Take 10 cedis. Oh, I have bought you cloth (dress)." They support me. – NIP003 (Female slum participant).

> There is a neighbour in the house, a tenant. She has taken me like her mother. They help me with everything… even cooking. If I say I can't cook, they will come and cook for me. – AA006 (Female non-slum participant).

Although social supports for older adults existed in both neighborhoods, the supports received in the slum were said to be superior and much more institutionalized, in accordance with Islamic teachings. For example, in addition to receiving financial and material supports from neighbors, some older slum dwellers reportedly also enjoyed rent-free housing, all of which went into enhancing their physical, emotional, and psychological wellness.

DISCUSSION

Guided by the P-E hypothesis, this study identified factors influencing the health and well-being of older adults residing in two contrasting residential neighborhoods in Accra, Ghana. The reported susceptibility of older slum and non-slum dwellers to infectious and parasitic diseases is consistent with findings from previous studies with older urban populations in the region (49, 50). However, in low-income urban communities such as slums, older adults' vulnerability to such inflictions is likely to be higher, given what may appear to be a mismatch between their personal competences and the environmental press presented by the residential settings in which they live (23). The environmental press identified in the present study (e.g., clogged open drains and piles of uncollected refuse in the slum and floodwaters in the non-slum) supports this assertion and may have contributed to the disease burden of older adults whose health was possibly already under threat from a plethora of non-communicable illnesses (51). Yet, health programs specifically targeting the unique healthcare needs of older adults are almost nonexistent in the Ghanaian context (52). A community-based primary care model integrating both treatment and preventive interventions would help to address the double-burden of disease confronting older Ghanaians residing in low-income settings. The National Health Insurance Scheme (NHIS) could, for example, be better positioned to deliver an integrated model of care for low-income older adults, including those residing in the studied neighborhoods. Social policies targeting improvements in the living conditions of older adults are also warranted, given the observed relationship between poor housing and ill-health.

Mobility and recreational walking among older adults in the slum were curtailed by the neighborhood's spatial disorganization, particularly the open drains and limited streets and sidewalks that characterized much of its built environment. The walkability of the non-slum was similarly affected by vehicular traffic and encroaching street traders who seized much of the available space for their business activities. This environmental press reflects a larger systemic problem in the urban architecture of SSA, where vehicular-dependency predominates and spaces for walking remain limited (53). The near absence of dedicated spaces for walking, running, and biking appears to contribute to physical inactivity, particularly among older adults whose fear of the outdoors may partly be responsible for the rising levels of obesity, diabetes, and cardiovascular diseases in African cities (54). As the population of urban older adults is projected to rapidly increase, neighborhoods must be (re) designed to ensure they are safe for physical activities.

Excessive noise pollution was a general issue of public concern in the city (55). For older adults, this upheaval was intolerable, as it presented a common environmental press affecting their health and well-being. Our observations conformed with an emerging scientific consensus suggesting a general decline in noise tolerance with increasing age, a physiological change widely associated with hypersensitivity of the aging brain (56, 57). Excessive neighborhood noise can cause sleep disruption and mental health problems for older adults (58), who, owing to their advance age, may require a greater amount of uninterrupted rest. The participants' experiences of anxiety and irritation arising from neighborhood noise reflected this general pattern. A similar P-E misfit was reported in relation to older adults' experience with neighborhood crime, whether actual or perceived. Consistent with earlier observations in the United States (16, 59), this study found fear of crime to play a role in restricting free movement of older adults.

Older adults in both neighborhoods reported experiencing housing precariousness. In the slum, most residents resided in overcrowded, poorly ventilated, and unsanitary housing conditions with limited access to potable water and safe sanitation, which, according to participants, increased their risk of respiratory and sleep problems. The gentrification of the overaged housing stock in the non-slum contributed to homelessness among older adults in this neighborhood. The housing experiences of older adults in both neighborhoods resonate with those of their counterparts residing elsewhere in the sub-Saharan African region. In Kenya, for example, overcrowding in slums remains a key challenge to the health and well-being of older adults, despite recent attempts at upgrading (60). Although private sector-led slum upgrading and gentrification of decaying neighborhoods are often well-intended, human rights activists have remained skeptical, particularly in the face of mounting evidence suggesting displacement of poorer residents in areas where these initiatives have been implemented (61). This discourse suggests a need for state-led interventions to improve the health and well-being of low-income older adults. Large-scale public sector investment in social housing is currently underway in Brazil and India (62), and Ghana could learn valuable lessons from such ambitious initiatives as it attempts to improve the residential conditions of low-income older adults.

The experience of aging in the two neighborhoods was not overwhelmingly negative. In fact, several attributes of the two neighborhoods mitigated, to some extent, the harmful effects of the identified health threats. The non-slum residents benefitted psychosocially from their neighborhood's aesthetic appeal and prestige as a political enclave for famous Ghanaian politicians and statesmen. Similarly, slums may be reimagined as ambiguous places offering both "hope" and "despair" (63). Consistent with the literature (64, 65), the slum neighborhood indeed possessed certain therapeutic qualities – e.g., affordable housing, social supports, and a strong sense of community belonging. In particular, a culture of gift-giving, enshrined in Islamic ethos (66), provided a safety net against poverty and destitution among older slum dwellers.

SUMMARY AND CONCLUSION

Our qualitative inquiry identified several barriers to health among older slum and non-slum residents. Open drainage systems in the slum and unregulated upstream residential developments in the non-slum were associated with infectious diseases (e.g., malaria, pneumonia, etc.), fear of physical harm, and physical inactivity among older adults. Substandard housing in the slum and an aging housing stock in the non-slum posed similar health threats to older adults. In particular, insufficient living space and poor ventilation in the slum were associated with incidences of pneumonia among older residents, while the damp and moldy conditions of the aging housing stock in the non-slum were widely seen as a risk factor for this disease. Although to varying degrees, sanitation conditions in both neighborhoods were summarily poor and inimical to the health and well-being of older adults. For example, toilet facilities and waste disposal systems were reportedly inadequate and inappropriate in both the slum and non-slum, serving as risk factors for cholera and other infectious diseases among older residents. Social incivilities such as crime and noise pollution were reported in both neighborhoods as significant sources of physical and psychological discomfort to older residents, including experiences of sleep problems and lack of concentration. The health impacts of these environmental conditions were, however, mitigated by several health-enhancing conditions, including affordable housing and generous social support systems in the slum and appealing outdoors in the non-slum. Nonetheless, public sector interventions are needed to remediate the aforementioned health risks.

In conclusion, despite distinct spatial and socioeconomic characteristics, we found similar patterns of health risks in the two contrasting neighborhoods. However, the factors underlying these risks were, in many instances, specific to each community. A more critical exploration of causal relationships points to structural determinants of health barriers, which then manifest differently at the neighborhood level as community-specific risk factors for poor health. For example, urban poverty and a neoliberal development paradigm undermining the needs of older adults are largely responsible for their poor living conditions across the city. Given these broader observations, enhancing the health and well-being of slum and non-slum older adults would, among others, require improvements to their current housing and neighborhood conditions, including their access to municipal services, crime-free outdoors, and suitable sanitation infrastructure. It is also critical, in view of the findings, to re-examine the slum and non-slum dichotomy in Ghanaian settlement classifications. While the two neighborhoods aligned with official definitions of slum and non-slum, in terms of whether they are planned or unplanned, the lived experiences of the participants demonstrated more convergence than divergence. We therefore suggest that interventions to address health vulnerabilities among older adults be based on assessment of actual need rather than settlement classifications.

STUDY LIMITATIONS

The study sample was small in size, purposive, and statistically unrepresentative of the population of older adults residing in the slum and non-slum. This limitation potentially affects the generalizability of the findings. Future research relying on statistical sampling techniques and collection of large quantitative data would help extend public health understanding of variations in health risks among slum and non-slum neighborhoods. The generalizability of our findings is further curtailed by our limited focus on two neighborhoods. Future comparative studies exploring the health of older adults could be much broader in geographical scope, covering multiple slum and non-slum settlements. Furthermore, as a qualitative study, we were unable to establish correlations between neighborhood environmental factors and the health conditions reported by participants. As such, our claims of causal relationships relied exclusively on participant narratives. Epidemiological studies are thus needed to further public health knowledge of associations between neighborhood conditions and health risks pertaining to older adults in SSA. Nonetheless, our study demonstrates that older adults, regardless of neighborhood location, face similar environmental barriers to health.

DATA AVAILABILITY STATEMENT

This paper utilized original data collected by the authors. Inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The University of Alberta Research Ethics Board and University of Ghana Research Ethics Committee reviewed and approved the study protocol. All participants provided informed written consent to participate in the interviews.

AUTHOR CONTRIBUTIONS

All authors contributed to the conceptualization, investigation, writing, review, and editing of the manuscript. All authors approved the submitted version.

FUNDING

This research was funded in part by an establishment grant held by Menon.

REFERENCES

1. World Health Organization. *Global health and aging*. Geneva: World Health Organization (2011).
2. Beard JR, Officer A, de Carvalho IA, Sadana R, Pot AM, Michel JP, et al. The World report on aging and health: a policy framework for healthy aging. *Lancet*. (2016) 387:2145–54. doi: 10.1016/S0140-6736(15)00516-4
3. Ghana Statistical Service. *2010 Population and Housing Census Report: The Elderly in Ghana*. Accra: Ghana Statistical Service (2013).
4. Van Dijk HM, Cramm JM, Van Exel JOB, Nieboer AP. The ideal neighbourhood for aging in place as perceived by frail and non-frail community-dwelling older people. *Aging Soc.* (2015) 35:1771–95. doi: 10.1017/S0144686X14000622

5. Satariano WA, Ory MG, Lee C. Planned and built environments in public health. In: Prohaska TR, Anderson LA, Binstock RH, editors. *Public Health for an Aging Society*. Baltimore, MD: The Johns Hopkins Press (2012). p. 327–52.
6. Gardner PJ. Natural neighborhood networks—Important social networks in the lives of older adults aging in place. *J Aging Stud.* (2011) 25:263–71. doi: 10.1016/j.jaging.2011.03.007
7. Glass TA, Balfour JL. Neighborhoods, aging, and functional limitations. In: Kawachi I, Berkman LF, editors. *Neighbourhoods and Health*. New York: Oxford University (2003). p. 303–34.
8. Robert SA, Li LW. Age variation in the relationship between community socioeconomic status and adult health. *Res Aging.* (2001) 23:234–59. doi: 10.1177/0164027501232005
9. Mendes de Leon CF, Cagney KA, Bienias JL, Barnes LL, Skarupski KA, Scherr PA, et al. Neighborhood social cohesion and disorder in relation to walking in community-dwelling older adults: a multilevel analysis. *J Aging Health.* (2009) 21:155–71. doi: 10.1177/0898264308328650
10. Michael YL, Green MK, Farquhar SA. Neighborhood design and active aging. *Health Place.* (2006) 12:734–40. doi: 10.1016/j.healthplace.2005.08.002
11. Beard JR, Blaney S, Cerda M, Frye V, Lovasi GS, Ompad D, et al. Neighborhood characteristics and disability in older adults. *J Gerontol Series B.* (2009) 64:252–7. doi: 10.1093/geronb/gbn018
12. Clark CR, Kawachi I, Ryan L, Ertel K, Fay ME, Berkman LF. Perceived neighborhood safety and incident mobility disability among elders: the hazards of poverty. *BMC Public Health.* (2009) 9:162. doi: 10.1186/1471-2458-9-162
13. Eisenstein AR, Prohaska TR, Kruger J, Satariano WA, Hooker S, Buchner D, et al. Environmental correlates of overweight and obesity in community residing older adults. *J Aging Health.* (2011) 23:994–009. doi: 10.1177/0898264311404557
14. Schootman M, Andresen EM, Wolinsky FD, Malmstrom TK, Miller JP, Miller DK. Neighborhood conditions and risk of incident lower-body functional limitations among middle-aged African Americans. *Am J Epidemiol.* (2006) 163:450–8. doi: 10.1093/aje/kwj054
15. Balfour JL, Kaplan GA. Neighborhood environment and loss of physical function in older adults: evidence from the Alameda County Study. *Am J Epidemiol.* (2002) 155:507–15. doi: 10.1093/aje/155.6.507
16. Wilson-Genderson M, Pruchno R. Effects of neighborhood violence and perceptions of neighborhood safety on depressive symptoms of older adults. *Soc Sci Med.* (2013) 85:43–9. doi: 10.1016/j.socscimed.2013.02.028
17. Zhang Z, Zhang J. Perceived residential environment of neighborhood and subjective well-being among the elderly in China: a mediating role of sense of community. *J Environ Psychol.* (2017) 51:82–94. doi: 10.1016/j.jenvp.2017.03.004
18. Kitchen P, Williams A, Chowhan J. Sense of community belonging and health in Canada: a regional analysis. *Soc Indi Res.* (2012) 107:103–26. doi: 10.1007/s11205-011-9830-9
19. Zhao Y, Chung PK. Neighborhood environment walkability and health-related quality of life among older adults in Hong Kong. *Arch Gerontol Geri.* (2017) 73:182–6. doi: 10.1016/j.archger.2017.08.003
20. Gao M, Ahern J, Koshland CP. Perceived built environment and health-related quality of life in four types of neighborhoods in Xi'an, China. *Health Place.* (2016) 39:110–15. doi: 10.1016/j.healthplace.2016.03.008
21. Parra DC, Gomez LF, Sarmiento OL, Buchner D, Brownson R, Schimd T, et al. Perceived and objective neighborhood environment attributes and healrelated quality of life among the elderly in Bogota, Colombia. *Soc Sci Med.* (2010) 70:1070–6. doi: 10.1016/j.socscimed.2009.12.024
22. Keene DE. Qualitative methods and neighborhood health research. In: Duncan DT, Kawachi I, editors. *Neighborhoods and Health*. New York, NY: Oxford University Press (2018). p. 193.
23. Iwarsson S. A long-term perspective on person–environment fit and ADL dependence among older Swedish adults. *Gerontologist.* (2005) 45:327–36. doi: 10.1093/geront/45.3.327
24. Domènech-Abella J, Mundó J, Leonardi M, Chatterji S, Tobiasz-Adamczyk B, Koskinen S, et al. Loneliness and depression among older European adults: The role of perceived neighborhood built environment. *Health Place*. (2019) 62:102280. doi: 10.1016/j.healthplace.2019.102280
25. Ahn M, Kwon HJ, Kang J. Supporting aging-in-place well: findings from a cluster analysis of the reasons for aging-in-place and perceptions of well-being. *J Appl Gerontol.* (2020) 39:3–15. doi: 10.1177/0733464817748779
26. Park S, Han Y, Kim B, Dunkle RE. Aging in place of vulnerable older adults: Person–environment fit perspective. *J Appl Gerontol.* (2017) 36:1327–50. doi: 10.1177/0733464815617286
27. Choi YJ, Matz-Costa C. Perceived neighborhood safety, social cohesion, and psychological health of older adults. *Gerontologist.* (2018) 58:196–206. doi: 10.1093/geront/gny021
28. Park S, Lee S. Age-friendly environments and life satisfaction among South Korean elders: person–environment fit perspective. *Aging Men Health*. (2017) 21:693–702. doi: 10.1080/13607863.2016.1154011
29. Majale M. The relevance of settlement typologies to upgrading interventions in Nairobi, Kenya. *Forum*. (1993) 2:47–56.
30. Essamuah M, Tonah S. Coping with urban poverty in Ghana: an analysis of household and individual livelihood strategies in Nima/Accra. *Leg J Sociol.* (2004) 1:79–96. doi: 10.10520/AJA08556261_55
31. Arn J. Third world urbanization and the creation of a relative surplus population: a history of Accra, Ghana to 1980. *Review.* (1996) 19:413–43.
32. Van Riel K. *Negotiating the Slum Understanding the Human-Spatial Dynamics of Nima.* Accra: Master Thesis, Radboud University Nijmegen (2015).
33. Morinville C, Harris LM. Participation, politics, and panaceas: exploring the possibilities and limits of participatory urban water governance in Accra, Ghana. *Ecol Soci.* (2014) 19:36. doi: 10.5751/ES-06623-190336
34. Ghana Statistical Service. *2010 Population and Housing Census: District analytical report – Accra Metropolitan*. Accra: Ghana Statistical Service (2014).
35. Agyei-Mensah S, Owusu G. Ethnic residential clusters in Nima, Ghana. *Urban Forum.* (2012) 23:133–49. doi: 10.1007/s12132-011-9127-8
36. Verutes GM, Fiocco MB, Weeks JR, Coulter LL. Health, poverty, and place in Accra, Ghana: mapping neighborhoods. *J Maps.* (2012) 8:369–73. doi: 10.1080/17445647.2012.744365
37. Pellow D. *Landlords and Lodgers: Socio-Spatial Organization in an Accra Community*. Westport, CT: Praeger Publishers (2008).
38. Yankson PW. Rental Housing and Tenancy Dynamics with Particular Focus on Low-income Households in Greater Accra Metropolitan Area. In: Ardayfio-Schandorf EA, Yankson PWK, Bertrand M, editors. *The Mobile city of Accra: Urban families, Housing, and Residential Practices.* Codesria: Dakar (2012). p. 183–206.
39. Tengan C, Aigbavboa CO. *Addressing Flood Challenges.* Ghana: A Case of the Accra Metropolis (2016).
40. Bentil NL. *Asylum Down, Adabraka Gaining Commercial Status*. (2009). Available online at: http://bentil.blogspot.com/2009/11/asylum-down-adabraka-gaining-commercial.html (accessed January 05, 2021).
41. Herbert S. For ethnography. *Prog Hum Geog.* (2000) 24:550–68. doi: 10.1191/030913200100189102
42. Walton E. Vital places: facilitators of behavioral and social health mechanisms in low-income neighborhoods. *Soc Sci Med.* (2014) 122:1–12. doi: 10.1016/j.socscimed.2014.10.011
43. Government of Ghana. *National Ageing Policy: Ageing with Security and Dignity*. (2010). Available online at: https://www.mogcsp.gov.gh/mdocs-posts/national-ageing-policy-ageing-with-security-and-dignity/ (accessed January 05, 2021).
44. Sandelowski M. Sample size in qualitative research. *Res Nurs Health.* (1995) 18. 179–83. doi: 10.1002/nur.4770180211
45. QSR International Pty Ltd. *NVivo Qualitative Data Analysis Software*, Doncaster: QSR International. Version 10. (2012).
46. Fereday J, Muir-Cochrane E. Demonstrating rigor using thematic analysis: a hybrid approach of inductive and deductive coding and theme development. *Int J Quali Meth.* (2006) 5:80–92. doi: 10.1177/160940690600500107
47. Green J, Willis K, Hughes E, Small R, Welch N, Gibbs L, et al. Generating best evidence from qualitative research: the role of data analysis. *Aust N Zeal J Pub Health.* (2007) 31:545–50. doi: 10.1111/j.1753-6405.2007.00141.x
48. Pellatt G. Ethnography and reflexivity: emotions and feelings in fieldwork. *Nurse Res*. (2003) 10:28–37. doi: 10.7748/nr2003.04.10.3.28.c5894
49. Johnstone S, Page N, Madhi S, Mutevedzi P, Myburgh N, Herrera C, et al. *Diarrhoeal diseases.* Soweto: A community survey (2020).

50. Gavazzi G, Herrmann F, Krause KH. Aging and infectious diseases in the developing world. *Clin Inf Dis.* (2004) 39:83–91. doi: 10.1086/421559
51. Assunção MRSD, Pinto SIM, José HMG. Public and health policy for the aged in Africa to the South of Saara. *Rev Bras Enferm.* (2020) 73:1–10. doi: 10.1590/0034-7167-2019-0313
52. Essuman A, Gold KJ, Vitale C, Toma G, Cigolle C, Gyakobo MA, et al. Establishing the first geriatric medicine fellowship program in Ghana. *J Am Geri Soci.* (2019) 67:1718–23. doi: 10.1111/jgs.16014
53. Sietchiping R, Permezel MJ, Ngomsi C. Transport and mobility in sub-Saharan African cities: An overview of practices, lessons and options for improvements. *Cities.* (2012) 29:183–9. doi: 10.1016/j.cities.2011.11.005
54. Smit W, de Lannoy A, Dover RV, Lambert EV, Levitt N, Watson V. Making unhealthy places: the built environment and non-communicable diseases in Khayelitsha, Cape Town. *Health Place.* (2016) 39:196–203. doi: 10.1016/j.healthplace.2016.04.006
55. Clark SN, Alli AS, Brauer M, Ezzati M, Baumgartner J, Toledano MB, et al. Protocol: high-resolution spatiotemporal measurement of air and environmental noise pollution in sub-saharan African cities: pathways to equitable health cities study protocol for Accra, Ghana. *BMJ Open.* (2020) 10:1–10, doi: 10.1136/bmjopen-2019-035798
56. Schreckenberg D, Griefahn B, Meis M. The associations between noise sensitivity, reported physical and mental health, perceived environmental quality, and noise annoyance. *Noise Health.* (2010) 12:7–16. doi: 10.4103/1463-1741.59995
57. Matsumura Y, Rylander R. Noise sensitivity and road traffic annoyance in a population sample. *J Sound Vib.* (1991) 151:415–9. doi: 10.1016/0022-460X(91)90538-U
58. Muzet A. Environmental noise, sleep and health. *Sleep Med Rev.* (2007) 11:135–42. doi: 10.1016/j.smrv.2006.09.001
59. Gallagher NA, Gretebeck KA, Robinson JC, Torres ER, Murphy SL, Martyn KK. Neighborhood factors relevant for walking in older, urban, African American adults. *J Aging Phys Act.* (2010) 18:99–115. doi: 10.1123/japa.18.1.99
60. Aboderin I, Kano M, Owii HA. Toward "age-friendly slums"? Health challenges of older slum dwellers in Nairobi and the applicability of the age-friendly city approach. *Int J Environ Res Pub Health.* (2017) 14:1259. doi: 10.3390/ijerph14101259
61. Gulyani S, Bassett EM. Retrieving the baby from the bathwater: slum upgrading in Sub-Saharan Africa. *Environ Plan C Gov Pol.* (2007) 25:486–515. doi: 10.1068/c4p
62. Sengupta U. State-led housing development in Brazil and India: a machinery for enabling strategy? *Int J Hous Policy.* (2019) 19:509–35. doi: 10.1080/19491247.2018.1510076
63. Stokes CJ. A theory of slums. *Land Eco.* (1962) 38:187–97. doi: 10.2307/3144581
64. Shortt NK, Hammett D. Housing and health in an informal settlement upgrade in cape Town, South Africa. *J Hous Built Environ.* (2013) 28:615–27. doi: 10.1007/s10901-013-9347-4
65. Shetty P. Health care for urban poor falls through the gap. *Lancet.* (2011) 377:627–8. doi: 10.1016/S0140-6736(11)60215-8
66. Weiss H. Reorganising social welfare among muslims: islamic voluntarism and other forms of communal support in Northern Ghana. *J Relig Afri.* (2002) 32:83–109. doi: 10.1163/15700660260048483

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 04 June 2021
doi: 10.3389/fpubh.2021.634751

Check for updates

Neighborhood Environments and Utilitarian Walking Among Older vs. Younger Rural Adults

Chanam Lee[1]*, *Chunkeun Lee*[1], *Orion T. Stewart*[2,3], *Heather A. Carlos*[4,5], *Anna Adachi-Mejia*[4], *Ethan M. Berke*[6,7] and *Mark P. Doescher*[8]

[1] Department of Landscape Architecture and Urban Planning, Texas A&M University, College Station, TX, United States, [2] California Department of Public Health, Sacramento, CA, United States, [3] University of Washington, Seattle, WA, United States, [4] Geisel School of Medicine at Dartmouth, Lebanon, NH, United States, [5] Norris Cotton Cancer Center at Dartmouth-Hitchcock, Lebanon, NH, United States, [6] Optum (United States), Eden Prairie, MN, United States, [7] The Dartmouth Institute for Health Policy and Clinical Practice, Geisel School of Medicine at Dartmouth, Lebanon, NH, United States, [8] University of Oklahoma Health Sciences Center, Oklahoma City, OK, United States

Introduction: Walking has the potential to promote health across the life span, but age-specific features of the neighborhood environment (NE), especially in rural communities, linked with walking have not been adequately characterized. This study examines the relationships between NE and utilitarian walking among older vs. younger adults living in US rural towns.

Methods: Data for this cross-sectional study came from telephone interviews in 2011–2012 with 2,140 randomly sampled younger (18–64 years, $n = 1{,}398$) and older (65+ years, $n = 742$) adults, collecting personal and NE perception variables. NE around each participant's home was also measured objectively using geographic information system techniques. Separate mixed-effects logistic regression models were estimated for the two age groups, predicting the odds of utilitarian walking at least once a week.

Results: Perceived presence of crosswalks and pedestrian signals was significantly related to utilitarian walking in both age groups. Among older adults, unattended dogs, lighting at night, and religious institutions were positively while steep slope was negatively associated with their walking. For younger adults, traffic speed (negative, –), public transportation (positive, +), malls (–), cultural/recreational destinations (+), schools (+), and resource production land uses such as farms and mines (–) were significant correlates of utilitarian walking.

Conclusion: Different characteristics of NE are associated with utilitarian walking among younger vs. older adults in US rural towns. Optimal modifications of NE to promote walking may need to reflect these age differences.

Keywords: physical activity, neighborhood environment, rural communities, older adults, walking

OPEN ACCESS

Edited by:
Katherine Henrietta Leith, University of South Carolina, United States

Reviewed by:
Clas-Håkan Anders Nygård, Tampere University, Finland
Calum Mattocks, University of Cambridge, United Kingdom

Correspondence:
Chanam Lee
chanam@tamu.edu

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *28 November 2020*
Accepted: *13 April 2021*
Published: *04 June 2021*

Citation:
Lee C, Lee C, Stewart OT, Carlos HA, Adachi-Mejia A, Berke EM and Doescher MP (2021) Neighborhood Environments and Utilitarian Walking Among Older vs. Younger Rural Adults. Front. Public Health 9:634751. doi: 10.3389/fpubh.2021.634751

INTRODUCTION

Walking, with all of its health benefits particularly for older adults, has the potential to promote health outcomes as adults age (1). According to the 2014 Behavioral Risk Factor Surveillance System (BRFSS) data, 26.9% of older adults aged 65–74 years reported no physical activity outside of work during the last month, and the number increased to 35.3% as age increased to 75 years and above (2). A growing body of research has begun to illuminate the differing roles that the neighborhood environment (NE) plays in promoting or, as is often the case, hindering walking as adults age (3).

Most studies to date about environment–walking relationships among older or general adults have been limited to metropolitan or urban areas. However, rural towns are home to 10% of the US population, have a disproportionately large number of older adults, and are aging more rapidly than the rest of the United States (4). Several recently published studies carried out in rural communities reported both similarities and differences in the correlates of walking between urban and rural residents (5–7). The study of Stewart et al. comparing one urban community and nine small rural towns in the United States found that the same land use (i.e., restaurants) can be positively associated with utilitarian walking in urban settings while negatively associated in rural settings, and NE is more strongly associated with utilitarian walking in urban communities. They also observed a higher prevalence of recreational walking in rural towns, and traffic speed was a significant predictor of recreational walking only in rural communities. The study of Doescher et al., further examining the same nine rural towns, reported that crosswalks, pedestrian signals, park/natural recreational areas, and manufacturing land uses were positively correlated with utilitarian walking in these communities (5). Another study in Japan explored the roles of street layout design and found that street intersection density was linked with increased walking for errands in urban areas, while street integration was positively associated with walking for commuting in rural areas (6). All of these studies were based on the general adult population. Little is known about the age-varying associations between walking and NE in these rural/small towns that are also known to be subject to significant health inequities (8).

Substantial empirical evidence based on general adult studies suggests that walkable neighborhoods typically feature compact development patterns, proximately located destinations, connected street/sidewalk networks, and safety from traffic and crime (9, 10). The roles of walkable neighborhood features, however, may differ among people from different age groups. One study indicated that NE may play a less significant role in walking for older adults compared to their younger counterparts (11). Another older adult study suggested that NE may be more important for influencing the amount of walking among those who already walk than encouraging non-walkers to walk (12). Age differences in transportation walking were found to be greater in lower walkability neighborhoods than in higher walkability neighborhoods (13). Other research pointed to the synergistic effects of NE and personal factors (e.g., socioeconomic status, self-efficacy, and personal barriers) on walking among older adults (14, 15). Studies examining self-report barriers and facilitators of walking and route choice models suggested that the characteristics of NE that influence walking behaviors in older adults might be highly fine-grained and location-specific (3, 16). One study found that the decline in walking for transport over a 4-year period was less among those living in walkable neighborhoods (17). A review study suggested that proximity to destinations, connected street networks, and safety from traffic were associated with older adults' mobility (18). Studies also showed that people with a longer residential history tend to be less fearful of their neighborhood (19) and walk more for exercise (20). These studies indicate that walkable NE has some potential to support mobility and aging in place.

The purpose of this study was to identify NE characteristics that are associated with utilitarian walking among older vs. younger adults living in US rural towns. This study focuses on utilitarian walking because it is associated more strongly with NE and less strongly with personal factors than recreational walking (7, 9) and because it is more likely to bring long-term lifestyle changes, is easily incorporated into the daily routine, helps preserve independent mobility of aging populations, and accompanies additional economic and environmental benefits resulting from reduced automobile use (21). Utilitarian walking is especially important for increasing or maintaining mobility and independence among older adults, supporting the aging in place initiatives (22, 23).

NE is the target setting of this study due to the increasing importance of the residential neighborhood among older adults, as they spend most of their time at home and rely more on proximately available resources within the neighborhood for their physical and psychosocial needs (24, 25). Furthermore, older adults tend to be more vulnerable to environmental challenges or barriers. For example, older adults walk at slower speeds and thus may have more difficulty crossing busy streets, especially when there are no crosswalks or when the crosswalk signals are too short (3).

The social ecological framework provides a theoretical foundation and guidance for this paper. It emphasizes the dynamic interplays between people and their environments (26). Compared to other common theories in the health promotion or behavior change literature that tend to focus on intrapersonal factors, the social ecological model draws attention to the social and physical environments as key determinants of individual health/behavioral outcomes (27). Lawton applies an ecological theory to describe the aging process as an evolving process of human adaptation to their environment (28). His theory highlights the importance of immediate contexts (social, physical, and technological) in determining such process and outcomes (28, 29). Both theories recognize the importance of environmental contexts such as neighborhoods in determining health behaviors such as walking and physical activity. They also agree that the nature of the environment–behavior relationships is highly dependent on the specific behavior, population, and the community context being targeted (30). These theories offer useful insights and support for environment–behavior studies to examine the population- and context-specific correlates of an explicit target outcome, such as utilitarian walking. Both theories further recognize the multilevel characteristics of the environment, including interpersonal, sociocultural, institutional, and physical environments; proximal to distal environments; and the interplay within and between factors at different levels (23). This study focuses on age (intrapersonal variable) and NE (both perceived and objectively measured environmental variables) to explore their roles in promoting or hindering utilitarian walking in US rural towns as the understudied settings for this type of study.

METHODS

This cross-sectional study examines the correlates of utilitarian walking in neighborhoods among 2,140 randomly sampled younger (18–64 years, $n = 1{,}398$) and older (65+ years, $n = 742$) adults. We used the age of 65 as the threshold in this study as it is the most commonly used and accepted threshold for defining older adults in the United States (e.g., Census Bureau, National Institutes of Health). Utilitarian walking in this paper is defined as walking to or from any destinations including recreational ones (e.g., grocery store, school, and park). Two separate mixed-effects multivariable logistic regression models were estimated for the two age groups, adjusting for the town-level clustering effect.

Setting

In order to represent a diversity of rural towns in the United States, this study was carried out in nine towns from three diverse geographic regions: the Northwest (Washington), the Northeast (New Hampshire and New York), and the South (Texas) (**Table 1**). The selection criteria included: (a) geographically isolated rural towns located in counties classified as "micropolitan statistical areas" based on the US Census (31) with sufficient population (10,000–40,000) to support services for daily living; (b) clustered residential areas to permit walking between homes and routine destinations; (c) diverse racial/ethnic composition and education/income levels; and (d) availability of geographic information systems (GIS) data. More information about the study setting and data collection methods can be found elsewhere (Blinded for Review, 2016).

Survey

All personal variables were obtained from an ∼20-min-long telephone survey administered in 2011 in both English and Spanish. The survey instrument was developed by taking items used in previous peer-reviewed research, including the International Physical Activity Questionnaire (32), the Neighborhood Environment Walkability Scale (33), the Behavioral Risk Factor Surveillance System (34), and the Rural Active Living Perceived Environment Support Scale (35), and by pilot testing it with 50 randomly sampled respondents from the same study population. The final survey instrument included demographics, race and ethnicity, health and socioeconomic status, barriers and facilitators of walking, walking and sedentary behaviors, and neighborhood perceptions. The survey protocol and instrument were approved at each of the investigators' universities.

The study used a spatial sampling strategy that involved random sampling of residential units from those selected into the sample frame (36). The sample frame was spatially delineated to include all census blocks that contained the top 80% of the population in each study town. This excluded very low-density residential areas often located in farmland and undeveloped areas wherein no nearby destinations were available for utilitarian walking. Phone numbers were identified through a reverse directory landline lookup for the selected units, which yielded an approximate matching rate of 40%. The phone interviews were conducted over four months in 2011 when the weather was most favorable for walking in each region, with a maximum of nine callbacks and an estimated response rate of 18.8%. The respondent eligibility criteria were (a) aged 18 years or older; (b) resided at the current address for at least 1 year; and (c) being able to walk without special equipment for 5 minutes.

Geographic Information Systems

GIS was used to generate the objective measures of NE related to walkability. Raw data were obtained from each jurisdiction, and additional data were collected from aerial photos, online maps, and various agencies (e.g., tax assessor's office, parks and recreation department, and transit agency). A detailed protocol and definition for each GIS measure was developed and followed to ensure valid and consistent measures across all nine towns. GIS measurements were carried out in 2013 and included buffer-based measures (e.g., total number of banks and average residential unit density), which were taken from a 1-km street network "sausage" buffer (37) around each survey respondent's home, and proximity measures (e.g., distance to the closest park) taken as the shortest distance from the home to each target destination along the road network up to 2 km. The sausage buffer method is similar to the standard street network buffer, but it excludes interior areas inside the street block where pedestrians are not likely to see or get to. Details about the GIS method, measures, and protocols used in this study can be found in a previously published paper (Blinded for Review, 2016).

Variables

The outcome was a binary variable, walking at least once a week vs. not. It was generated from the survey questions asking about the number of times per month walked from home to a series of common destinations, which were converted to weekly frequencies. Predictor variables included personal and environmental variables. Descriptive statistics and the coding schemes of only those that retained statistical significance at the 0.1 level in the final multivariable models are included in **Tables 2** and **3**. All personal variables were derived from the survey data and consisted of five domains: demographics, health and socioeconomic status, behavior, barrier to walking, and residential self-selection. The environmental variables came from both survey (neighborhood perception) and GIS (objective built environment). Neighborhood perception variables (11 variables considered) included safety, street/traffic conditions, visual quality, sidewalk availability, shade condition, and presence of destinations. The GIS variables included eight sub-domains: generalized land use (19 variables), destination land use (102), residential density (six), transportation infrastructure (52), economic environment (nine), employment (six), regional location (two), and natural environment (six).

Statistical Analysis

We used mixed-effects multivariable logistic regression models to account for the town-level data clustering and identified the factors significantly associated with the odds of walking at

TABLE 1 | Survey respondents by town and by age group.

Region	City, state	Size (mi.^{2})[a]	Population[a]	Density[a,b]	Income (US $)[a,c]	Younger adults (18–64 years)		Older adults (>65 years)	
						Freq.	%	Freq.	%
Northwest	Walla Walla, WA	10.82	31,731	2,933	41,236	173	77.6	50	22.4
	Moses Lake, WA	10.18	20,366	2,001	47,535	148	66.1	76	33.9
	Aberdeen, WA	10.62	16,896	1,591	39,530	166	68.0	78	32.0
Northeast	Plattsburgh, NY	5.04	19,989	3,966	35,528	145	66.2	74	33.8
	Berlin, NH	61.70	10,051	163	38,107	144	66.7	72	33.3
	Lebanon, NH	40.36	13,151	326	54,969	223	73.8	79	26.2
South	Kerrville, TX	16.70	22,347	1,338	41,064	99	40.7	144	59.3
	Huntsville, TX	30.90	38,548	1,248	29,465	138	58.2	99	41.8
	Bay City, TX	8.49	17,614	2,075	37,601	162	69.8	70	30.2
Total						1,398	65.3	742	34.7

[a]*Census 2010.*
[b]*Persons/square mile.*
[c]*Median household income.*

least once a week in the neighborhood to reach a destination. The interclass correlation coefficient (ICC) values of the final multivariable models were 0.048 in the older adult model and 0.011 in the younger adult model. This means that the town-level effect accounts for 4.8% and 1.1% of the total variances explained in the older and younger adult models, respectively.

Due to the lack/shortage of theoretical foundations to guide the selection of the environmental variables, especially the GIS variables that tend to be highly correlated with each other, a three-step modeling process was employed to systematically test and isolate the most significant variables: (1) estimation of the base model with the personal variables only; (2) one-by-one test of the environmental variables by adding one environmental variable at a time to the base model; and (3) estimation of the final model by considering all the significant variables identified in step 2. To further examine the moderation effect of the age variable, we carried out a formal moderator test (38). It involved adding the interaction terms between age and the predictor variables, one at a time, to the final model. The statistical significance was set to $p < 0.10$ in steps 1 and 2 for more thorough considerations of all potential predictors and given the data-driven nature of the screening process (step 2) that was necessary, although not ideal, for the environmental variables. In the final models, we stayed with the standard alpha level of 0.05 for reporting and discussing the significant findings. All statistical analyses were carried out in 2013 using STATA version 12.0 (StataCorp LP, College Station, TX).

RESULTS

The participants (1,398 younger and 742 older adults) were primarily white and non-Hispanic, with 80.0% of the younger adults and 91.5% of the older adults being white and 85.5% and 97.0%, respectively, reporting a non-Hispanic origin. Based on the body mass index estimated from the self-reported weight and height, 26.1% of the younger adults belonged to the obese category compared to only 17.5% among the older adults. About 4.5% of the older adults, compared to 3.7% among the younger adults, lived in a household without a car; 57.1% of the older and 72.8% of the younger adults were married or lived with a partner. **Table 4** displays the significant correlates of walking identified for each age group after adjusting for other significant covariates.

Personal Correlates

From the multivariable analyses, we found two personal variables associated with home-based utilitarian walking regardless of age. Females were less likely to walk to destinations than males in both age groups, with odds ratios (ORs) of 0.53 ($p < 0.001$) for the younger adults and 0.51 ($p = 0.003$) for the older adults. Those who walked for utilitarian purposes also walked more for recreational purposes regardless of their age group ($p < 0.001$ in both models).

Age was negatively associated with walking in the younger adult model only (OR = 0.98, $p = 0.001$). A 1-year increase in age was associated with an ∼2.5% decrease in the odds of walking for utilitarian purposes. On the other hand, education (OR = 1.33, $p = 0.004$) and time barrier (OR = 2.25, $p = 0.002$) were positively while income (OR = 0.85 and $p = 0.026$), difficulty in walking (OR = 0.27, $p < 0.001$), and screen time (OR = 0.98, $p = 0.004$) were negatively associated with walking among the older adults only. The ease of walking to retail, services, and transit being considered when choosing where to reside served as a proxy for residential self-selection and showed a positive relationship with walking in the older adults only.

Environmental Correlates

One environmental variable was significant in predicting the odds of home-based utilitarian walking in both age groups: perceived presence of crosswalks and pedestrian signals (OR = 1.81, $p = 0.012$, for the older adults; OR = 1.71, $p = 0.002$, for the younger adults).

For the older adults, perceptions related to having more unattended dogs (OR = 3.07, $p = 0.002$) and better lighting conditions (OR = 1.65, $p = 0.029$) were positively associated with

TABLE 2 | Descriptive statistics and bivariate tests of the study variables used in the final models: personal variables (survey).

Domain	Variable	Younger adults		Older adults	
		Freq. or mean	**% or SD**	**Freq. or mean**	**% or SD**
Demographics	Total *N*	1,398		742	
	Age (years)	48.8	11.1	74.1	6.7
	Gender: $\chi^2 = 0.385$, $p = 0.535$				
	Male (ref.)	531	38.0	292	39.4
	Female	867	62.0	450	60.6
Health and socioeconomic status	*Household annual income* (US $): $\chi^2 = 85.819$, $p < 0.000$ | $t = 7.151$, $p < 0.001$				
	≤25,000	237	19.1	155	25.1
	25,001–50,000	261	21	221	35.8
	50,001–100,000	509	41	194	31.4
	>100,000	233	18.8	47	7.6
	Nine-category version (1: lowest–9: highest)[a]	5.6	2.1	4.9	1.9
	Education: $\chi^2 = 19.931$, $p = 0.001$ | $t = -1.446$, $p = 0.148$				
	≤High school graduate	389	27.9	215	29.1
	Some college/associate degree	400	28.6	197	26.6
	≥College graduate	608	43.5	330	44.5
	Seven-category version (1: lowest–7: highest)[a]	5.2	1.3	5.3	1.3
	Difficulty walking: $\chi^2 = 46.535$, $p < 0.000$				
	Not at all difficult (ref.)	1,321	94.5	637	85.9
	Difficult or do not do this activity	77	5.5	105	14.1
Behavior	*Utilitarian walking* (h/week): $\chi^2 = 80.237$, $p < 0.001$				
	Non-walker (ref.)	287	20.5	286	38.5
	Walker	1,111	79.5	456	61.5
	Recreational walking (h/week): $\chi^2 = 22.470$, $p = 0.001$ | $t = 3.114$, $p = 0.002$				
	0 [0]	110	7.9	101	13.6
	0.1–0.5 [1]	166	11.9	100	13.5
	0.6–1.5 [2]	273	19.5	121	16.3
	1.6–2.5 [3]	205	14.7	113	15.2
	2.6–5.0 [4]	312	22.3	150	20.2
	5.1–7.0 [5]	119	8.5	56	7.6
	7.1+ [6]	213	15.2	101	13.6
	Seven-category version (0: lowest - 6: highest)[a]	3.2	1.8	2.9	1.9
	Screen time (h/week): $t = -5.815$, $p < 0.001$	15.6	12.9	19.2	14.5
Walking barrier	*Lack of time* (Does this keep you from walking?): $\chi^2 = 215.839$, $p < 0.001$				
	Yes	782	56.1	169	22.9
	No (ref.)	612	43.9	570	77.1
Residential self-selection	*Ease of walking to retail, services, and transit* (Was this important in choosing where to live?): $\chi^2 = 11.096$, $p = 0.001$				
	Yes	523	37.7	223	30.5
	No (ref.)	863	62.3	509	69.5

Coding for income (in US $): 1: ≤10,000; 2: 10,001–15,000; 3: 15,001–25,000; 4: 35,001–35,000; 5: 35,001–50,000; 6: 50,001–75,000; 7: 75,001–100,000; 8: 100,001–150,000; 9: ≥150,001. Coding for education: 1: Never attended school; 2: Elementary; 3: Some high school; 4: High school graduate; 5: Some college/associate degree; 6: College graduate; 7: Graduate school or more.

[a]*Originally captured as ordinal categorical variables and treated as continuous variables in the multivariable models.*

utilitarian walking. The presence of religious institutions within the 1-km home buffer (OR = 1.92, $p = 0.009$) was positively while more sloped (>8.33% or >1:12 slope) areas within the buffer (OR = 0.33, $p = 0.049$) were negatively associated with walking among the older adults.

For the younger adults, perceptions of slow traffic speed in the neighborhood were positively associated with walking (OR = 1.54, $p = 0.016$). From the objective variables, the amounts of cultural–entertainment–recreational land use (e.g., public parks, private resorts, and places of assembly) were positively while resource production and extraction land uses (e.g., farms and mines) were negatively associated with utilitarian walking. Objective measured availability of public transportation captured as the presence of intercity transit stops (OR = 3.50, $p = 0.011$)

TABLE 3 | Descriptive statistics and bivariate tests of the study variables used in the final models: environmental variables (survey and GIS).

Domain	Variable	Younger adults		Older adults	
		Freq. or mean	% or SD	Freq. or mean	% or SD
Neighborhood perception (survey)	*Crosswalks and pedestrian signals* (There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood): $\chi^2 = 21.281$, $p < 0.001$				
	Agree	810	58.2	350	47.8
	Disagree (ref.)	581	41.8	383	52.2
	Sidewalks or shoulders (There are sidewalks or shoulders where people can walk in my neighborhood): $\chi^2 = 5.000$, $p = 0.025$				
	Agree	1,027	74.1	509	69.5
	Disagree (ref.)	359	25.9	223	30.5
	Unattended dogs (Unattended dogs are a problem in my neighborhood): $\chi^2 = 14.182$, $p < 0.001$				
	Agree	245	17.6	84	11.4
	Disagree (ref.)	1,149	82.4	654	88.6
	Well lit at night (My neighborhood is well lit at night): $\chi^2 = 6.618$, $p = 0.010$				
	Agree	865	62.8	490	68.4
	Disagree (ref.)	513	37.2	226	31.6
	Slow traffic speed (The speed of traffic on most nearby streets is usually slow): $\chi^2 = 0.0049$, $p = 0.944$				
	Agree	1,031	75.0	543	74.9
	Disagree	343	25.0	182	25.1
Generalized land use (GIS)	*Resource production and extraction land uses* (% area within buffer): $\chi^2 = 2.614$, $p = 0.271$				
	0% (ref.)	660	47.5	321	44.0
	0.1–3.0%	418	30.1	240	32.9
	>3.0%	311	22.4	169	23.1
	Cultural, entertainment and recreational land uses (% area within buffer): $\chi^2 = 18.870$, $p < 0.001$				
	0% (ref.)	285	20.5	149	20.4
	0.1–1.5%	404	29.1	235	32.2
	1.6–4.0%	460	33.1	182	24.9
	>4.0%	240	17.3	164	22.5
Destination land use (GIS)	*Religious institutions* (presence within buffer): $\chi^2 = 10.207$, $p = 0.001$				
	Absence (ref.)	1,091	78.0	533	71.8
	Presence	307	22.0	209	28.2
	Schools (total counts within buffer): $t = 4.585$, $p < 0.001$	1.482	1.3	1.203	1.3
	Malls (presence within buffer): $\chi^2 = 1.488$, $p = 0.222$				
	Absence (ref.)	1,139	82.0	614	84.1
	Presence	250	18.0	116	15.9
Transportation (GIS)	*Public transportation* (total counts within buffer): $\chi^2 = 0.5934$, $p = 0.441$				
	Absence (ref.)	1,279	92.1	679	93.0
	Presence	110	7.9	51	7.0
Natural environment (GIS)	*Slope* (mean % within buffer): $\chi^2 = 0.307$, $p = 0.580$				
	≤8.33% (ref.)	1,344	96.8	703	96.3
	>8.33%	45	3.2	27	3.7

and the presence of schools (OR = 1.22, $p = 0.007$) within the 1-km buffer from home were positive predictors; the presence of malls (OR = 0.60, $p = 0.022$) within the buffer was a negative predictor of walking among the younger adults.

Moderator Test of Age Effects

No significant interaction terms were found for the younger age model. For the older adults, two interaction terms were significant: age*income and age*recreational walking. **Figures 1**, **2** show the predicted probability of becoming a utilitarian walker across the different age ranges (within the older adult group) by income and by recreational walking. The results indicate that age intensifies the negative relationship between annual household income and the probability of utilitarian walking, while age attenuates the positive relationship between hours of recreational walking and the probability of utilitarian walking.

DISCUSSIONS AND CONCLUSION

Older Adults

We found that both personal and environmental characteristics were associated with adults' utilitarian walking in rural US

TABLE 4 | Multilevel correlates of neighborhood utilitarian walking among younger vs. older adults: results from multivariable mixed-effects models.

Domain	Variable†	Older adults				Younger adults			
		Odds ratio	*p*-value	95% CI		Odds ratio	*p*-value	95% CI	
				Lower	Upper			Lower	Upper
Personal correlates (survey)									
Demographics	Female	0.513**	**0.003**	0.329	0.799	0.527**	**<0.001**	0.374	0.742
	Age (years)					0.974**	**0.001**	0.959	0.989
Health and socioeconomic status	Education (seven ordinal categories)	1.332**	**0.004**	1.094	1.623				
	Income (nine ordinal categories)	0.850*	**0.026**	0.737	0.981	0.920	0.057	0.844	1.002
	Difficulty in walking	0.273**	**<0.001**	0.150	0.496				
Behavior	Recreational walking (seven ordinal categories)	1.342**	**<0.001**	1.196	1.506	1.467**	**<0.001**	1.330	1.617
	Screen time (h/week)	0.978**	**0.004**	0.963	0.993				
Walking barrier	Lack of time	2.254**	**0.002**	1.355	3.747				
Residential self-selection	Ease of walking to retail, services, and transit	1.735*	**0.033**	1.044	2.884				
Environmental correlates—neighborhood perception (survey)									
Neighborhood perception	Unattended dogs	3.071**	**0.002**	1.532	6.158				
	Well lit at night	1.648*	**0.029**	1.052	2.584				
	Crosswalks and pedestrian signals	1.806*	**0.012**	1.139	2.863	1.713**	**0.002**	1.224	2.397
	Sidewalks or shoulders	1.486	0.098	0.929	2.377				
	Slow traffic speed					1.537*	**0.016**	1.084	2.179
Environmental correlates—objective built environment (GIS)									
Generalized land use	Resource production and extraction land uses (% area within buffer)								
	0.1–3.0% (ref.: 0%)					0.590*	**0.010**	0.394	0.882
	>3% (ref.: 0%)					0.355**	**<0.001**	0.229	0.551
	Cultural, entertainment, and recreational land uses (% area within buffer)								
	0.1–1.5% (ref.: 0%)					1.538	0.058	0.985	2.402
	1.6–4.0% (ref.: 0%)					2.058**	**0.004**	1.264	3.352
	>4.1% (ref.: 0%)					1.589	0.083	0.941	2.683
Destination land use	Religious institutions (presence within buffer)	1.920**	**0.009**	1.176	3.134				
	Schools (counts within buffer)					1.224**	**0.007**	1.056	1.418
	Malls (presence within buffer)					0.601*	**0.022**	0.388	0.931
Transportation	Public transportation (presence within buffer)					3.498*	**0.011**	1.330	9.198
Natural environment	Slope (mean % slope within buffer: >8.33% or >1:12 slope, ref: ≤8.33%)	0.334*	**0.049**	0.112	0.995				

Older adults model: N = 548, pseudo-R^2 = 0.226, AIC = 589.118, BIC = 653.713.
Younger adults model: N = 1,207, pseudo-R^2 = 0.196, AIC = 1,000.963, BIC = 077.402.
†*See **Tables 2**, **3** for detailed variable coding schemes.*
*Boldface indicates statistical significance (*p < 0.05, **p < 0.01).*

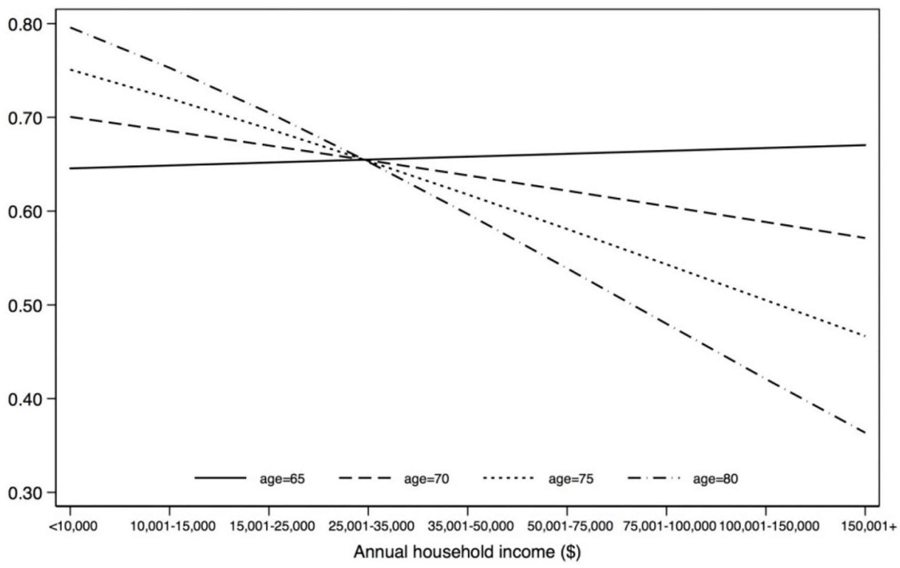


FIGURE 1 | Moderating effect of age: predicted probability of becoming a utilitarian walker by age and income (older adult model). Age (OR = 1.096, $p = 0.046$, 95% CI = 1.002–1.200); income (OR = 4.623, $p = 0.019$, 95% CI = 1.286–16.613); age*income (OR = 0.977, $p = 0.008$, 95% CI = 0.960–0.994).

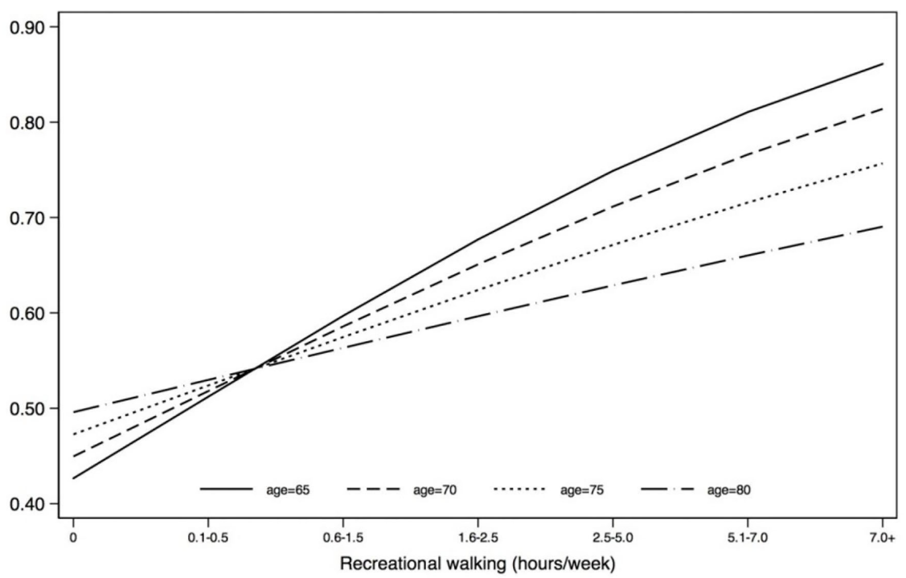


FIGURE 2 | Moderating effect of age: predicted probability of becoming a utilitarian walker by age and recreational walking (older adult model). Age (OR = 1.025, $p = 0.360$, 95% CI = 0.972–1.080); recreational walking (OR = 1.348, $p < 0.001$, 95% CI = 1.197–1.518); age*recreational walking (OR = 0.982, $p = 0.029$, 95% CI = 0.966–0.998).

towns. The findings suggest that walkable NE for older adults could focus on safety-related features. All four significant environmental variables, including lighting, unattended dogs, crosswalks/pedestrian signals, and slope, were directly or indirectly related to the multifaceted concept of safety (39). In addition, perceived availability of sidewalks/shoulders (OR = 1.49, $p = 0.098$) which approached the significant level is relevant to pedestrian safety. This finding is consistent with previous studies reporting environmental factors associated with utilitarian walking in neighborhoods, in which safety has been one of the most frequently documented domains of correlates (9, 40, 41). Furthermore, older adults are more vulnerable to safety-related environmental challenges due to their functional and cognitive declines (28), and therefore providing safe and barrier-free environments may hold even greater importance to support their walking. One specific finding on unattended dogs that had a positive relationship with walking may be considered counterintuitive, but this can be attributable to the likelihood that those who walk more are more likely to observe unattended dogs. The findings on unattended dogs from previous studies have been inconsistent. For example, a study on the correlates of physical activity among African American women in South Carolina found no significant relations between stray dogs and physical activity (42), while another study among middle-aged and older women reported positive relationships between unattended dogs and physical activity (43).

Steep slope was negatively associated with older adults' utilitarian walking in this study, which was defined as >8.33% (1:12 slope), the maximum slope allowed for wheelchair ramps (44). Previous studies on recreational or exercise walking have reported positive roles of slope among older adults (45) and among adults in general (46). The positive relationships with recreational/exercise walking could potentially be due to hilly areas' co-occurring features and benefits such as attractive views and increased exercise benefits, while hilly terrains may function as a barrier to utilitarian walking in which the walker is primarily interested in reaching the destination easily.

Among the land use-related GIS variables examined in this study, only one variable, having one or more religious institutions within 1 km from their home, was shown to be positively associated with walking among the older adults. This finding suggests limited roles of the land use domain for older adults' walking while also suggesting the strong potential for religious institutions to serve as multifunctional destinations not only for religious services but also for other sociocultural and service activities among older adults. The health beneficial roles of religious involvement have been previously reported, including mortality, well-being, and social support (47, 48). This study's finding on the role of religious institutions as walking-friendly destinations suggests that these institutions may also serve to bring additional health benefits to community-dwelling older adults.

The moderator test for the age effect revealed that two age interaction terms were significant. The age and recreational interaction effect suggests that the positive relationship between hours of recreational walking and the probability of utilitarian walking was weakened with older age. This finding also implies that the two different purposes of walking, recreational and utilitarian, in our study are mutually reinforcing (rather than replacing), but its magnitude is attenuated with age. Income showed an opposite pattern of association. For example, at the age of 65, income is estimated to have little impact on the probably of utilitarian walking. At the age of 80, income is expected to have a strong negative association with the probably of walking (ranging from 0.80 of walking probability for those with less than US $10,000 per year of household income to about 0.35 among those earning more than US $150,000).

Younger Adults

More environmental factors, compared to the personal factors and to older adults, were found to be significant for younger adults' walking. From the neighborhood perception domain, perceptions of slow traffic speed and presence of crosswalks and pedestrian signals in the neighborhood were positively associated with their walking. Perceived presence of crosswalks and pedestrian signals was the only environmental variable that showed significance in both age groups and, therefore, worth attention as an intervention target given its consistent significance and its relative affordability for installation. We would anticipate effective interventions from combining crosswalks with raised traffic tables to reduce the traffic speed and/or with pedestrian signals to further enhance pedestrian safety. In addition, recreational walking showed a positive relationship with utilitarian walking in both age groups. Specific relationships (reinforcing, substituting, etc.) between the different types/purposes of walking have not been fully explored in previous studies, and this study adds helpful insights on their relationships.

Land uses were important for the younger adults' walking, more so than for the older adults. The results suggested that incorporating cultural, entertainment, and recreational land uses (e.g., public parks, private resorts, and places of assembly) and schools with walking/running tracks and other recreational facilities open to the public into residential communities could facilitate younger adults' utilitarian walking. However, resource production/extraction land uses (e.g., farms and mines) and malls, which tend to occupy large land areas with extensive surface parking and limited pedestrian accessibility, could discourage their walking. This finding is consistent with previous studies that reported generally positive roles of destinations, measured as land use mix, accessibility to places, etc., in promoting adults' utilitarian walking (9, 49).

Limitations

The findings from this study may not be generalizable to areas other than the study towns. However, this study went beyond most previous studies that were carried out in a single community by including nine towns from three diverse regions. As a cross-sectional study, only correlational associations among the variables can be established, and there are likely missing covariates not captured in our study, such as additional correlates that may be important to one or the other age group only. The response rate could have been higher with different or additional survey methods, but not feasible for this multi-year, multi-region study. Our respondents had lower representations of younger, male, and Latino populations when compared to the Census data (Blinded for Review, 2014), possibly due to its participant recruitment through landline phone numbers. No formal reliability or validity test results are available for our survey instrument. However, most survey items were adopted directly or modified from existing surveys, and the instrument was finalized after a series of pilot testing. While we considered residential preferences and attitudinal factors related to walking, it is still possible that respondents, compared to non-respondents, comprised those who were more likely to walk or over-reported their walking. However, we do not believe that such possibilities vary by the NE characteristics, which are the key independent variables in this study (Blinded for Review, 2014). We found that perceived lack of time was associated with higher amounts of walking among the older adults. We were not able to use these data to further explore this puzzling finding, but it is possible that those who engage in walking are more likely to be aware of or sensitive to barriers to walking, such as a lack of time.

Conclusion

Our findings suggest that, in rural US towns, NE influences home-based utilitarian walking for all adults. However, safety and slope are important primarily for the older adults, while the availability of recreational opportunities and the absence of malls have more prominent roles for the younger adults. For the older adults, relatively low-cost NE features such as crosswalks and lighting appear effective in stimulating their walking, making them appealing intervention targets especially given the growing number of older adults in the United States. For younger adults, additional interventions requiring longer-term land use changes appear necessary. Increased attention to NE by policymakers and professionals in aging, public health, transportation, and urban planning sectors could lead to increased walking among older and younger adults in rural towns.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

This study was reviewed and approved by the Institutional Review Boards at the three participating institutions: Texas A&M University, University of Washington, and Dartmouth College.

AUTHOR CONTRIBUTIONS

ChaL: conceptualization, research design, data analysis and interpretation, manuscript writing, and review and finalization. ChuL: data analysis, data interpretation, and manuscript writing. OS: conceptualization, research design, manuscript writing, and data interpretation. HC: conceptualization, data collection, and manuscript review. AA-M: research design, data interpretation, and manuscript review. EB: conceptualization, data interpretation, and manuscript review. MD: research design, conceptualization, data interpretation, and manuscript review. All authors contributed to the article and approved the submitted version.

FUNDING

This study was supported by a grant from the National Institutes of Health (1R01HL103478).

ACKNOWLEDGMENTS

The authors wish to acknowledge additional members of this research team—Anne Vernez Moudon, Brian Saelens, Davis Patterson, Glen Duncan, Barbara Matthews, Chuck Huber, Li Li, Phil Hurvitz, Woosung Lee, and Zhipeng Lu—for their inputs and guidance on this research.

REFERENCES

1. Taylor AH, Cable NT, Faulkner G, Hillsdon M, Narici M, Van der Bij AK. Physical activity and older adults: a review of health benefits and the effectiveness of interventions. *J Sports Sci.* (2004) 22:703–25. doi: 10.1080/02640410410001712421
2. Watson KB. Physical inactivity among adults aged 50 years and older—United States, 2014. *MMWR.* (2016) 65:954–8. doi: 10.15585/mmwr.mm6536a3
3. Lee C, Ory MG, Yoon J, Forjuoh SN. Neighborhood walking among overweight and obese adults: age variations in barriers and motivators. *J Commun Health.* (2013) 38:12–22. doi: 10.1007/s10900-012-9592-6
4. U.S. Census Bureau. *Patterns of Metropolitan and Micropolitan Population Change: 2000 to 2010.* (2012). Available online at: https://www.census.gov/prod/cen2010/reports/c2010sr-01.pdf (accessed March 22, 2014).
5. Doescher MP, Lee C, Berke EM, Adachi-Mejia AM, Lee CK, Stewart O, et al. The built environment and utilitarian walking in small US towns. *Prevent Med.* (2014) 69:80–6. doi: 10.1016/j.ypmed.2014.08.027
6. Koohsari MJ, Sugiyama T, Shibata A, Ishii K, Liao Y, Hanibuchi T, et al. Associations of street layout with walking and sedentary behaviors in an urban and a rural area of Japan. *Health Place.* (2017) 45:64–9. doi: 10.1016/j.healthplace.2017.03.003
7. Stewart OT, Moudon AV, Saelens BE, Lee C, Kang B, Doescher MP. Comparing associations between the built environment and walking in rural small towns and a large metropolitan area. *Environ Behav.* (2016) 48:13–36. doi: 10.1177/0013916515612253
8. Hartley D. Rural health disparities, population health, and rural culture. *Am J Public Health.* (2004) 94:1675–8. doi: 10.2105/AJPH.94.10.1675
9. Saelens BE, Handy SL. Built environment correlates of walking: a review. *Med Sci Sports Exer.* (2008) 40:S550–66. doi: 10.1249/MSS.0b013e31817c67a4
10. Smith M, Hosking J, Woodward A, Witten K, MacMillan A, Field A, et al. Systematic literature review of built environment effects on physical activity and active transport–an update and new findings on health equity. *Int J Behav Nutr Phys Act.* (2017) 14:158. doi: 10.1186/s12966-017-0613-9
11. Shigematsu R, Sallis JF, Conway TL, Saelens BE, Frank LD, Cain KL. et al. Age differences in the relation of perceived neighborhood environment to walking. *Med Sci Sports Exer.* (2009) 41:314. doi: 10.1249/MSS.0b013e318185496c
12. Nagel CL, Carlson NE, Bosworth M, Michael YL. The relation between neighborhood built environment and walking activity among older adults. *Am J Epidemiol.* (2008) 168:461–8. doi: 10.1093/aje/kwn158
13. Ghani F, Rachele JN, Washington S, Turrell G. Gender and age differences in walking for transport and recreation: are the relationships the same in all neighborhoods? *Prevent Med Rep.* (2016) 4:75–80. doi: 10.1016/j.pmedr.2016.05.001
14. Hall KS, McAuley E. Individual, social environmental and physical environmental barriers to achieving 10 000 steps per day among older women. *Health Educ Res.* (2010) 25:478–88. doi: 10.1093/her/cyq019
15. Notthoff N, Carstensen LL. Promoting walking in older adults: perceived neighborhood walkability influences the effectiveness of motivational messages. *J Health Psychol.* (2015) 22:834–43. doi: 10.1177/1359105315616470
16. Borst HC, de Vries SI, Graham JMA, van Dongen JEF, Bakker I, Miedema HME. Influence of environmental street characteristics on walking route choice of elderly people. *J Environ Psychol.* (2009) 29:477–84. doi: 10.1016/j.jenvp.2009.08.002
17. Shimura H, Sugiyama T, Winkler E, Owen N. High neighborhood walkability mitigates declines in middle-to-older aged adults' walking for transport. *J Phys Act Health.* (2012) 9:1004–8. doi: 10.1123/jpah.9.7.1004

18. Rosso AL, Auchincloss AH, Michael YL. The urban built environment and mobility in older adults: a comprehensive review. *J Aging Res.* (2011) 2011:816106. doi: 10.4061/2011/816106
19. Roman CG, Chalfin A. Fear of walking outdoors. A multilevel ecologic analysis of crime and disorder. *Am J Prevent Med.* (2008) 34:306–12. doi: 10.1016/j.amepre.2008.01.017
20. Hannon L 3rd, Sawyer P, Allman RM. Housing, the neighborhood environment, and physical activity among older African Americans. *J Health Disparities Res Pract.* (2012) 5:27–41.
21. Maizlish N, Woodcock J, Co S, Ostro B, Fanai A, Fairley D. Health cobenefits and transportation-related reductions in greenhouse gas emissions in the San Francisco Bay area. *Am J Public Health.* (2013) 103:703–9. doi: 10.2105/AJPH.2012.300939
22. Clarke P, Gallagher NA. Optimizing mobility in later life: the role of the urban built environment for older adults aging in place. *J Urban Health.* (2013) 90:997–1009. doi: 10.1007/s11524-013-9800-4
23. Greenfield EA. Using ecological frameworks to advance a field of research, practice, and policy on aging-in-place initiatives. *Gerontologist.* (2012) 52:1–12. doi: 10.1093/geront/gnr108
24. Alidoust S, Bosman C, Holden G. Talking while walking: an investigation of perceived neighbourhood walkability and its implications for the social life of older people. *J Housing Built Environ.* (2018) 33:133–50. doi: 10.1007/s10901-017-9558-1
25. Gardner PJ. Natural neighborhood networks—Important social networks in the lives of older adults aging in place. *J Aging Stud.* (2011) 25:263–71. doi: 10.1016/j.jaging.2011.03.007
26. Stokols D. Translating social ecological theory into guidelines for community health promotion. *Am J Health Promot.* (1996) 10:282–98. doi: 10.4278/0890-1171-10.4.282
27. McLeroy KR, Bibeau D, Steckler A, Glanz K. An ecological perspective on health promotion programs. *Health Educ Behav.* (1988) 15:351–77. doi: 10.1177/109019818801500401
28. Lawton MP, Nahemow L. *Ecology and the Aging Process*. Washington, DC: American Psychological Association (1973).
29. Wahl HW. *Theories of Environmental Influences on Aging and Behavior Encyclopedia of Geropsychology*. Singapore: Springer (2015). p. 1–8.
30. Golden SD, McLeroy KR, Green LW, Earp JAL, Lieberman LD. Upending the social ecological model to guide health promotion efforts toward policy and environmental change. *Health Educ Behav.* (2015) 42:8S−14S. doi: 10.1177/1090198115575098
31. U.S. Census Bureau. *2010 Census of Population, Public Law 94-171*. U.S. Census Bureau (2010).
32. Craig C, Marshall A, Sjostrom M. International physical activity questionnaire: 12-country reliability and validity. *Med Sci Sports Exer.* (2003) 35:1381–95. doi: 10.1249/01.MSS.0000078924.61453.FB
33. Saelens BE, Sallis JF, Black JB, Chen D. Neighborhood-based differences in physical activity: an environment scale evaluation. *Am J Public Health.* (2003) 93:1552–8. doi: 10.2105/AJPH.93.9.1552
34. Centers for Disease Control and Prevention. *Behavioral Risk Factor Surveillance System Survey Questionnaire*. Atlanta, Georgia: Centers for Disease Control and Prevention (2019).
35. Umstattd MR, Baller SL, Hennessy E, Hartley D, Economos CD, Hyatt RR, et al. Development of the rural active living perceived environmental support scale (RALPESS). *J Phys Act Health.* (2012) 9:724–30. doi: 10.1123/jpah.9.5.724
36. Lee C, Moudon AV, Courbois JYP. Built environment and behavior: spatial sampling using parcel data. *Ann Epidemiol.* (2006) 16:387–94. doi: 10.1016/j.annepidem.2005.03.003
37. Forsyth A, Van Riper D, Larson N, Wall M, Neumark-Sztainer D. Creating a replicable, valid cross-platform buffering technique: the sausage network buffer for measuring food and physical activity built environments. *Int J Health Geogr.* (2012) 22:14. doi: 10.1186/1476-072X-11-14
38. Fairchild AJ, MacKinnon DP. A general model for testing mediation and moderation effects. *Prevent Sci.* (2009) 10:87–99. doi: 10.1007/s11121-008-0109-6
39. Loukaitou-Sideris A. Is it safe to walk? Neighborhood safety and security considerations and their effects on walking. *J Plan Liter*. (2006) 20:219–32. doi: 10.1177/0885412205282770
40. Mirzaei E, Kheyroddin R, Behzadfar M, Mignot D. Utilitarian and hedonic walking: examining the impact of the built environment on walking behavior. *Eur Trans Res Rev.* (2018) 10:20. doi: 10.1186/s12544-018-0292-x
41. Thomson JL, Goodman MH, Landry AS. Assessment of neighborhood street characteristics related to physical activity in the Lower Mississippi Delta. *Health Promot Perspect.* (2019) 9:24. doi: 10.15171/hpp.2019.03
42. Ainsworth BE, Wilcox S, Thompson WW, Richter DL, Henderson KA. Personal, social, and physical environmental correlates of physical activity in African-American women in South Carolina. *Am J Prevent Med.* (2003) 25:23–9. doi: 10.1016/S0749-3797(03)00161-2
43. King AC, Castro C, Wilcox S, Eyler AA, Sallis JF, Brownson RC. Personal and environmental factors associated with physical inactivity among different racial–ethnic groups of US middle-aged and older-aged women. *Health Psychol.* (2000) 19:354. doi: 10.1037/0278-6133.19.4.354
44. Americans With Disabilities Act of 1990. Public Law 101-336. *108th Congress*, 2nd Session (1990).
45. Joseph A, Zimring C. Where active older adults walk understanding the factors related to path choice for walking among active retirement community residents. *Environ Behav.* (2007) 39:75–105. doi: 10.1177/0013916506295572
46. Lee C, Moudon AV. The 3Ds+ R: quantifying land use and urban form correlates of walking. *Trans Res Part D Trans Environ.* (2006) 11:204–15. doi: 10.1016/j.trd.2006.02.003
47. Strawbridge WJ, Sheman SJ, Cohen RD, Kaplan GA. Religious attendance increases survival by improving and maintaining good health behaviors, mental health, and social relationships. *Ann Behav Med.* (2001) 23:68–74. doi: 10.1207/S15324796ABM2301_10
48. Yen HY, Lin LJ. Quality of life in older adults: benefits from the productive engagement in physical activity. *J Exer Sci Fitness.* (2018) 16:49–54. doi: 10.1016/j.jesf.2018.06.001
49. Owen N, Humpel N, Leslie E, Bauman A, Sallis JF. Understanding environmental influences on walking: review and research agenda. *Am J Prevent Med.* (2004) 27:67–76. doi: 10.1016/j.amepre.2004.03.006

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 16 June 2021
doi: 10.3389/fpubh.2021.568822

Creating a Social Learning Environment for and by Older Adults in the Use and Adoption of Smartphone Technology to Age in Place

Marjolein den Haan[1], Rens Brankaert[1,2], Gail Kenning[3,4] and Yuan Lu[1]*

[1] *Department of Industrial Design, Eindhoven University of Technology, Eindhoven, Netherlands,* [2] *Institute of Allied Health Professions, Fontys University of Applied Sciences, Eindhoven, Netherlands,* [3] *Ageing Futures Institute, University of New South Wales, Sydney, NSW, Australia,* [4] *Faculty of Arts and Social Sciences, University of Technology Sydney, Sydney, NSW, Australia*

OPEN ACCESS

Edited by:
Anna Patricia Lane,
Singapore University of Technology and Design, Singapore

Reviewed by:
Hélio José Coelho Jr.,
Catholic University of the Sacred Heart, Rome, Italy
Kate O'Loughlin,
The University of Sydney, Australia

***Correspondence:**
Marjolein den Haan
m.c.wintermans@tue.nl

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *02 June 2020*
Accepted: *14 May 2021*
Published: *16 June 2021*

Citation:
Haan Md, Brankaert R, Kenning G and Lu Y (2021) Creating a Social Learning Environment for and by Older Adults in the Use and Adoption of Smartphone Technology to Age in Place. Front. Public Health 9:568822. doi: 10.3389/fpubh.2021.568822

Smartphone technologies can support older adults in their daily lives as they age in place at home. However, they may struggle to use these technologies which impacts acceptance, adoption, and sustainable use. Peer to peer community learning has the potential to support older adults to learn using (smartphone) technologies. This paper studies such a learning community approach and how it can support older adults to learn using and adopt the smartphone application GoLivePhone. This technology assists older adults in their daily living by supporting them through fall detection and activity tracking. In particular, the interface of this application can evolve and adapt as older adults become more knowledgeable during the use process or as their abilities change. This paper shows a field study with seven older adults learning and using the GoLivePhone technology through a living lab approach. These older adults participated in this research in a technology learning community that was set-up for research purposes. For this we used ordinary Samsung A3 smartphones with the simplified GoLivePhone software, particularly designed for older adults. At the end of the learning class we conducted an additional focus group to both explore factors facilitating older adults to learn using this technology and to identify their main personal drivers and motivators to start and adopt this technology. We collected qualitative data via open questions and audio recording during the focus group. This collected data was subject to a thematic analysis, coding was primarily performed by the first author, and reviewed by the other authors. We provide insights into how peer to peer community learning can contribute, and found both *super-users* and recall tools to be helpful to support sustainable use of smartphone technology to support older adults to age in place.

Keywords: aging in place, healthy aging, older adults, learning, smartphones

INTRODUCTION

In this paper we align with the concept of healthy aging as being health beyond illness, and also consider enrichment, fun, and good quality of life. As per the World Health Organization guidelines of 2020: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (1).

Many older adults want to remain at home as they age, if possible, which means the individual's home needs to support continuity in the living environment and the maintenance of daily independence and social contact (2). As the needs of people living independently increase and extends beyond personal care, and with the number of older adults increasing, this potentially places a financial burden on the system (1). Therefore, effective, efficient ways of supporting older adults to remain independent are needed.

People aspiring to age in place can benefit from digital opportunities. But, how and why people use and adopt technology varies between older adults, and *in situ* research about aging in place is limited (3). Wang et al. (4) investigated the barriers and facilitators for adopting aging in place technologies in the United States (U.S.) population over 65 years of age. They found five factors impacting use: (1) technology usability, (2) technology literacy, (3) data management, (4) privacy attitudes, and (5) co-design. They recommended educating not only the older adults in the use of technology but also technology designers in the design.

Currently, society continues to enjoy many digital developments, such as technologies that promote exercise (5), prevent falls (6), and facilitate cognitive training (7). Furthermore, Information and Communication Technologies (ICT) are used for staying socially connected, accessing instant information, and performing everyday tasks such as shopping, traveling, and banking (8). The value of the newly introduced technology should be clearly communicated to older adults so that they can recognize the potential usefulness and benefits (9). Meanwhile, designers need to understand how the user experience can go beyond functionality to also emotionally engage older adults (10).

Alongside communicating clearly about the values of a particular technology, we also recognize people have different needs, wants, and dreams (11) and widely varying abilities (12–14). This means, it is important to have technology that is able to cater for these individual differences or be adaptable to them (15).

Several studies have shown the challenges and opportunities of mobile health interventions. Joe and Demiris (16) argue that older adults are more likely to have a mobile phone than a desktop or laptop. Therefore, mobile phones seem an ideal technology platform to reach many older adults. Furthermore, Klasnja and Pratt (17) reviewed the body of work on mobile phone health applications and concluded that there were five intervention strategies for such applications: (1) tracking health information, (2) involving the healthcare team, (3) receiving support from your social environment, (4) increasing the health information accessibility, and (5) promoting entertainment. All of these could potentially support older adults to age in place. However, there remain challenges with regard to using mobile health technology for older adults, for example, Wildenbos et al. (18) cognition, physical ability, perception, and motivation to negatively impact using mobile technology. Other barriers include issues with familiarity, willingness to ask for help, trusting technology, privacy, and challenges in catering for physical and cognitive changes associated with aging (19). Additionally, another study found that tablets are currently too complex and recommend reducing available options on them (20). Furthermore, there is a need to ensure there is appropriate support matching the experiences of older adults with (self) supporting measures, tools and social networks (20–23), that the context for use is optimized (3), and that actions are performed along with peers to positively influence learning (24).

In this study we therefore apply a peer learning model as it provides older adults with an effective and rewarding learning environment (25). We used a specific peer learning model, called super-users, which will be addressed in the material and method section. In our work, we study a specific mobile technology, the GoLivePhone, via a Living Lab approach. In this we explore how new technology is used in the "real-life" and engage with people in-context (26). The Living Lab setup allows participants to become active contributors during the evaluation of technology (27).

Smartphone technologies can support older adults as they age in place in their homes. However, adoption of smartphone technology is often still challenging for older adults. This paper engages with a community of independent older adults aged between 66 and 86 from a predominantly rural area in the Netherlands, while they learn how to use the novel smartphone technology. During this smartphone learning class we investigated the participants' motivators and barriers to start and continue learning using the smartphone technology; to observe older adults and understand *how* they learned, what facilitated this learning and to provide insights to the smartphone company.

THE STUDY—MATERIALS AND METHODS

We explored through the study (1) How can older adults be assisted in effectively learning to use a smartphone which supports their independence? (2) What drives older adults to begin and continue using a smartphone which supports them in aging in place?

In the following sections, we will elaborate on: (1) the use of peer-to-peer teaching and a learning class in a Living Lab approach, (2) the role of participants as *users* and *super-users*, (3) the specific smartphone technology used, and (4) how data was collected.

The Use of Peer-to-Peer Teaching and a Learning Class in a Living Lab Approach

Over the course of a 13 week period, seven older adults met every Friday afternoon from 2 pm to 4 pm as part of a smartphone learning class (with four peer teachers). The atmosphere of the sessions was informal with the group sitting around a coffee table in a community center called "The Living Room." The community center was close-by for all older adults, being in the city center of a village, so they could easily reach it. This contributed to the sustained attendance of the group. The room was equipped with a projector and projector screen, which the lead researcher used to introduce the research study to potential participants through a presentation. Members of the smartphone learning class were invited to take part in a series of focus groups over a period of 5 weeks (out of the 13 weeks class). The focus group methodology was used to follow users' progress as they learned how to use a smartphone (28). Based on existing studies using focus groups it was expected that data saturation would be reached within 5 weeks, and attending the full 13 weeks would not provide additional information (29). For the 5 weeks when the focus groups took place two researchers were present during the session, and particularly at the end of the session most of the interaction took place between researchers and participants. A predefined set of topics was developed for discussion to capture prevailing opinions about smartphone technologies and evaluate usage and general experience. Participant responses were written down by the participants themselves, and in the final session, additionally, a transcript of an audio recording was made. All written answers and the transcript were coded by the lead researcher and analyzed by all co-authors. This approach was selected as it could provide feedback that could contribute to innovating technology development and use through the involvement of participants in a real-life setting (30). It could also promote group interaction and so provide better insights into the experiences and opinions of the participants (31).

The Role of Participants as Users and Super-Users

A call for attendees for the smartphone learning class was made by an older adult, who had previously been trained in using the technology (identified in the research as a super-user), through a local association for older adults and a local newspaper. Attendees of the class were offered an opportunity to become acquainted with a smartphone aimed at fostering longer independent living. The class objective was to educate the local community by using volunteers and working with the local municipality and the local older adults association, to improve the environment for aging. The research study participants were the attendees of these pre-arranged learning sessions who agreed to take part in the focus groups and to be observed by researchers. The number of participants in the learning experience and the research study was small to ensure personal feedback could be provided to everyone who participated and to be manageable for the super-users to teach effectively.

The research study was part of the European AAL project *ENSAFE* (32) which aimed to support effective prevention and self-care strategies for older adults to foster independent living. We were not required by the university to obtain formal approval through an ethics board, however general ethical procedures were followed to protect the participants. All participants in the research study signed a consent form agreeing to share their experiences which would be de-identified and analyzed anonymously. The participants were made aware of how to contact the researchers for concerns, their participation was voluntary, and they could withdraw at any point. To ensure the overall well-being of all participants, one older adult, who hosted the learning session as a so-called super-user, was in charge of communicating to the researcher any discomfort or health issues expressed by participants.

TABLE 1 | Background information of our seven participants (P).

P	Living situation	Frequency of using technology	Perceived technology level
1	Living independently	Daily	None
2	Living with partner	N/A	N/A
3	Living independently	Daily	Low
4	Living with partner	Daily	Low
5	Living with partner	Daily	None
6	Living independently	Daily	Low
7	Living with partner	Daily	Low

The study participant group consisted of seven older adults who wanted to learn to use the smartphone, referred to as "users" (**Table 1**). For the research study, this constituted a purposive sample providing information-rich, in context, qualitative data (33). This sample size is appropriate for findings that are not intended to be generalizable across populations but are transferable to context-specific populations.

The hosts or facilitators of the learning sessions, were called super-users because of three main characteristics, they: (1) were experienced users of this particular smartphone, (2) have similar social-cognitive profiles to the participants, meaning a similar age range and similar ability, and (3) trained in providing expertise on the technology at hand. These super-users, like the general attendees (users) were invited to become participants in the research study, with their presence, activities and influences observed alongside the other participants. Along with introducing and teaching the system step-by-step, these super-users simplified the text and structure of a printed manual based on what the company of the smartphone technology provided on their website, enabling the users to continue practicing at home. This reflects the position of Mitzner et al. (9), who suggests a manual "may not be optimal because they contain tech jargon."

The four super-users had been in a similar program before and were informed and educated about the particular smartphone prior to the sessions and could download and install software on a Samsung Galaxy A3 (2016) using a descriptive manual provided by the company. A 1 h follow-up session of questions was organized by the company.

The Specific Smartphone Technology Used

The technology used in the learning class and research study was a smartphone Samsung A3 with a custom *GoLivePhone* user interface on "top" of the usual interface, explicitly designed for independently living older adults to age in place (**Figure 1**).

FIGURE 1 | The Samsung smartphone with custom GoLivePhone User Interface, specifically designed for and evaluated with older adults (picture by Gociety Solutions in 2017).

"Independently living older adults" refers to older adults living with or without a partner in a regular home environment. The custom interface aims to make the interaction with the technology easier for older adults by offering clear pictograms, sizable icons, and high contrast. In addition to the common smartphone applications, this smartphone offers, amongst other things, fall prevention tips, fall detection, automatic activity tracking, and guidance to home or parking place (34). If desired, older adults can enable the sending of a warning to their (grand) children whenever a fall is detected or when a GPS zone is crossed (digital fencing), all aimed to create a digital remote support network to allow people to age in place. For the participants, keeping an overview on your health in this way was compared to taking your car for a regular check-up, showing how it could automatically track their activity by them simply carrying the smartphone in their pocket. Comparing their own health to car maintenance provided a metaphor to explain the concept of the technology and made users conscious about healthy aging as suggested by Mitzner et al. (9) when trying to clarify the potential benefit that technologies can bring.

The learning class introducing the smartphone focused on introducing three functionalities in the first session, to make the learning process manageable. These include connecting to Wi-Fi, managing contacts, and reaching out to somebody (either by calling or by using messaging service WhatsApp). In the second session, these functionalities were repeated, and three more functionalities were added, namely: using the camera, exploring photos via an album and sharing photos and videos using WhatsApp. All functionalities can be individually enabled or disabled in the main menu, in line with the older adult's interests, ability, and learning pace. An explanation of how to do this themselves was also given in the second session. To conclude, a group WhatsApp was created amongst participants for them to practice sharing photos and videos. In the third session, they repeated taking and sharing photos and videos. In addition, a new functionality was introduced to connect family members to their accounts, so they receive a notification if a fall occurs—if the user permits. In the fourth session, particular *GoLivePhone* applications were introduced, and in the final fifth session, a group discussion was done which was audio-recorded and the older adults were thanked for their participation in our research and given a postcard with a small present to thank them for their contribution in the study.

How Data Was Collected

We held an open focus group after the learning class to let users reflect and voice their perspectives on the technology and learning process. This allowed older adults to actively participate and make their voices heard as equal partners in their introduction to, and assessment of the technology. The data were subject to a thematic analysis (35). This analysis was used to search for themes and patterns across the entire data set, rather than focusing on the responses of individual participants. By doing so, we found recurring use patterns for the whole group. The thematic analysis contained six phases, using the procedures described by Braun and Clarke (35): (1) familiarize yourself with the data by reading and noting down initial ideas, (2) generate initial codes across the entire data set, (3) search for potential themes by gathering codes, (4) review these themes and create a "map" of the analysis, (5) define and name each theme more to refine the specifics of each theme, and (6) produce the report on the final analysis with the selection of vivid, compelling extract examples.

RESULTS

Background information about the seven participants (P) is shown in **Table 1**, based on multiple-choice questions in which the frequency of using technology and "tech-savviness" of the participants were self-reported. For example, participants advised if they used desktop computer, phone (without internet), tablet, e-reader, smartphone, camera, smart television, technological care services or other technology. The only exclusion and inclusion criteria were that they need to be able to read the smartphone screen and be physically able to interact with it, and so in practice, this meant most of the participants had not used a smartphone before.

Through a process of familiarization with the focus group data, initial codes were generated, and searches for potential themes were carried out. The two main overarching themes were related to "learning" and "personal drivers," each with multiple themes and subthemes (**Table 2**). "Learning," related to how people prefer to learn, which tools contribute to learning, and who facilitates learning. "Personal drivers," related to information about why people started using the phone and what keeps them motivated to continue doing so. We will provide more details on these themes and illustrate the content by including quotes from participants. As the researcher joined five of the sessions, we will phrase the specific quotes of participants (P) and super-users (SU) in time as Q1, Q2, Q3, Q4, and Q5, respectively.

TABLE 2 | Our thematic analysis with the two overarching themes "learning" and "personal drivers" including their themes and subthemes.

	Theme	Subthemes
Learning	Step by step	In class guidance Introduction of tech options
	Repetition	
	Tools	Manual Quick reference guide
	Who facilitates the learning	
Personal drivers	Why start	Preparation for the future Move with the times
	Social	
	Product-related values	Feeling of safety Accessibility

Learning

Learning consisted of four themes: (1) step-by-step, (2) repetition, (3) tools, and (4) learning facilitators.

How People Prefer to Learn (Step by Step and Repetition)

The general view on the technology was clear: "It [GoLivePhone] is easy to use." (P7, Q1), and "It [interface] has big tiles, and the overview is not cluttered." (P4, Q2). We found step-by-step introductions, in both the course material and the number of technological functionalities offered at once, were key factors to facilitating learning: "Take it easy, step by step!" (P5, Q3). Also, frequent repetition is essential: "I see the GoLivePhone as a tool to become more knowledgeable." (P3, Q4) but, he added, "People have to explain it to me 2–3 times." (P3, Q5).

Which Tools Contribute to Learning

The smartphone community relied on one particular learning tool, which is a manual containing all course material: "If you practice using the GoLivePhone for a week and then do not use it for a month, you lose how to work with it. I am not sure I can remember everything, so that is why I need a step-by-step manual to help me out." (P4, Q5). However, at the final evaluation, super-users initiated the request for a quick reference guide as well, of which all participants agreed: "It is difficult for people to start using the GoLivePhone. It would be handy to have a short recap for every application for daily use, to be able to look something up quickly." (all SU, Q5).

Who Facilitates the Learning

Learning to use smartphone technology in a group setting was experienced as positive and motivating: "I think it is very motivating to participate with multiple people. You can exchange experiences, and you do not feel so alone." (P4, Q5) and "I think it is a nice club. It is a little difficult though." (P1, Q3). Furthermore, both the super-users and peers were appreciated as the relationship continued to be built: "I think it is very nice they [super-users] organized this course because I can practice the manual, challenge my difficulties and try to make it a nice thing [smartphone] for myself!" (P3, Q5) and "We get to know each other better." (P4, Q3). A conversation between two participants in the final evaluation, shows their concerns about the appropriateness of using a phone in the presence of others. They felt technological interactions were taking over regular day-to-day interactions. P4, Q5: "I think it is necessary and valuable that super-users can give extra explanation personally in-between if you cannot keep up with the speed of the group lesson." P3, Q5: "But people also explain things to each other on a birthday". She goes on to explain her concern of how this is interfering. "Then there is this couple explaining things to each other, while they should celebrate a birthday! Then I think, what are you doing?"

Personal Drivers

Personal drivers for smartphone use focusses on three different themes: motivation to use the smartphone, social motivators, and product-related values.

Motivations to Use the Smartphone

Within this theme, there were two prominent subthemes. Firstly, the need to prepare for the future and, for example, for health-related purposes: "I think an advantage is the tips we get from the medical applications for elderly people." (P6, Q1). They expected that getting used to new technology might become more difficult as they aged: "Start using the GoLivePhone now, before you cannot learn it anymore." (P7, Q3). Secondly, there was a perceived need to "Move with the times." (P5, Q1) as to be valued as part of ongoing society: "Everything I learn helps to keep up with the modern times." (P3, Q4) and "I think it is convenient to use a timer on the GoLivePhone because my granddaughter said an egg timer is old-fashioned." (SU3, Q5). However, some participants explained they had limited time to practice the GoLivePhone: "There are functionalities which I cannot manage, and that is because I am swamped and have limited time to sit down and work on it." (P4, Q5) and "I do not have time to use it, and I find it difficult, I am 86 years young." (P1, Q3).

While the participants were motivated to respond to the calls put out by the hosts to come and learn how to use these phones, it is possible they would have responded to the call for the use of any phone, but because this had an interface designed for older adults it may have been more encouraging because they knew the technology was aimed at people like them.

Social Motivators

Participants are very enthusiastic because it offers connectivity to their families: "I use WhatsApp [a simple messaging service] to communicate with my grandchildren!" (P5, Q1) and "When I try to call my children, then they might not be home or do not pick up the phone. However, with WhatsApp, you are in contact immediately. I like it because I am sure I get a response, and I think they like the fact that I am not bothering them for half an hour during a phone call." (P4, Q5). Similarly, P2 appreciates that she can keep in contact with her children: "I can see how my kids are doing, without even picking up the phone!" (P2, Q1) But she does not want the phone to replace all communication:

"I use WhatsApp a lot, but I hardly make a phone call. I think WhatsApp replaces calling. However, I do not want to give a lot of personal details; I do not like that. I also do not like meeting people who are walking in the park, only looking at their phones." (P2, Q5). Careful attention should be paid to the latter statement as a smartphone, according to her, has both positive and negative connotations.

Product-Related Values

Within this theme, participants gave a few examples of product-related values, as the smartphone is most commonly used for communication: "An advantage is to be able to have contact with my girlfriend. It generates more contact with people." (P3, Q2). It is also interesting to note attitude toward the perceived usefulness of the technology toward the end of the study: "Calling and WhatsApp are the biggest advantages to me." (P6, Q4), "There are a lot of nice things in the GoLivePhone." (P1, Q4), "I use WhatsApp, calling, and internet the most." (P5, Q3) and "The smartphone is indispensable for me now." (P5, Q3). In addition, the technology gave people a feeling of safety: "It is handy to have such a phone with you." (P1, Q2) and "I think sending messages, calling, taking pictures and having a backup in case of an emergency, are the advantages to me." (P4, Q1).

It is interesting to note the different perceptions of the warning feature to informal caregivers. One participant stated, "I am healthy, so I do not need this feature yet." (P4, Q5) and someone else mentioned, "They do not always need to know where I am, I think it should be possible to disable this functionality." As the alarm functionality also shared the location, it would be interesting to see when older adults make the change from wanting to maintain their privacy to wanting to benefit by sharing information about their health with caregivers. Interestingly, a super-user's mother is using the GoLivePhone, and the super-user mentioned this location information gave a feeling of security from the caregiver perspective: "When they are away together, they are actually not alone [because she knows where her parents are in case of an emergency]." (SU1, Q5).

DISCUSSION

In this research, we found strategies to facilitate smartphone learning and identify the daily drivers of using this technology for aging in place. This study findings are potentially transferable to a similar context such as a small group of older adults learning new technology in a social setting and might inspire other smartphone technology research projects. The study also contributes to our general understanding of learning and using smartphone technology.

Learning

How People Prefer to Learn

People made use of the two learning styles we offered: (1) practicing at home using the manual, and (2) coming to class and learning with and from peers.

Manual and Quick Reference Guide

Both the manual and quick reference guide were perceived as a comforting backup reference, both for learning the complete functionalities in detail (manual) and for looking things up quickly (quick reference guide). The manual used needs to match the level of expertise of the participants. Research suggests sharing notes is an ICT learning strategy when people translate the formally written manual to a more understandable and personalized style (36). Here the super-users were able to do this translation. This addresses the need that was recommended by Fondevila Gascon et al. (22) to provide clearer manuals. This highlights how the communication style most fitting this group was the translation from a company manual to an improved version, through the eyes of an older adult. So, rather than peers sharing their personalized notes, the super-user can adapt the manual before handing it out in class. Furthermore, we found it was valuable for people to be able to dedicate time for specific prioritization of different functionalities. This reflects the position of Müller et al. (21) by creating anchor points to connect technology with people's daily lives. The super-users can then suggest specific pathways for learning using the manual, but the older adult can decide which track is most meaningful for them. This promotes autonomy for the older adults, to consider their learning styles, interests, and expectations (8).

The course material consisted of an extensive text-driven binder explaining all functionalities and steps in detail. These step by step instructions are known to enable participants to learn faster and more accurately (37). In addition, the participants also requested a quick reference guide as a tool for small reminders. We created this guide focusing on specific interactions, resulting in a low-text A4 page. This addresses the needs of people who have a basic understanding already and know most steps to be executed. The quick reference guide provides security rather than being needed all the time. This guide also allows for a quick lookup of functions related to the most frequently used daily tasks. By facilitating this, we enable them to take control of their learning (38). Also, the older adults in this community associated the course material and quick reference guide as "trustworthy" and "comforting." We observed that it is comforting for people not to have to remember everything at once in class and to have the opportunity to extend and practice to learning at home. We recommend including these tools in the learning process so that it becomes an integral part of the technology proposition itself.

Physical Classroom

We found needs regarding the learning process on several levels: (1) the individual (older adult), (2) the super-user (older adult, facilitator), and (3) the group (all older adults together in class). The super-users who facilitate the course need to be as motivated as others (24). Our results show general guidelines that can be followed, such as having one-on-one interaction with super-users to discuss what the focus of the next meeting should be. We also learned from our participants that the regular face to face sessions with peers made them confident learners. Seeing that others can use the technology, made participants feel they could do it as well, and so it became a joint effort in the use of new technology (10).

Who Facilitates the Learning

In being part of a community, people are motivated to address and work on their difficulties together. Sayago et al. (36) addressed this as collaborative and informal learning. Collaborative learning proves to be more effective for older adults than competitive or individual learning (36). In this work, we proposed two separate levels of collaborative learning: peers and super-users.

Peers

With peer learning, we saw the informal in-between class learning in their natural social environment (24), where people help each other, so everybody learned at the same pace. They all have the same goal to get acquainted with technology, as the technology has been unfamiliar from the start for all of them, together they make faster progress in learning.

Super-Users

In addition to peers, super-users were the people who hosted the session, who took the lead in facilitating which steps to practice next and joined in executing tasks together. Master-apprentice roles is an acknowledged way of learning (39), that transfers to this context, to make this work trust in each other is essential. The availability of support, in this case through super-users, influences how older adults experience certain challenges (10). And sometimes super-users changed roles between facilitating and being a peer learner, as they relearn and repeat steps with their peers one on one.

Sustainable Learning Process

The compelling aspect of this collaborative learning community is that peers can grow toward becoming super-users, which turns this approach into a sustainable learning process in the community. We have seen 1 year after this project, there have been four different groups practicing the smartphone, and from this study, everyone became a super-user later. It is a low-cost way to facilitate teaching, and the social value of getting together to learn with peers is an essential motivator. We believe this role of super-user stimulates continued learning, as people seem to value being recognized as a super-user (40). This credit gives an extra stimulus for participants to become super-users.

Acknowledgment and Support From the Municipality

We have seen this growing group of older adults to come together and learn has caught attention from the municipality as they benefit from a healthier and happier community. Therefore, the municipality subsequently subsidizes the ongoing service costs of the smartphone for all participants who accomplished the first class. This need for organizational collaboration is expressed by policy advisors in order to enable successful implementations of technology for aging in place (41). Furthermore, participants of the smartphone classes gained recognition as they were acknowledged in a local news article and received a certificate of their successful participation.

Informal Atmosphere

We saw a social atmosphere where people shared personal learning stories. Work from Sayago et al. (36) shows such learning does not depend on knowing more or less as your peers, but the social and informal atmosphere itself is motivating. We saw through this informal atmosphere, that accepting new functionalities was easier, as users saw their peers using this. However, there is a limit to this informal setting, for two participants a birthday gathering was not appropriate for example. This shows, on the one hand, the integration of the device in people's daily life but, on the other hand, some non-acceptance (yet) of others. We believe the learning atmosphere should be informal, but the importance of attending classes and of making use of fixed timeslots to learn together needs to be emphasized. We have seen our participants had a busy lifestyle, we observed people needed frequent repetition. By having a dedicated timeslot to learn, they could keep up with the pace.

Personal Drivers

Within the category of personal drivers concerning smartphone use, we will elaborate on three different themes: motivations to use the smartphone, social motivators, and product-related values.

Motivations to Use the Smartphone

Preparing for the Future and Not for Me (yet)

Participants indicated one reason for joining the class is preparing for the future, when they might be more dependent. This illustrated how the participants were engaged in future thinking (42). This need is prevention-driven, to prepare for the changes which might follow in later life when more support is needed. Most participants saw the smartphone as a system, which could help them to achieve that and provide a feeling of being prepared. Not only did they think about the use of a specific application for today or tomorrow, but the driver for some of our participants was also to get acquainted with the smartphone before they could not learn it because, for example, the onset of dementia. They saw the smartphone as a means of giving them a secure, safe, and in control perspective on the future. In addition to keeping up with modern times, as reflected in the findings of Rosales et al. (43).

We found our participants were still healthy and not in need of the health support functions of the smartphone technology yet. Literature shows that older adults perceive certain stigmas with technology designed for them, such as is discussed in the work of Neven (44) where participants imagined potential users of a health robot as a lonely person who is in need of care and company. However, our participants mentioned that it motivated them to start using the smartphone, and getting acquainted with the novel technology now, and be able to start integrating the device into their daily lives. This makes sense for older adults who want a device that addresses their current needs and to use a technology shaped in dialogue with their everyday practice now (45), with options to support them in a different way later with regard to their personal health. As was shown by their wanting to move with the times, and not be left out (20), our participants happily agreed to learn a smartphone now 'with some additional care functions for later'.

Fun and Social Functionalities

Often technology focusses on what is no longer possible, trying to "solve aging problems" (46). However, we saw that the value technology brings is much more than that. It creates opportunities to enrich people's daily life. For example, it is an easy way to stay in contact when living far away from each other. Therefore, we have to recognize and emphasize the need for fun and social smartphone functionalities (such as WhatsApp) in addition to care functionalities (such as fall prevention). These do not have to be contradictory or independent from each other (9). People might not feel like they need care services but instead want to interact and share meaningful things with their surrounding network (47). These drivers can be used to fuel learning and link a technology to different essential real-life needs (36), which can be complementary to daily life now as well as in the future.

Social Motivators

Emotional Response to Technology

Sayago et al. (36) suggest learning is driven by real-life situations, such as a son who keeps telling his parents to learn to use email for communication. Children could for example lay a major role in motivating technology addition as suggested by Fausset et al. (48). And even if the older adults themselves do not believe it is important, if family members think it is important, they may still comply with them (49). Our study showed, in the communication and use of WhatsApp, that the smartphone technology facilitated participants to stay in touch with social networks. These findings expand on existing literature showing that in addition to showing a willingness to use technology, it is crucial to building the experience toward not only a functional response but an emotional one such as facilitated by social contact (10).

Immediate and Flexible Contact

As people value the smartphone as an enabler to have contact with their loved ones (50), they also specifically point out the value of immediate and flexible contact. Our participants compare sending a message vs. a phone call and prefer the message so that their busier family members can respond any time rather, and they do not feel like they are bothering them with a long call. This extends the findings of Lindley et al. (51), saying that older adults do not want to become burdensome or intrusive when staying in contact.

Product-Related Values

Security and Privacy

While we see, in general, a positive view of people expressing why they value the smartphone, the security and privacy topic still evoked mixed responses among the participants. On the one hand, our participants suggested they feel safer because in our system they could chose an informal caregiver to reach out to them and monitoring their location, whenever in need of help. On the other hand, participants mentioned they value their privacy and do not want to be tracked by anyone else (52). This is a personal preference, and in some cases, it is the older adult and, in some cases, it is the (informal) caregiver who might feel safer due to the technology. With our smartphone, older adults can decide with whom they share information, which is important for data privacy (53). There we propose that the freedom of choice should always be facilitated by technology, also in the case of people in need.

CONCLUSIONS

In this study, with seven users and four super-users, we have explored a social learning environment for older adults to learn how to use new technology and share their knowledge. Older adults in this study prefer to take a step by step approach, with the support of their peers and a plain-language manual. They showed to be motivated to learn to keep in touch with friends and family. Additionally, super-users contribute to a sustainable learning process as users could later become super-users and can help understand other older adults to use technology. This means people setting up learning experiences for older adults should consider peer to peer and user lead approaches.

These findings are of an explorative nature and therefore not generalizable to a broader population of older adults, we suggest that our findings are transferable to similar groups and could inspire other researchers working with individuals in a specific context. Furthermore, we have addressed some touchpoints that can support new technology learning and adoption, depending on people's previous technology experience and current context in which they are learning. Currently, we worked together with a group of people who did not have previous smartphone experience. However, for an increasing number of older adults, smartphones will become a part of their lives. Thus, when designing for this target group, it is also important to facilitate a stimulating and social learning experience.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

MH and RB conducted the fieldwork. MH took the lead in writing the manuscript. All authors discussed the results and contributed to the final manuscript.

FUNDING

This project was provided by the European AAL Programme in the ENSAFE project (Elderly-oriented, Network-based Services Aimed at independent life). The project started on July 1 2015, and ran for 36 months.

ACKNOWLEDGMENTS

The authors would like to thank the participants and the coordinator of the smartphone class, for making this study possible.

REFERENCES

1. World Health Organization. *Basic Documents: Forty-Ninth Edition (including amendments adopted up to 31 May 2019)*. Geneva: World Health Organization (2020).
2. Barrett P, Hale B, Gauld R. Social inclusion through ageing-in-place with care? *Ageing Soc.* (2011) 32:361–78. doi: 10.1017/S0144686X11000341
3. Peek S, Luijkx K, Rijnaard M, Nieboer M, van der Voort C, Aarts S, et al. Older Adults' reasons for using technology while aging in place. *Gerontology.* (2015) 62:226–37. doi: 10.1159/000430949
4. Wang S, Bolling K, Mao W, Reichstadt J, Jeste D, Kim H-C, et al. Technology to support aging in place: older adults' perspectives. *Healthcare.* (2019) 7:60. doi: 10.3390/healthcare7020060
5. Stuckey MI, Carter SW, Knight E. The role of smartphones in encouraging physical activity in adults. *Int J Gen Med.* (2017) 10:293–303. doi: 10.2147/IJGM.S134095
6. Barros AC de, Leitão R, Ribeiro J. Design and evaluation of a mobile user interface for older adults: navigation, interaction and visual design recommendations. *Procedia Comput Sci.* (2014) 27:369–78. doi: 10.1016/j.procs.2014.02.041
7. Klimova B, Valis M. Smartphone applications can serve as effective cognitive training tools in healthy aging. *Front Aging Neurosci.* (2018) 9:436. doi: 10.3389/fnagi.2017.00436
8. Martínez-Alcalá CI, Rosales-Lagarde A, Alonso-Lavernia M de los ángeles, Ramírez-Salvador JA, Jiménez-Rodríguez B, Cepeda-Rebollar RM, et al. Digital inclusion in older adults: a comparison between face-to-face and blended digital literacy workshops. *Front ICT.* (2018) 5:21. doi: 10.3389/fict.2018.00021
9. Mitzner T, Boron J, Fausset C, Adams A, Charness N, Czaja S, et al. Older adults talk technology: technology usage and attitudes. *Comput Human Behav.* (2010) 26:1710–21. doi: 10.1016/j.chb.2010.06.020
10. Barnard Y, Bradley M, Hodgson F, Lloyd A. Learning to use new technologies by older adults: perceived difficulties, experimentation behaviour and usability. *Comput Human Behav.* (2013) 29:1715–24. doi: 10.1016/j.chb.2013.02.006
11. Brown T, Katz B. Change by design. *J Prod Innov Manag.* (2011) 28:381–3. doi: 10.1111/j.1540-5885.2011.00806.x
12. Cabrita M, Nassabi MH, Akker H op den, Tabak M, Hermens H, Vollenbroek M. An unobtrusive system to monitor physical functioning of the older adults: results of a pilot study. In: *International Workshop on Personalization and Adaptation in Technology for Health Held in Conjunction With the 23rd Conference on User Modelling, Adaptation and Personalisation*. Dublin (2015).
13. Gregor P, Newell A, Zajicek M. Designing for dynamic diversity - interfaces for older people. In: *Proceedings of the ACM Conference on Assistive Technologies, ASSETS*. Edinburgh (2002). doi: 10.1145/638276.638277
14. Lerouge C, Ma J, Sneha S, Tolle K. User profiles and personas in the design and development of consumer health technologies. *Int J Med Inform.* (2011) 82:e251–68. doi: 10.1016/j.ijmedinf.2011.03.006
15. Nunes A, Limpo T, Castro SL. Acceptance of mobile health applications: examining key determinants and moderators. *Front Psychol.* (2019) 10:2791. doi: 10.3389/fpsyg.2019.02791
16. Joe J, Demiris G. Older adults and mobile phones for health : a review. *J Biomed Inform.* (2013) 46:947–54. doi: 10.1016/j.jbi.2013.06.008
17. Klasnja P, Pratt W. Healthcare in the pocket: mapping the space of mobile-phone health interventions. *J Biomed Inform.* (2012) 45:184–98. doi: 10.1016/j.jbi.2011.08.017
18. Wildenbos GA, Peute L, Jaspers M. Aging barriers influencing mobile health usability for older adults: a literature based framework (MOLD-US). *Int J Med Inform.* (2018) 114:66–75. doi: 10.1016/j.ijmedinf.2018.03.012
19. Fischer SH, David D, Crotty BH, Dierks M, Safran C. Acceptance and use of health information technology by community-dwelling elders. *Int J Med Inform.* (2014) 83:624–35. doi: 10.1016/j.ijmedinf.2014.06.005
20. Vaportzis E, Clausen MG, Gow AJ. Older adults perceptions of technology and barriers to interacting with tablet computers: a focus group study. *Front Psychol.* (2017) 8:1687. doi: 10.3389/fpsyg.2017.01687
21. Müller C, Hornung D, Hamm T, Wulf V. Measures and tools for supporting ICT appropriation by elderly and non tech- savvy persons in a long-term perspective. In: *ECSCW 2015: Proceedings of the 14th European Conference on Computer Supported Cooperative Work*. Oslo (2015).
22. Fondevila Gascon JF, Carreras-Alcalde M, Seebach S, Pesqueira Zamora MJ. How elders evaluate apps: a contribution to the study of smartphones and to the analysis of the usefulness and accessibility of ICTS for older adults. *Mob Media Commun.* (2015) 3:250–66. doi: 10.1177/2050157914560185
23. Seifert A, Reinwand DA, Schlomann A. Designing and using digital mental health interventions for older adults: being aware of digital inequality. *Front Psychiatry.* (2019) 10:568. doi: 10.3389/fpsyt.2019.00568
24. de Sales MB, Silveira RA, de Sales AB, de Cássia Guarezi R. Learning by peers: an alternative learning model for digital inclusion of elderly people. *IFIP Int Fed Inf Process.* (2009) 302:436–44. doi: 10.1007/978-3-642-03115-1_46
25. Clark F, Heller AF, Rafman C, Walker J. Peer learning: a popular model for seniors education. *Educ Gerontol.* (1997) 23:751–62. doi: 10.1080/0360127970230801
26. Bergvall-Kåreborn B, Ståhlbröst A. Living lab: an open and citizen-centric approach for innovation innovation. *Int J Innov Reg Dev.* (2009) 1:356. doi: 10.1504/IJIRD.2009.022727
27. Brankaert R, den Ouden E. The design-driven living lab: a new approach to exploring solutions to complex societal challenges. *Technol Innov Manag Rev.* (2017) 7:44–51. doi: 10.22215/timreview1049
28. Ireland C. Qualitative methods: from boring to brilliant. In: Laurel B, editor. *Design Research: Methods Perspectives*. London: MIT Press (2003). p. 23–9.
29. Guest G, Namey E, McKenna K. How many focus groups are enough? Building an evidence base for nonprobability sample sizes. *Field Methods.* (2017) 29:3–22. doi: 10.1177/1525822X16639015
30. Dell'Era C, Landoni P. Living lab: a methodology between user-centred design and participatory design. *Creat Innov Manag.* (2014) 23:137–54. doi: 10.1111/caim.12061
31. Barrett J, Kirk S. Running focus groups with elderly and disabled elderly participants. *Appl Ergon.* (2000) 31:621–9. doi: 10.1016/S0003-6870(00)00031-4
32. Ruis M. *The ENSAFE Pilots Kicked Off in the Four Regions!*. (2017). Available online at: https://www.ensafe-aal.com/the-ensafe-pilots-kicked-off-in-the-four-regions/ (accessed May 27, 2020).
33. Creswell JW, Clark VLP. Designing and conducting mixed methods research. *Aust N Z J Public Health.* (2007) 31:388. doi: 10.1111/j.1753-6405.2007.00096.x

34. Gociety Solutions. *The Functionalities of the GoLivePhone*. (2020). Available online at: https://www.goliveclip.eu/solutions/golivephone-app/ (accessed September 9, 2020).
35. Braun V, Clarke V. Using thematic analysis in psychology. *Qual Res Psychol.* (2006) 3:77–101. doi: 10.1191/1478088706qp063oa
36. Sayago S, Forbes P, Blat J. Older people becoming successful ICT learners over time: challenges and strategies through an ethnographical lens. *Educ Gerontol.* (2013) 39:527–44. doi: 10.1080/03601277.2012.703583
37. Hickman JM, Rogers WA, Fisk AD. Training older adults to use new technology. *Journals Gerontol Ser B.* (2007) 62:77–84. doi: 10.1093/geronb/62.special_issue_1.77
38. Mitzner TL, Fausset CB, Boron JB, Adams AE, Dijkstra K, Lee CC, et al. Older Adults' training preferences for learning to use technology. *Proc Hum Fact Ergon Soc Anim Meet*. (2008) 52:2047–51. doi: 10.1177/154193120805202603
39. Calvert I. *Investigating the One-on-One Master-Apprentice Relationship: A Case Study in Traditional Craft Apprenticeship*. (2014). Available online at: https://scholarsarchive.byu.edu/etd/4154 (accessed April 29, 2021).
40. Morrison D, McCutheon J. Empowering older adults' informal, self-directed learning: harnessing the potential of online personal learning networks. *Res Pract Technol Enhanc Learn.* (2019) 14:11. doi: 10.1186/s41039-019-0104-5
41. Peek S, Wouters E, Luijkx K, Vrijhoef H. What it takes to successfully implement technology for aging in place: focus groups with stakeholders. *J Med Internet Res.* (2016) 18:1–13. doi: 10.2196/jmir.5253
42. Light A, Leong TW, Robertson T. Ageing well with CSCW. In: *ECSCW 2015: Proceedings of the 14th European Conference on Computer Supported Cooperative Work, 19-23 September 2015.* Oslo (2015). p. 295–304.
43. Rosales A, Fernández-ardèvol M, Comunello F, Mulargia S, Ferran-ferrer N. Older people and smartwatches, initial experiences. *El Prof Inf.* (2017) 26:457–63. doi: 10.3145/epi.2017.may.12
44. Neven L. "But obviously not for me": robots, laboratories and the defiant identity of elder test users. *Sociol Heal Illn.* (2010) 32:335–347. doi: 10.1111/j.1467-9566.2009.01218.x
45. Righi V, Sayago S, Blat J. When we talk about older people in HCI, who are we talking about? Towards a 'turn to community' in the design of technologies for a growing ageing population. *Int J Hum Comput Stud.* (2017) 108:15–31. doi: 10.1016/j.ijhcs.2017.06.005
46. Lazar A, Diaz M, Brewer R, Kim C, Piper AM. Going gray, failure to hire, and the ick factor: analyzing how older bloggers talk about ageism. *CSCW.* (2017) 17:655–68. doi: 10.1145/2998181.2998275
47. Rogers Y, Paay J, Brereton M, Vaisutis K, Marsden G, Vetere F. *Never Too Old: Engaging Retired People Inventing the Future with MaKey MaKey*. Toronto, ON: CHI (2014). doi: 10.1145/2556288.2557184
48. Fausset CB, Harley L, Farmer S, Fain B. Older adults' perceptions and use of technology: a novel approach. In: *International Conference on Universal Access in Human-Computer Interaction*. p. 51–8. Available online at: https://link.springer.com/content/pdf/10.1007%252F978-3-642-39191-0.pdf (accessed April 29, 2021).
49. Venkatesh V, Davis FD. A theoretical extension of the technology acceptance model: four longitudinal field studies. *Manage Sci.* (2000) 46:186–204. doi: 10.1287/mnsc.46.2.186.11926
50. Vroman KG, Arthanat S, Lysack C. "Who over 65 is online?" Older adults' dispositions toward information communication technology. *Comput Human Behav*. (2015) 43:156–66. doi: 10.1016/j.chb.2014.10.018
51. Lindley SE, Harper R, Sellen A. Desiring to be in touch in a changing communications landscape: attitudes of older adults. In: *Proceedings of the 27th International Conference on Human Factors in Computing Systems - CHI 09.* Boston, MA (2009).
52. Niemeijer AR, Depla MFIA, Frederiks BJM, Hertogh CMPM. The experiences of people with dementia and intellectual disabilities with surveillance technologies in residential care. *Nurs Ethics.* (2015) 22:307–20. doi: 10.1177/0969733014533237
53. Mittelstadt B, Fairweather B, Shaw M, McBride N. Ethical issues of personal health monitoring. In: *ETHICOMP 2011 Conference Proceedings.* Sheffield (2011).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 18 June 2021
doi: 10.3389/fpubh.2021.566960

Check for updates

Housing and Care for Older Women in Australia

Julie E. Byles[1,2]*, Emily M. Princehorn[1,2], Peta M. Forder[1,2] and Md Mijanur Rahman[3]

[1] Centre for Women's Health Research, The University of Newcastle, Callaghan, NSW, Australia, [2] School of Medicine and Public Health, The University of Newcastle, Callaghan, NSW, Australia, [3] Centre for Health Service Development, University of Wollongong, Wollongong, NSW, Australia

Background: Housing is essential for healthy ageing, being a source of shelter, purpose, and identity. As people age, and with diminishing physical and mental capacity, they become increasingly dependent on external supports from others and from their environment. In this paper we look at changes in housing across later life, with a focus on the relationship between housing and women's care needs.

Methods: Data from 12,432 women in the 1921–26 cohort of the Australian Longitudinal Study on Women's Health were used to examine the interaction between housing and aged care service use across later life.

Results: We found that there were no differences in access to home and community care according to housing type, but women living in an apartment and those in a retirement village/hostel were more likely to have an aged care assessment and had a faster rate of admission to institutional residential aged care than women living in a house. The odds of having an aged care assessment were also higher if women were older at baseline, required help with daily activities, reported a fall, were admitted to hospital in the last 12 months, had been diagnosed or treated for a stroke in the last 3 years, or had multiple comorbidities. On average, women received few services in the 24 months prior to admission to institutional residential aged care, indicating a potential need to improve the reach of these services.

Discussion: We find that coincident with changes in functional capacities and abilities, women make changes to their housing, sometimes moving from a house to an apartment, or to a village. For some, increasing needs in later life are associated with the need to move from the community into institutional residential aged care. However, before moving into care, many women will use community services and these may in turn delay the need to leave their homes and move to an institutional setting. We identify a need to increase the use of community services to delay the admission to institutional residential aged care.

Keywords: housing, healthy ageing, home and community care, residential aged care, longitudinal data

OPEN ACCESS

Edited by:
Xuemei Zhu,
Texas A&M University, United States

Reviewed by:
Annie Lu Nguyen,
University of Southern California, United States
Sherry Ahrentzen,
University of Florida, United States

***Correspondence:**
Julie E. Byles
julie.byles@newcastle.edu.au

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *29 May 2020*
Accepted: *28 April 2021*
Published: *18 June 2021*

Citation:
Byles JE, Princehorn EM, Forder PM and Rahman MM (2021) Housing and Care for Older Women in Australia. Front. Public Health 9:566960. doi: 10.3389/fpubh.2021.566960

INTRODUCTION

As the key foundation for provision of community aged care, "housing" represents an important resource in later life, is a central concern as people age, and is integral to older people's well-being (1). Housing is a source of shelter, purpose and identity, and can be more or less supportive of people's changing needs as they become increasingly susceptible to environmental constraints in later life. As people age into their 80 and 90's, and with diminishing physical and mental capacity, housing becomes more important in protecting the older person from harm, and providing a space where they can receive care and support for their needs.

The housing needs of older people will change with their needs for support, sometimes necessitating dramatic changes in the home environment, either through modifications, moving, or admission to residential aged care in an institutional setting, long term care facility or nursing home (hereafter referred to as residential aged care or RAC). However, research assessing the physical capacities of older people and determining their intentions to modify their homes or move, found that most people were satisfied with their homes and had no plans to move (2). This commitment on the part of the older people was despite the findings that their homes lacked design features to support an older person with greater levels of physical disability (2). Deciding the optimal housing conditions for older people is fraught with difficulty, and often when people do need to move they are least well-equipped to make decisions and to act autonomously.

While remaining in the family home is a key goal for both older people and service providers, the ability to "age in place" is limited not only by health, functional capacity, and available supports, but also by housing type. Recent research highlights the importance of housing as an essential basis for providing care in home and community settings (3–7). Home ownership and arrangements for independent living have also been shown to affect the timing of entry into residential aged care (3, 5, 6, 8–11). However, there is little research on how housing type influences the specific services older people receive. Conceivably, housing type may influence access to services, the type of services that can be provided, the extent to which the older person's needs are met, and the overall goals and outcomes of care. In turn, such services may support an older person to remain in their own home and to continue their participation within their community (3, 12).

In this paper we look at changes in housing and care across later life. We start from a premise that people will want to remain in their own home in the community, and that informal care and formal services can support people to remain in the community with a high level of satisfaction and well-being. We also acknowledge people may alter their housing location and type as they age for various reasons. We further recognise a reality that many people will end their days in RAC, when their needs are too great to remain living in the community even with high levels of support. These housing settings represent a pathway that people can progress along, moving from independent living, to supported care at home, to care in an institutional setting. Along this pathway, different levels of care can support people's functional abilities and ensure a dignified later life (13).

A Conceptual Model for Housing and Care

The later period of life can be associated with increasing burden of disease and disability, decline in physical function, decreased capacity for well-being and quality of life, reduced social participation and increased needs for health and social care. However, as shown by Byles (2019), Leigh (2017), and others, there is great heterogeneity of ageing experience, although many people will experience some decline in physical function as they age (14, 15). **Figure 1** shows the conceptual relationships between physical functioning, **housing pathways**, and the needs for care as people age (**care pathways**). The line in the figure shows a theoretical age-related decline in physical functioning from very good at younger ages to poorer levels of function in later life. This decline in physical functioning occurs through a dynamic balance between intrinsic capacity and environmental supports. Decline in physical functioning is also associated with decline in cognitive functioning and other capacities, and with increasing disease and comorbidity and need for health care, support from families, and aged services (16). This stage of life can also be a time for transition in housing with some people moving from the family home, to smaller accommodation (downsizing), a village for older people, or residential aged care. The goals for care and support also change according to where people are along this pathway. At earlier ages when people have higher levels of ability, their needs are for supportive environments that enable their participation in family and community life, and encourage prevention of disease and functional decline. These needs remain important as they age and their intrinsic capacities decline, but further needs for support in daily activities to reverse losses and to regain abilities (reablement) begin to have greater priority (see lower left corner in **Figure 1**). In later life, people need more and more help to compensate for loss of capacity and diminished ability to perform activities of daily living. At the last stages of life, the emphasis of care and support may be to provide for the basics of personal care, and to ensure quality of life and dignity (see upper right corner in **Figure 1**).

Housing Pathways

When it comes to housing for older people, Australia's older population faces a clash between personal preferences, cultural values, and social expectations. While most older people in Australia own their own home (1), there is a tension between social and environmental factors that push for moving from the family home into retirement villages and residential aged care facilities, and more personal factors that pull towards remaining in their existing homes. For the most part Australians place cultural value on ageing independently within their own homes, and most older people understandably do not want to move away from their homes and familiar neighbourhoods. These values are supported in Australia with a policy emphasis on ageing-in-place, and by providing care in people's own homes rather than in institutional settings. At the same time, there is a strong social expectation that people will "downsize" into smaller homes and apartments, or move into retirement communities that are

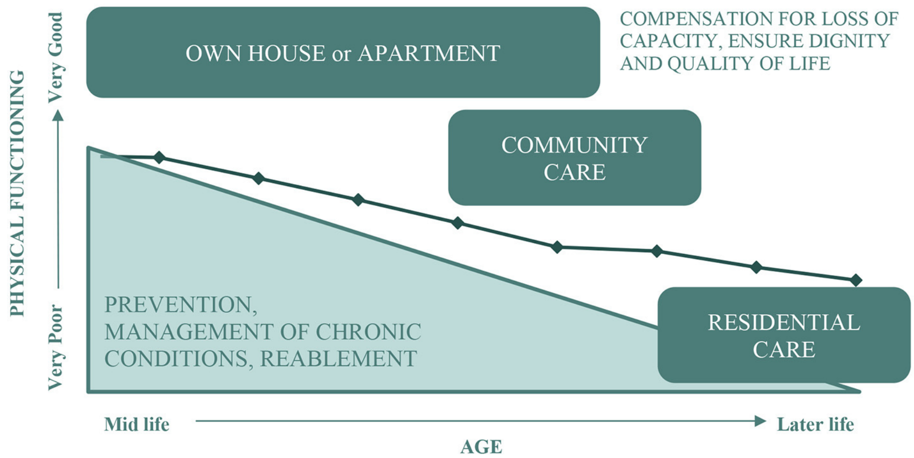


FIGURE 1 | Conceptual model of the association between physical functioning, housing, and the needs for care.

designed to meet the specific social and health care needs of older people. This expectation stems from assumptions that older people require less space, or need different types of housing to support their physical needs. The current lack of affordable inner city housing in Australia's capital cities also creates additional pressure to free up valuable housing space. Given this tension, older people find decisions about housing complex and of paramount concern. Moreover, their decisions are not entirely governed by their own preferences but are also influenced by housing markets and social expectations. Residential relocation is also a major life event, and must be considered within the context of an older persons' overall life course.

Care Pathways in Australia

Most older Australians live in the community, often with their spouse and/or other family members (58%) or alone (25%) (17). While people in their 60 and 70's generally require very little support, as they age into their 80 and 90's they are likely to become frail and experience multiple morbidities and disabilities. These frail older people are particularly dependent on care in order to meet basic daily needs. Mostly these needs are met through informal care provided by family and friends, with support of formal services. Formal aged care in Australia is heavily subsidised by government, with the government responsible for accreditation and accountability of aged care services run by private providers and (for profit and not for profit) organisations. Until recently, these aged care services were provided mainly through Home and Community Care (HACC) in the person's home or in community settings, or through RAC. In more recent years, the HACC program has been replaced with the Commonwealth Home Support Program. This support program provides a range of entry-level aged care services designed to help older people to remain at their home as long as possible by providing practical assistance and social support. Home Care Packages provide more intensive in-home support to those with higher care needs, and seek to avoid admission to RAC.

Home and community care is provided to people living in their own home, either at home or in a community setting. The care can take many forms, including transport, social support, home modifications, home maintenance, meals, allied health (e.g., physiotherapy, occupational therapy, podiatry, dietitian; rehabilitative care to regain function and strength after an illness or injury), and nursing. Profiles of community care service use have been identified by Kendig et al. using data for men and women in the Sax Institute 45 and Up Study (18). This study identified nine different service use groups across these different service types, with most people using few services to meet low level needs across their later life.

RAC is provided in instititutional settings to those older people who are no longer able to be supported in their own home. RAC provides round-the-clock assistance with personal and care needs and many people who have high-levels of dependency, including those with advanced dementia, may be admitted to a RAC facility for full-time care. At any point in time, around 6% of people aged 65 years or over live in RAC (19–21), and <8% of people aged 60 years and over think they will ever need to move into RAC (1). However, the proportion of the population in institutional care increases with age, particularly in the months or years before death. The estimated life-time risk of RAC for people aged 65 and over in Australia is around 40%, with women more likely to be admitted to RAC than men (20, 21).

Respite and Transitional (flexible) care services are also available. Respite allows for a short stay in RAC and allows carers to take a break or to address their own needs. Transitional care is designed as rehabilitation upon discharge from hospital, aiming to enable older people to return home rather than entering permanent RAC.

The assessment of need for aged care services is undertaken by a multidisciplinary team through the Aged Care Assessment Program (ACAP), which provides comprehensive assessment of people with more complex needs. The ACAP assessment includes social, medical, physical, and psychological domains, and clients may be referred to RAC, home care packages, transitional care, and/or respite care. ACAP assessment is essential in order to be eligible for government subsidised RAC. ACAP also has a role in promoting home and community care, in order to prevent or delay admission to RAC (22, 23).

Pathways of Housing and Care Among Women in Australia

In this paper, we examine the interaction between housing pathways and care pathways for Australian women as they age from their 70's to their 90's, drawing on a wealth of data from the Australian Longitudinal Study on Women's Health (ALSWH). This population study has followed 12,432 women in the 1921–26 birth cohort for 25 years (to date), from when they were aged in their early 70's (in 1996) through to their late 90's, providing information on changes in women's health, housing, and use of health care and aged services (21, 24). The women were randomly selected from the Australian universal health database (Medicare) and with oversampling of women living in rural and remote areas. These women were representative of Australian women in this age group, with slight over-representation of married, Australian born and women with higher level of education. Survey data on a range of demographic, psychological, social and health variables were collected by postal questionnaires every three years from 1996 to 2011 and six-monthly thereafter. In addition to the longitudinal survey data, the study has access to linked data on health and aged care use. These data provide detailed information on the timing and type of services received by the women. The study is also able to ascertain date of death through the National Death Index (NDI) (25). Women generally have longer life expectancy than men and, since they frequently outlive their partners, they often live alone in their later years and have less access to live-in support. We therefore believe that a gendered study looking at the care needs of women is of significance.

A number of papers have already been published reporting on housing and care pathways for women in the 1921–26 cohort of the ALSWH. We summarise these findings here first, before moving to new and additional analyses to examine ACAP assessments of care needs, the use of home and community care, and how these relate to housing type. We are particularly interested in knowing whether women living in a house are more likely to receive ACAP assessments and home care services, compared to women in other housing types.

Summary and Synthesis of Previous ALSWH Research on Housing and Care

Our first analysis took a longitudinal approach to identify changes in housing type within the context of women's later lives (26). We followed women from the 1921–26 cohort of the ALSWH as they aged from 73–78 to 85–90 years, analysing housing, sociodemographic and health data. The research revealed seven distinct housing patterns that can broadly be categorised as stable, downsize, and transitional. Stable patterns are defined as (1) House (bungalow)—living in a house for most surveys (47.0%); (2) House (bungalow) to the end—living in a house but with earlier death (13.7%); (3) Apartment—living in an apartment (12.8%); and (4) Living in a retirement village/hostel (5.8%). Downsize pattern is defined as (5) Moving from a house to retirement village (6.6%). The remaining patterns are defined in terms of transition from (6) Apartment or retirement village to residential aged care and death (7.8%); and (7) House to residential aged care (6.4%). Few women downsized to an apartment or retirement village, highlighting a disparity between social expectations and the reality for older women.

The vast majority of women remained in a freestanding house giving credence to policy objectives of ageing-in-place. It is also in keeping with our understanding of peoples' attachment to place and the importance of the family home. Stability could also be considered reflective of women's adaptability as well as the ability to modify their environment to suit their changing needs. The person-environment fit also seemed to be important, with women in stable housing patterns tending to be healthier with less need for help with daily tasks. The two transitional patterns reflect the poorer physical health of women moving to RAC with greater need for supportive care.

Hypothesising that some housing types may be more supportive than others, we then examined the association between housing type and the rate of admission to RAC, while also accounting for death as a competing risk. Admission to RAC was strongly associated with age, and with social and demographic characteristics (e.g., education level, marital status/living alone) and health needs (e.g., incontinence, stroke, falls, problems with vision and hearing, levels of physical functioning). Use of RAC was reduced by 13% for women living in rural/remote areas compared to those in major cities. After adjusting for these other factors, participants living in a house had the lowest risk of admission to RAC, while participants living in retirement village/self-care units/hostels had the highest risk. Incidence of admission to RAC over 13 years from their mid 70's to late 80's, was around 27% for women living in a house, 36% for women living in an apartment or townhouse, 44% for women living in a retirement village or self-care unit, and 37% for women living in other types of residences. In contrast, there was little difference in death rates over the 13 years of follow up according to housing type (21).

Our next set of studies examined patterns of use of community care through analysis of the HACC data. This analysis identified six distinct patterns of community care use (provided under HACC). Approximately 54% of the HACC users belonged to a cluster in which women used a minimum volume and number of services and 25% belonged to three complex care use clusters with higher volume and number of services. Significantly higher odds of using HACC were associated with: living in remote or regional areas; being widowed or divorced; difficulty in managing income; not receiving Veteran's Affairs benefits (since Veterans can use an alternative care program), having chronic conditions; lower health related quality of life scores; and poor/fair self-rated health (24). These service use patterns are shown in **Figure 2**, and indicate a higher use of services such as domestic assistance, transport and meals. These services are considered to be "high volume, low skill." The services which required more skilled care provision (including personal care, nursing and allied health services) were more concentrated in the complex care groups.

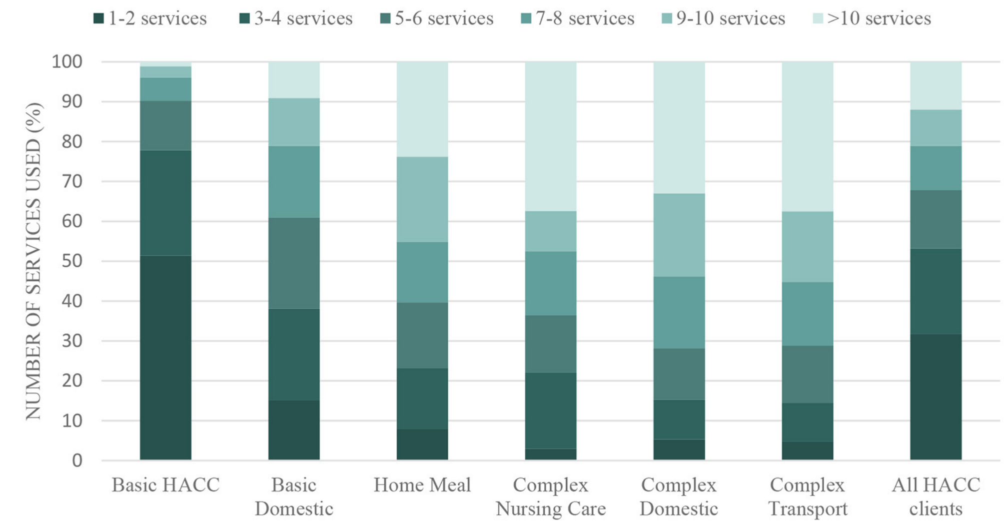


FIGURE 2 | Number of HACC services used by women in different service clusters over the period July 2001 to December 2011. Adapted by permission from Rahman et al. (24).

Social care and centre-based day care were used by less than one third of the women.

Using the HACC, RAC and NDI data for each calendar year, we further classified women as either using none of the aged care services, using only limited basic home and community care services, using a larger volume and multiple types of home and community services (moderate to high home care) in RAC, or having died. More than one-third of participants died during the study period, of whom 75% used one or more types of aged care, increasing with proximity to the time of death. Care use among surviving women is illustrated in **Figure 3**. At age 75–80, most women were not receiving any formal aged care, and only 2% of the women were in RAC. By age 85–90, 21% of surviving women were in RAC, and only 35% were in the community with no formal aged care services (27).

Using latent class analysis, we identified four different pathways through aged care. We found around 40% of women had very low aged care needs, with limited use of home care after age 85. These women had the best physical and mental health and social functioning. Around 25% of women consistently used home care from age 75 onwards, with increased use of RAC in their late 80's and early 90's. A further 10% had high use of RAC from 75 years onwards, and around 25% had earlier mortality and died before their mid 80's, having high use of home care and RAC in the years immediately preceding death. These women had the worst scores for physical function and social function, with more chronic conditions (27).

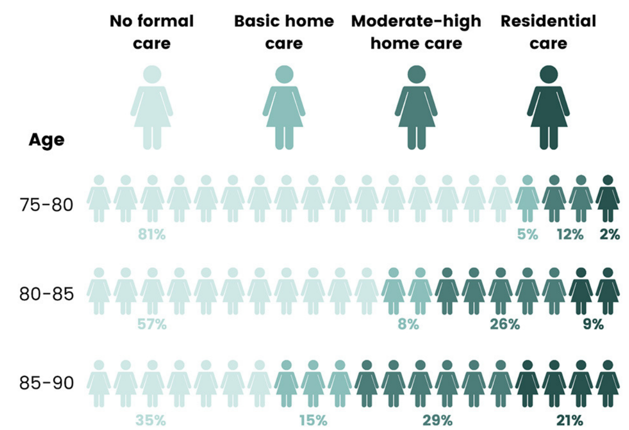


FIGURE 3 | Use of aged care services by women as they aged from 75–80 years (2001) to 85–90 years (2011). Adapted from Rahman et al. (27), with permission from Elsevier.

Women who used home care were more likely to transition to RAC than to remain in home care until the end of life (28). However, we also found that home care use can delay admission to RAC with earlier use of more home services reducing the cumulative incidence rate of admission to RAC. Compared to those who use few basic services, those who used more complex care services had a significantly lower rate of admission to RAC, up to nine years from their first HACC service. After nine years, there was no difference in admission to RAC between the home care groups, indicating that RAC may still be required in later life after a very long period of supported home care (29). Across the cohort, from around age 78, we forecast that, on average, women survive around eight years without using aged care services, five years using home care, and around two and a half years in RAC (28).

Once women enter RAC, they undergo further changes in their health and care needs. These changes can be tracked for the women in the ALSWH using data from the Aged Care Funding Instrument which assesses aged care residents' levels of need across domains of: Activities of Daily Living, behaviours, and complex care needs. Using these data we were able to differentiate women who had been admitted to RAC into five groups. These groups were based on the trajectories of care needs in terms of activities of daily living, behaviours of concern in relation to dementia, and complex health care needs with large variation in the combinations of levels of care needs over time (30). Approximately 28% of residents belonged to the "high dependent–behavioural and complex need" group, which had high care needs in all three domains over time and who tended to be older and have multiple morbidities. Over two-fifths of residents (41%) comprised two trajectory groups ("high dependent–complex need" and "high dependent–behavioural need"), which had medium to high care needs in two domains. Around one-third of residents (31%) were included in two trajectory groups ("less dependent–increasing need" and "less dependent–low need"), which had low or low to medium care needs over time. These latter two groups may represent women who may have been managed in their own home if they had better access to in-home care (28). To explore this possibility, we looked retrospectively at the use of HACC for women who had been admitted to RAC and in accordance with their care need trajectories. The detail on care services provided in **Table 1** suggests much room for increased delivery of in-home services prior to admission to RAC. It is possible that RAC admission may have been able to be delayed for many of these women had they received more home support earlier. This is in keeping with our earlier findings on the effectiveness of home and community care in delaying admission to a RAC institution.

We have also examined the outcomes of ACAP assessment in terms of uptake of community care or admission to RAC (31). In this analysis, very few women did not access any services after ACAP approval. These individuals had more social resources, and were less likely to live alone. They were also more likely to live in metropolitan areas, where other services may be more accessible. The mean elapsed time for those accessing community care was 159 days, compared to 101 days for those entering RAC. The probability of entering community care was 30% within 100 days, and 53% within 500 days.

For entering RAC, the chances were 20% within 100 days, and 39% within 500 days. These data indicate significant wait times for services, and are consistent with more recent estimates from the Australian Productivity Commision (32). Of those approved for RAC, 47% had mental and behavioural conditions, including dementia, while 62% experienced conditions including amnesia, falls and disorientation. Those accessing community care after the assessment were less likely to have these needs (37 and 57%, respectively). Approval for community-based care was also associated with requiring assistance with communication, health, meals, bodily movement, and self-care. Age was a significant factor for entry into RAC. Living alone increased the rate of access to RAC and decreased rate of access to community care. Having higher education was associated with shorter wait times, and living in an outer regional area was associated with longer wait times for RAC. Entry to RAC was faster if the ACAP assessment took place in a hospital. The results indicate that, while assessed need was the primary driver for access to care, there is also a socioeconomic and geographical gradient (31).

These previous studies illustrate pathways of housing and care, with some evidence that housing type may be associated with more rapid transition into RAC. We also show that earlier and more home and community care may delay admission to a RAC institution, and that the use of these home and community services in the months prior to RAC admission is proportionately low. In the further analyses presented here, we examine whether housing type is associated with greater use of ACAP and/or greater use of home and community care services.

MEASURES AND METHODS

Data were from the 1921–26 cohort of ALSWH linking survey data (Survey 4, 2005, $n = 7{,}158$ women; Survey 5, 2008, $n = 5{,}560$; Survey 6, $n = 4{,}055$; and 6 monthly surveys thereafter), aged care data and National Death Index data for the years 2003 (age 77–82) to 2014 (88–93). Ethical approval for this study was obtained from the Universities of Newcastle and Queensland (Ethics approvals H0760795 and 2004000224). Ethics approval for linkage of ALSWH survey data to aged care and death data was approved by the Australian Department of Health and the Australian Institute of Health and Welfare (AIHW).

Data on Housing

The housing type variable in this study was obtained at ALSWH surveys using the question "Which of the following best describes your housing situation?" with responses "A house," "A flat/unit/apartment/villa/townhouse," "Mobile home/caravan/cabin/houseboat," "Retirement village/self-care unit," "Nursing home," "Hostel," and "Other." Missing responses in this variable at a particular time point were filled in using the first valid response from the nearest preceding two surveys. If these were also missing, missing responses were filled using the response at the next survey. Information on admission to RAC was ascertained from administrative data provided by the AIHW (see below). If participants had a record of admission to permanent RAC, housing type at subsequent surveys was updated to "permanent RAC." Housing type was then categorised into four mutually exclusive groups including "House/Other," "Apartment/Unit/Flat/Villa," "Retirement village/self-care unit," and "RAC/nursing home."

Data on Aged Care

Data on aged care were obtained from multiple administrative data bases including the HACC program which provides services to people living in the community, the ACAP which assesses people for their aged care needs, and RAC data on people receiving care in an institutional setting. For those in RAC, we also had data from the Aged Care Funding Instrument which assessed peoples' levels of need across domains of: Activities of Daily Living, behaviours, and complex care needs. These data are linked to ALSWH survey data by the AIHW using a probabilistic linkage algorithm (33). Since the outcomes of interest (home and community care, and ACAP assessment) were ascertained

TABLE 1 | Proportion and median amount of HACC services for older Australian women over the 24 months prior to admission into RAC, according to the five trajectory groups in RAC ($n = 3,468$).

HACC services	Group 1: Less dependent, low need ($n = 441$)	Group 2: High dependent, complex need ($n = 706$)	Group 3: Less dependent, increasing need ($n = 628$)	Group 4: High dependent, behavioural and complex needs ($n = 954$)	Group 5: High dependent, behavioural need ($n = 739$)
Domestic assistance					
% using service	38	40	33	29	29
Median hours (IQR)	40 (13–65)	44 (14–67)	39 (13–64)	29 (10–61)	32 (8–59)
Meals					
% using service	28	32	28	23	28
Median number (IQR)	59 (17–201)	72 (17–220)	58 (18–181)	79 (25–218)	98 (22–261)
Nursing care					
% using service	27	36	28	36	30
Median hours (IQR)	6 (3–18)	10 (3–26)	9 (3–23)	11 (4–32)	8 (3–22)
Allied health at home					
% using service	11	15	12	15	13
Median hours (IQR)	4 (2–7)	3 (1–7)	4 (2–8)	4 (2–8)	4 (1–8)
Allied health at centre					
% using service	12	13	11	10	9
Median hours (IQR)	3 (1–6)	4 (1–7)	4 (2–7)	3 (2–7)	3 (1–6)
Case management					
% using service	7	9	8	11	11
Median hours (IQR)	3 (1–4)	3 (1–26)	2 (1–3)	4 (2–6)	2 (1–3)
Care coordination					
% using service	20	26	22	23	24
Median hours (IQR)	3 (1–6)	3 (1–33)	3 (1–6)	3 (1–8)	3 (1–8)
Counselling					
% using service	7	10	11	11	10
Median hours (IQR)	3 (1–4)	2 (1–4)	2 (1–4)	2 (1–6)	2 (1–5)
Centre based day care					
% using service	14	15	16	14	17
Median hours (IQR)	117 (24–356)	113 (26–351)	127 (33–327)	192 (38–386)	144 (40–397)
Home maintenance					
% using service	18	18	13	14	14
Median hours (IQR)	4 (2–14)	3 (2–10)	4 (2–12)	5 (2–15)	5 (2–13)
Home modification					
% using service	5	6	4	8	7
Median AUD$ (IQR)	95 (30–411)	102 (50–284)	64 (31–168)	120 (50–328)	115 (40–306)
Meals at centre					
% using service	6	9	9	10	11
Median number (IQR)	22 (6–62)	24 (5–59)	20 (6–43)	22 (5–69)	17 (6–54)
Nursing care at centre					
% using service	9	7	6	7	6
Median hours (IQR)	2 (1–4)	2 (1–3)	2 (1–4)	2 (1–4)	1 (1–3)
Personal care					
% using service	12	23	16	22	21
Median hours (IQR)	8 (2–18)	11 (3–80)	12 (3–54)	27 (6–101)	16 (4–64)
Social care					
% using service	13	21	19	16	19
Median hours (IQR)	9 (3–35)	16 (5–53)	22 (7–59)	17 (5–61)	16 (6–54)

(Continued)

TABLE 1 | Continued

HACC services	Group 1: Less dependent, low need (*n* = 441)	Group 2: High dependent, complex need (*n* = 706)	Group 3: Less dependent, increasing need (*n* = 628)	Group 4: High dependent, behavioural and complex needs (*n* = 954)	Group 5: High dependent, behavioural need (*n* = 739)
Transport					
% using service	23	26	20	20	20
Median number (IQR)	15 (4–78)	18 (4–76)	16 (6–80)	22 (5–82)	18 (4–72)
Equipment and aids					
% using service	4	5	4	5	6
Median number (IQR)	3 (2–4)	2 (1–5)	2 (1–7)	2 (1–5)	3 (1–5)

All services were measured by hours of services except for "Transport" and "Equipment and aids" which were measured by frequence or number of occasions.
IQR, Inter-quartile range, for women receiving services; AUD, Australian dollar.

from linked administrative data, there is no concern for loss of follow-up of participants except for attrition by death.

The HACC data were provided for services used/accessed in a calendar quarter (i.e., January-March, April-June, July-September and October-December), with data capturing up to 29 different services options. These service categories were collapsed into 19 main service domains of: counselling (client); counselling (carer); assessment; allied health at home; allied health at centres; centre-based day care; domestic assistance; home maintenance; home modifications; meals (centre); meals (delivered); nursing care at home; nursing care at centre; personal care; respite care; social support; transport; aids; and case management/planning. These data were aggregated for each 12 month period (July-June).

ACAP data included date of assessment, setting of first face to face contact (hospital (acute care)/other inpatient setting/RAC service/other), availability of carer (co-resident carer/non-resident carer/has no carer), current assistance and recommended assistance (yes/no) for self-care, movement, moving around, communication, health, transport, social activity, domestic activity, meals, home entertainment, and other activity. Level of permanent RAC approved (not approved/low/high) was also included. The unit level records were summarised for ACAP assessments for each woman per year (July-June).

Statistical Analysis

Generalised estimating equations (GEE) were used to model the odds of using HACC services and of having an ACAP assessment according to housing type, adjusted for other demographic and health variables collected on ALSWH surveys. To reflect the women's circumstances at the start of a HACC period, ALSWH survey data from 2005 were aligned with ACAP/HACC usage from July 2005 to June 2008; survey data from 2008 were aligned with ACAP/HACC usage from July 2008 to June 2011; and 2011 survey data were aligned with ACAP/HACC usage from July 2011 to June 2014. A binomial distribution with a logit function and unstructured correlation matrix was used in the GEE models, providing odds ratios (OR) and corresponding 95% confidence intervals. Models initially included each variable adjusted for time period only, and then for each variable including adjustment for all other variables in the model. Women were included in the GEE models up to the period at which they did not return a survey, and so the GEE analysis may be biassed due to non-death attrition. However, previous analyses assess these effects to be small (34).

RESULTS

As of 2003, there were 10,297 eligible surviving women in the cohort out of the original 12,432 women, but 326 women were already in RAC. Survey 4 (2005, age 82–87) was completed by 7,044 women (eligible for data linkage).

However, 1,998 women were beneficiaries of the Department of Veterans' Affairs and potentially covered by veterans' programs. To avoid underestimation of service use by these women, these women were excluded, leaving 5,046 women for the analysis.

Of the 5,046 eligible women, 2,841 women had ACAP record(s) and HACC record(s). Another 300 women had ACAP record(s) only (no HACC), and 1,331 women had HACC record(s) only (no ACAP). Among the women who had both HACC and ACAP records, 21% had their first HACC service more than five years before their first aged care assessment; 51% had their first HACC service one to five years before their aged care assessment; 20% had their first HACC service in the same year as their first ACAP assessment; 8.0% had their first ACAP assessment one to five years prior to having their first HACC service; and 0.3% had their first aged care assessment more than five years prior to their first HACC assessment. Consistent with our other findings, these data indicate that women were likely to receive HACC well in advance of being assessed by ACAP as potentially needing RAC.

There were 4,158 women (82.4%) who had accessed at least one HACC service between 01 July 2003 and 30 June 2014. Around 55% of these women had used HACC services within the first three years of observation, while 90% of the women had used HACC services within eight years. **Table 2** shows the types of HACC services used by these women, based on the first services observed. There were very few differences in the specific services used, according to housing type. In the GEE

TABLE 2 | HACC services for older women in their first calendar quarter of access/use, according to housing status (*N* = 4,158).

HACC services used (%)	House/Other (*n* = 2,916) %	Unit/Flat/Apartment/Villa (*n* = 863) %	Retirement village/Self-care unit (*n* = 379) %
Aids[a]	2.7	2.3	1.3
Assessment	35.7	36.0	40.3
Allied Health – at home	16.8	18.5	17.6
Allied Health – at centre	3.4	4.9	4.7
Case management/planning[b]	1.0	1.0	0.8
Counselling – client	7.8	8.4	4.2
Counselling – carer	6.8	4.7	5.3
Centre-based day care	5.3	5.4	3.7
Domestic assistance[c]	28.2	26.5	30.0
Home maintenance	13.6	8.9	3.2
Home modifications	5.1	4.6	1.8
Meals – at centre	3.0	4.2	3.7
Meals – delivered to home	9.2	11.5	12.4
Nursing care – at centre	3.0	2.3	0.5
Nursing care – at home	16.5	13.1	17.1
Personal care[d]	4.4	3.2	5.5
Respite care	0.7	0.3	0.5
Social support	5.9	6.5	7.4
Transport	13.5	17.4	20.3

[a]Aids and devices for: self-care, support, and mobility, communication, reading, medical care, car modifcations, or other goods/equipment.
[b]Includes case management, case planning and care co-ordination services.
[c]Includes general housekeeping and cleaning activites, as well as "Other food services" not classified elsewhere.
[d]Includes bathing, showering, general hair care, and other toileting care.

TABLE 3 | Effect of housing and other factors on the use of HACC services over time among older Australian women.

	Adjusted for period only[c] OR (95% CI)	Full model[d] OR (95% CI)
Period[a]		
2005	1.00	1.00
2008	1.77** (1.64, 1.90)	1.79** (1.66, 1.93)
2011	2.64** (2.39, 2.92)	2.53** (2.28, 2.80)
Housing		
House/other	1.00	1.00
Apartment/unit/flat/villa/townhouse	1.12 (0.99, 1.26)	1.07 (0.95, 1.21)
Retirement village/self-care unit	1.03 (0.88, 1.20)	1.02 (0.87, 1.19)
Age at baseline	1.11** (1.07, 1.15)	1.10** (1.06, 1.14)
Partnered		
Partnered (married/defacto)	1.00	1.00
Not partnered	1.29* (1.16, 1.42)	1.23** (1.11, 1.36)
Ability to manage on income		
Easy	1.00	1.00
Difficult	1.45** (1.30, 1.62)	1.37** (1.23, 1.54)
Provide care for others		
No	1.00	–
Yes	0.94 (0.85, 1.05)	–
Need help with daily activities		
No	1.00	1.00
Yes	1.50** (1.32, 1.71)	1.30** (1.13, 1.49)
Had a fall in last 12 months		
No	1.00	1.00
Yes	1.22** (1.12, 1.34)	1.15** (1.04, 1.27)
Stroke in the last 3 years (diagnosed with or treated for)		
No	1.00	1.00
Yes	1.40** (1.15, 1.70)	1.28 (1.04, 1.57)
Admitted to hospital in last 12 months		
No	1.00	1.00
Yes	1.16** (1.07, 1.26)	1.07 (0.98, 1.16)
Number of comorbid conditions[b]		
0	1.00	1.00
1–2	1.33** (1.18, 1.50)	1.30** (1.15, 1.46)
3 or more	1.82** (1.59, 2.09)	1.66** (1.44, 1.91)

$^{*}p < 0.05$ and $^{**}p < 0.01$.
[a]Periods of time: 2005- includes period 01 July 2005 to 30 June 2008 (n = 4,252), 2008- includes period 01 July 2008 to 30 June 2011 (n = 3,360), 2011- includes period 01 July 2011 to 30 June 2014 (n = 2,422). The surveys coincided with the start of each period (i.e., 2005, 2008, and 2011).
[b]Comorbidities include high blood pressure, asthma, bronchitis/emphysema, osteoporosis, cancer, depression, anxiety, angina, heart attack, other heart problems, diabetes, dementia, and osteoarthritis.
[c]Shows association between each variable and HACC service use, adjusting only for time.
[d]Shows association between each variable and HACC service use, adjusting only for time and for all other variables in the model.

models, there was also little evidence to suggest that accessing HACC services while living in a unit/apartment (OR = 1.07, p = 0.27) or in a retirement village/self care/hostel was different to living in a house (OR = 1.02, p = 0.80). The odds of accessing HACC services increased as the women aged, and was higher if women were older at baseline, were not partnered, had difficulty managing on their available income, required help with daily activities, had a fall, or were admitted to hospital in the last 12 months, had been diagnosed or treated for a stroke in the last three years, or had comorbidities (**Table 3**).

There were 3,141 women (62.2%) who had at least one **ACAP assessment** for aged care services between 01 July 2003 and 30 June 2014. Only 21% of these women had received at least one aged care assessment within the first three years of observation, while 40% of women had an assessment within five years, and nearly 75% of the women had an assessment within eight years. At the time of their first aged care assessment, women who indicated on their previous survey that they were living in a house were more likely to report having a co-resident carer than if they indicated living in an apartment or a retirement village/self-care unit. The first face-to-face setting was similar for women who indicated residing in a house, unit or retirement village (**Table 4**). At the time of the first aged care assessment, living in a house had the lowest rate of permanent RAC approval (49%), with 52% of women living in apartments having RAC approval, and 59% of women living in retirement village/self-care/hostels having RAC approvals.

The results of the longitudinal analyses (**Table 5**) indicate that the number of ACAP aged care assessments increased over time as the women aged. Having an assessment was more likely if

TABLE 4 | Profile characteristics of the first aged care assessment for older women, according to housing status at the survey preceding the assessment ($N = 3,137^{*}$).

	House/other (*n* = 2,013) %	Unit/flat/ apartment/villa (*n* = 693) %	Retirement village/self-care unit (*n* = 431) %
Location of first contact			
Hospital (acute care)	16.2	16.2	13.0
Other inpatient setting	5.5	6.1	6.5
RAC service	1.2	1.7	1.9
Other[a]	69.0	68.0	70.5
Not stated/inadequately reported	8.1	8.0	8.1
Carer availability			
Co-resident carer	37.5	21.8	17.6
Non-resident carer	40.2	51.7	55.9
Not stated/inadequately described/not applicable	22.3	26.5	26.5
Current or recommended assistance with:			
Communications	10.2	8.1	10.9
Domestic activities	90.9	90.3	92.3
Health issues	59.2	55.0	58.5
Home maintenance	72.0	63.5	66.8
Meals	71.5	69.4	75.9
Bodily movement[b]	13.7	12.6	12.3
Moving around[c]	44.5	37.8	44.1
Self-care	48.6	43.6	44.1
Social activities	70.6	70.4	74.5
Transport	81.2	81.0	84.2
Other issues	8.7	9.8	8.6
Level of permanent RAC approved			
Not approved	51.4	48.2	41.1
Low	35.2	40.1	48.7
High	13.4	10.8	10.2

**Four women were excluded due to missing house status at the survey prior to their first ACAP assessment.*
[a]Other refers to all other settings such as private residences, outpatient clinics, retirement villages, independent living units, clinic offices, etc.
[b]Bodily movement refers to maintaining or changing position, carrying, moving or manipulating objects, getting in or out of a bed or chair.
[c]Moving around refers to walking and related activities, either around the home or away from home (excludes needing assistance with transport).

women were living in an apartment (OR = 1.34, 95% CI = 1.18–1.51) or in a retirement village/self-care unit/hostel (OR = 1.47, 95% CI = 1.27–1.69) when compared to women living in a house, even after accouting for other factors. The odds of having an ACAP aged care assessment were higher if women were older at baseline, required help with daily activities, reported a fall, were admitted to hospital in the last 12 months, had been diagnosed or treated for a stroke in the last three years, or had multiple comorbidities.

DISCUSSION

Individuals, families and governments support a shared goal for older people to remain in their own homes in the community. Realising this goal across the majority of later life, for the majority of people, will depend on a constructive balance between optimising the intrinsic capacities of older individuals, minimising disease and disability, providing environmental supports, and providing care. Housing is critical in providing a physically supportive and safe environment, and in offering a place where adequate care can be provided to support frailer individuals in their later years.

Data from the ALSWH highlight the interactions between housing and the use of aged care services over time. We find that coincident with changes in functional capacities and abilities, women make changes to their housing, sometimes moving from a house to an apartment, or to a village. For some, increasing needs in later life are associated with the need to move from the community and into RAC. However, before moving into RAC, many women will use community services and these may in turn delay the need to leave their homes and move to an institutional setting. In this work, we explored whether the housing type influences women's use of community services, assessment for aged care, or transition to RAC.

We found that there were no differences in access to home and community care according to housing type, but women living in an apartment and those in a retirement village/hostel were more likely to have an aged care assessment and had

TABLE 5 | Effect of housing and other factors on having an aged care assessment over time among older Australian women.

Covariates	Adjusted with period only[a] OR (95% CI)	Full model [b] OR (95% CI)
Period[α]		
1: 2005-	1	1
2: 2008-	1.99** (1.82, 2.18)	1.91** (1.73, 2.11)
3: 2011-	3.03** (2.73, 3.36)	2.67** (2.38, 2.99)
Housing		
House/other	1	1
Apartment/unit/flat/villa/townhouse	1.31** (1.16, 1.47)	1.34** (1.18, 1.51)
Retirement village/self-care unit	1.46** (1.26, 1.68)	1.47** (1.27, 1.69)
Age at baseline	1.15** (1.11, 1.19)	1.13** (1.09, 1.17)
Partnered		
Partnered (married/defacto)	1	-
Not partnered	1.05 (0.95, 1.16)	
Ability to manage on income		
Easy	1	1
Difficult	1.16** (1.03, 1.30)	1.00 (0.94, 1.06)
Provide care for others		
No	1	1
Yes	0.79** (0.71, 0.89)	0.88* (0.78, 0.99)
Need help with daily activities		
No	1	1
Yes	3.01** (2.65, 3.43)	2.57** (2.24, 2.94)
Had a fall in last 12 months		
No	1	1
Yes	1.55** (1.40, 1.71)	1.37** (1.23, 1.52)
Stroke in the last 3 years (diagnosed with or treated for)		
No	1	1
Yes	1.71** (1.42, 2.08)	1.40** (1.15, 1.71)
Admitted to hospital in last 12 months		
No	1	1
Yes	1.38** (1.27, 1.51)	1.16** (1.05, 1.27)
Number of comorbid conditions[β]		
0	1	1
1–2	1.36** (1.18, 1.56)	1.25** (1.08, 1.45)
3 or more	2.01** (1.73, 2.34)	1.53** (1.30, 1.79)

[α] *Periods of time: (1) 01 July 2005 to 30 June 2008 (n = 4,252); (2) 01 July 2008 to 30 June 2011 (n = 3,360); (3) 01 July 2011 to 30 June 2014 (n = 2,422). The surveys coincided with the start of each period (i.e., 2005, 2008, and 2011).*

[β] *Comorbidities include high blood pressure, asthma, bronchitis/emphysema, osteoporosis, cancer, depression, anxiety, angina, heart attack, other heart problems, diabetes, dementia, and osteoarthritis.*

$^{*}p < 0.05$ and $^{**}p < 0.01$.

[a] *Shows association between each variable and HACC service use, adjusting only for time.*

[b] *Shows association between each variable and HACC service use, adjusting only for time and for all other variables in the model.*

a faster rate of admission to RAC than women living in a house.

Whether this increased need for RAC arises from something particular to housing type, or whether housing type is associatied with other underlying needs is not clear from our studies. We have adjusted for social circumstances, phsyical functioning, and health conditions. However, it may be that living in settings other than a house may be another indicator of social and economic resources, at least within the Australian context. Our study of housing transitions (26) found that most of the women living in apartments had been there for a longer term, with few moving to an apartment in later life, having previously lived in a freestanding home. We have also not accounted for housing tenure, with the possibility that women living in apartments are more likely to be renting or living in social housing. Another Australian study reported that compared to those individuals who owned their own home, individuals living in social housing apartments were most likely to enter RAC (35).

Another possible reason for the protective effect of living in a house, which cannot be assessed in this study, may be that women made modifications to their house, increasing the suitability of the home to their increasing needs. Such changes may not be possible for women living in an apartment. It may also be that remaining in their own neighbourhood rather than moving may also have increased their social connections and reduced their need for care. The finding that people in retirement villages and hostels were more likely to move into RAC may also reflect the increasing needs of these people. From other data, a report by the Australian Institute of Health and Welfare found that, as compared to other housing settings, people living in retirement villages were more likely to be approved for entry into RAC (36). In another study, older people living in group homes or retirement villages tended to use more services than people living in the community (37), again potentially indicating a higher level of need among these people. Whether increasing the services to people in these settings could delay the need for admission to RAC is open to investigation. We and Jorgensen et al. have found that community care can delay the need for RAC. However, our other analyses show that use of services is low and often delayed, and largely independent of housing type except that women living in a house were less likely to have ACAP assessment or be admitted to RAC (38).

Regardless of the setting, older people are highly likely to require some sort of care as they age. Using a life table approach, it has been estimated that more than half of all women in Australia (and a third of men) will be admitted to permanent RAC at some time in their life (39), and a greater proportion will need some form of community care. Meinow's study in Sweden found that almost all older people required aged care in the last two years prior to death, either in their own home or in an institutional setting (40). In the same study, older age at death was associated with increased use of aged care services, even when adjusting for closeness to death. Likewise, modelling of longitudinal data from Japan estimated that at age 78, around 90% of women had no long term care, but the probability of surviving women transitioning from no care to some care within three years was 15% for community care, and 5% for institutional care. After six years, 31% of surviving women would be receiving community care and 7% would be receiving care in an institution (41). In our own analysis, most women used some form of aged care in their later life, with only 28% of women using no formal aged care services, most women using home and community care, and some transitioning into RAC. Most of those who entered RAC had already used some form of community care (28). These findings are also similar to national data reported by the Australian Institute of Health and Welfare (AIHW), showing that over two-thirds of residents in RAC had first used home and community care (42).

For some women, RAC may be the only way to adequately meet their needs. However, our data and data from other studies support that home and community care may have an important role in supporting people to stay at home and to delay or avoid admission to an institution (29, 43).

On the other hand, some women who need to enter RAC in order to support their high levels of need may be less likely to do so if they have inadequate financial assets (30). While RAC is subsidised by the Australian government, people with equity in their own home can draw down on this asset to pay for premium care with greater choice, comfort levels and extra services. Home ownership therefore may operate as a form of long term care insurance within the Australian context. A recent report published by the Centre of Excellence in Population Ageing Research considers this role of the family home in providing financial security in older age. Thus, the home can be considered not only as the place where care can be provided, but also as the means by which care may be afforded (44). The decline in home ownership in Australia may have important implications for the financing and affordability of RAC.

For women who have moved into RAC, the care facility should be seen not as an institution, but as their home. Given that most women who enter RAC will remain in that facility for at least two and a half years in our study (28) or longer (42), the RAC home is likely to become domicile, community and social network. The social and physical environment of the RAC setting is therefore another area of concern in considering the nexus between housing and care. Homelike environments can be promoted through design, the designation of private and shared places and through the ability to personalise their space. Safety, security and sense of autonomy also remain important for people in these settings (45).

Given the need for care as people age, and the context of population ageing which will see increasing demands for care, detailed information on housing transitions and use of services is vital for planning of aged and social care services, and to meet the needs of older people. Despite a preference for older people to live at home, there are few evaluations of the benefits of community care vs. RAC and of which home care services are the most beneficial (46). There is some concern that home care is fostering social isolation and that some older people would be better off in a RAC setting. There is a further issue that older people find it very difficult to navigate the aged care system, particularly in deciding what services they need and the potential benefits vs. perceived costs. This issue of identifying and selecting appropriate services may be particularly true for services that have a preventive or reablement approach that enables the person to participate in daily activities, as compared to services such as meals, shopping and cleaning that substitute for what the older person can no longer do. Older people could be better supported to make choices for their aged care, and their accommodation choices, if they had information about the benefits of different services, including those that will enable their continued independence and enable them to stay in their own home. Improvements to community care include greater provision for reablement needs to be assessed and reablement approaches to be embeded in the services provided (47). There is also need for better integration between health care and community supports (48), and for a stronger evidence-base for reablement approaches (49, 50). There is also a recognised need for better palliative and end-of-life care (46, 51).

In Australia, there has been a Royal Commission into Aged Care Quality and Safety which has identified the challenges faced by older people deemed eligible for a Home Care Package. These challenges are a result of older people, firstly, having to wait in the national prioritisation queue before a package of services is "assigned," and then, having to find a service provider to deliver their care (52).

The report acknowledged that this process can "*take a very long time*," especially for those who have higher care and support needs, with many people dying while waiting for a Home Care Package and others prematurely moving into RAC. There is also a widely recognised need to improve RAC for older people. The report from the Royal Commission, poignantly titled "Care, Dignity and Respect," acknowledged that people often enter RAC with great trepidation with fear of loss of individuality, autonomy and control over their own lives (52). This is particularly concerning, given ALSWH data indicates that around 40% of women will be admitted to permanent RAC at some point in their last years (around 80% for those with dementia), with two and a half years average length of stay (26), and rapidly increasing needs over the course of their aged care stay (25).

A Comment on Older Men

Research on ageing has tended to focus on women, who have a longer life expectancy than men, and make up the greatest proportions of people at oldest ages. However, men's life expectancy is increasing, and a growing proportion of older people are men (53). Compared to women, men are more likely to be partnered, living at home in a private dwelling (17), and to have someone to care for them (54). However, as men's life expectancy increases, a larger number of men are living to very old age, and increasing proportions live alone (53). These older men who live alone may have little in the way of informal support (55, 56), and may have greater mental and physical health needs and poorer health risk behaviours, compared to men who live with a partner (57), or to women. There is however little information on the health and care needs of older men. One study examined data from the Sax Institute 45 and Up Study to compare the mental health and physical functioning of community-dwelling men aged 70 years or over who live alone, and those who live with their partner or spouse. Among this large population of community-dwelling older men, those who did not have a spouse or partner had more adverse health risks (such as smoking, drinking and low BMI), and up to age 85, had poorer physical health-related quality of life and were more likely to have poor mental health compared to men with a partner (58).

As more men reach older ages, the number of older men requiring aged care is also increasing. However, in 2019, only one-third of people using aged care services in Australia were men (19). In their recent Australian study, Khadka and colleagues compared incidence rates of aged care service utilisation between 2008–09 and 2015–16. While the proportion of men utilising aged care services had increased slightly from 2008 to 2009 levels, they still only made up 39.7% of admissions to RAC in 2015–2016 (59). In comparing men and women's use of community services, Kendig et al. found that men were less likely to use transport services and domestic assistance, but more likely to use nursing services (18). Unpartnered men and women were more likely to use nursing services. Generally, men were less likely to use home and community care than women were, and people without a partner used more services than people with a partner (18).

The reasons that men do not use aged care in as great a proportion as women are likely to be multiple. In addition to their shorter longevity and greater likelihood of being partnered, they also tend to have lower levels of disability than similarly aged women and are less likely to be frail (60). It has also been suggested that masculine attitudes to help seeking may operate as a barrier to men accessing care. In one study undertaken in Australia, men saw aged care services as feminised and not "male friendly" (61). These gender issues are an important consideration in ensuring services are appropriate for older people, and not simply available.

CONCLUDING COMMENTS

Based on our findings we would argue that much needs to be done to increase access to more community services earlier, when women are living in their own homes, and to increase the opportunities for prevention and reablement within the aged care system. We also strongly believe that the system needs to encourage people to plan ahead for their ageing and aged care needs, with a focus on their goals, their identity and their right to make informed choices about their care and where they choose to live. We further assert that women should not have to leave their homes which have meaning to them to receive the care that they need.

We see aged care as "the long tail" of the prevention pathway with a focus on long term ability to engage meaningfully in life, long term dignity, and long-term autonomy. Even very old people can maintain their capacities, regain strengths and abilities, and can prevent future loss and decline with the appropriate support and social environments. Even when people's intrinsic capacities are greatly diminished and compromised, there is much that can be done to support their well-being. This balance between housing and aged care, as supporting people even when their intrinsic capacity is diminishing is in keeping with the World Health Organizations' goal of healthy ageing, helping older people to maintain their ability to "do the things they have reason to value."

DATA AVAILABILITY STATEMENT

Information on applying for ALSWH data is available from https://www.alswh.org.au/for-datausers/applying-for-data/. Data Access enquiries can be directed to this e-mail: alswh@uq.edu.au.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The University of Newcastle Human Research Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JB conceptualised and designed the studies reported here and wrote the first draught of the manuscript. PF and MR led and performed the analysis of the data and drafted the methods and results. EP wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

ACKNOWLEDGMENTS

This study was conducted as part of the Australian Longitudinal Study on Women's Health, managed jointly by the University of Newcastle and the University of Queensland. The authors are grateful to the Australian Government Department of Health for funding and for providing permission to access the aged care datasets, and to the women who provided the survey data. The authors acknowledge the assistance of the data linkage unit at the Australian Institute of Health and Welfare (AIHW) for undertaking the data linkage to the National Death Index (NDI) and administrative aged care data.

REFERENCES

1. Productivity Commission. *Housing Decisions of Older Australians, Commission Research Paper*. (2015). Available online at: https://www.pc.gov.au/research/completed/housing-decisions-older-australians/housing-decisions-older-australians.pdf (accessed May 20, 2021).
2. Byles JE, Mackenzie L, Redman S, Parkinson L, Leigh L, Curryer C. Supporting housing and neighbourhoods for healthy ageing: findings from the Housing and Independent Living Study (HAIL). *Austr J Age*. (2014) 33:29–35. doi: 10.1111/j.1741-6612.2012.00646.x
3. Bochel C, Bochel H, Page D. Housing: the foundation of community care? *Health Soc Care Commun*. (1999) 7:492–501. doi: 10.1046/j.1365-2524.1999.00216.x
4. Mathew Puthenparambil J, Kröger T, Van Aerschot L. Users of home-care services in a Nordic welfare state under marketisation: the rich, the poor and the sick. *Health Soc Care Commun*. 2015:12245. doi: 10.1111/hsc.12245
5. Roy N, Dubé R, Després C, Freitas A, Légaré F. Choosing between staying at home or moving: a systematic review of factors influencing housing decisions among frail older aduts. *PLoS ONE*. (2018) 13:e0189266. doi: 10.1371/journal.pone.0189266

6. Einiö E, Guilbault C, Martikainen P, Poulain M. Gender differences in care home use among older Finns and Belgians. *Population*. (2012) 67:75–101. doi: 10.3917/popu.1201.0075
7. Faulkner D, Bennett K. *Linkages Among Housing Assistance, Residential (re) Location, and Use of Community Health and Social Care by Old-Old Adults: Shelter and Non-shelter Implications for Housing Policy Development. Final Report*. (2002). Melbourne: Australian Housing and Urban Research Institute (AHURI).
8. Hancock R, Arthur A, Jagger C, Matthews R. The effect of older people's economic resources on care home entry under the United Kingdom's long-term care financing system. *J Gerontol Ser B Psychol Sci Soc Sci*. (2002) 57:S285–93. doi: 10.1093/geronb/57.5.S285
9. Luppa M, Luck T, Weyerer S, König HH, Riedel-Heller SG. Gender differences in predictors of nursing home placement in the elderly: a systematic review. *Int Psychogeriatr*. (2009) 21:1015–25. doi: 10.1017/S1041610209990238
10. McCann M, Grundy E, O'Reilly D. Why is housing tenure associated with a lower risk of admission to a nursing or residential home? Wealth, health and the incentive to keep "my home". *J Epidemiol Commun Health*. (2012) 66:166–9. doi: 10.1136/jech-2011-200315
11. Australian Institute of Health & Welfare. *Residential Aged Care in Australia 2010-11: A Statistical Overview. Aged Care Statistics Series No. 36. Cat. No. Age 68*. (2012). Canberra: AIHW.
12. Jorgensen D, Arksey H, Parsons M, Senior H, Thomas D. Why do older people in New Zealand enter residential care rather than choosing to remain at home, and who makes that decision? *Age Int*. (2009) 34:15–32. doi: 10.1007/s12126-009-9034-7
13. World Health Organization. *World Report on Ageing and Health*. (2015). Available online at: https://www.who.int/ageing/events/world-report-2015-launch/en/ (accessed May 20, 2021).
14. Byles JE, Rahman MM, Princehorn EM, Holliday EG, Leigh L, Loxton D, et al., Successful ageing from old to very old: a longitudinal study of 12,432 women from Australia. *Age Ageing*. (2019) 48:803–10. doi: 10.1093/ageing/afz116
15. Leigh L, Byles JE, Mishra GD. Change in physical function among women as they age: findings from the Australian Longitudinal Study on Women's Health. *Qual Life Res*. (2017) 26:981–91. doi: 10.1007/s11136-016-1422-3
16. Cordier R, Chen YW, Clemson L, Byles J, Mahoney N. Subjective memory complaints and difficulty performing activities of daily living among older women in Australia. *Aust Occup Ther J*. (2019) 66:227–38. doi: 10.1111/1440-1630.12548
17. Statistics ABo. *Census of Population and Housing: Reflecting Australia - Stories From the Census*, Canberra: Australian Bureau of Statistics (ABS), Commonwealth of Australia, (2016).
18. Kendig H, Mealing N, Carr R, Lujic S, Byles J, Jorm L. Assessing patterns of home and community care service use and client profiles in Australia: a cluster analysis approach using linked data. *Health Soc Care Commun*. (2012) 20:375–87. doi: 10.1111/j.1365-2524.2011.01040.x
19. Australian Institute of Health and Welfare. *People Using Aged Care*. (2019). Available online at: https://www.gen-agedcaredata.gov.au/Topics/People-using-aged-care (accessed May 20, 2021).
20. Broad JB, Ashton T, Gott M, McLeod H, Davis PB, Connolly MJ. Likelihood of residential aged care use in later life: a simple approach to estimation with international comparison. *Austr N Zeal J Public Health*. (2015) 39:374–9. doi: 10.1111/1753-6405.12374
21. Forder P, Byles J, Vo K, Curryer C, Loxton D. Cumulative incidence of admission to permanent residential aged care for Australian women—a competing risk analysis. *Aust N Z J Public Health*. (2018) 42:166–71. doi: 10.1111/1753-6405.12713
22. Temple JB, Jukic M, Dow B. Informal care relationships and residential aged care recommendations: evidence from administrative data. *BMC Geriatr*. (2017) 17:289. doi: 10.1186/s12877-017-0656-4
23. Kim MY, Subramaniam P, Flicker L. The Australian aged care and its implications for the Korean aging crisis. *Ann Geriatr Med Res*. (2018) 22:9–19. doi: 10.4235/agmr.2018.22.1.9
24. Rahman M, Efird JT, Kendig H, Byles JE. Patterns of home and community care use among older participants in the Australian Longitudinal Study of Women's Health. *Eur J Age*. (2019) 16:293–303. doi: 10.1007/s10433-018-0495-y
25. Powers J, Ball J, Adamson L, Dobson A. Effectiveness of the National Death Index for establishing the vital status of older women in the Australian Longitudinal Study on Women's Health. *Aust N Z J Public Health*. (2000) 24:526–8. doi: 10.1111/j.1467-842X.2000.tb00504.x
26. Byles J, Curryer C, Vo K, Forder P, Loxton D, McLaughlin D. Changes in housing among older women: latent class analysis of housing patterns in older Australian women. *Urban Studies*. (2016) 55:917–34. doi: 10.1177/00420980166 61309
27. Rahman M, Efird JT, Byles JE. Patterns of aged care use among older Australian women: a prospective cohort study using linked data. *Arch Gerontol Geriatr*. (2019) 81:39–47. doi: 10.1016/j.archger.2018.11.010
28. Rahman MM, Efird JT, Byles JE. Transitioning of older Australian women into and through the long-term care system: a cohort study using linked data. *BMC Geriatr*. (2019) 19:286. doi: 10.1186/s12877-019-1291-z
29. Rahman MM, Byles JE. Older women's patterns of home and community care use and transition to residential aged care: an Australian cohort study. *Maturitas*. (2020) 131:28–33. doi: 10.1016/j.maturitas.2019.10.004
30. Rahman MM, Byles JE. Trajectories of long-term residential care needs among older australian women: a cohort study using linked data. *J Am Med Dir Assoc*. (2019) 21:786–92.e2. doi: 10.1016/j.jamda.2019.08.019
31. Yu S, Byles J. Waiting times in aged care: what matters? *Australas J Ageing*. (2020) 39:48–55. doi: 10.1111/ajag.12665
32. Productivity Commission. *Report on Government Services 2018, Part F, Chapter 14*. (2018). Available online at: https://www.pc.gov.au/research/ongoing/report-on-government-services/2018/community-services/aged-care-services/rogs-2018-partf-chapter14.pdf (accessed May 20, 2021).
33. Karmel R, Anderson P, Gibson D, Peut A, Duckett S, Wells Y. Empirical aspects of record linkage across multiple data sets using statistical linkage keys: the experience of the PIAC cohort study. *BMC Health Services Res*. (2010) 10:41. doi: 10.1186/1472-6963-10-41
34. Brilleman SL, Pachana NA, Dobson AJ. The impact of attrition on the representativeness of cohort studies of older people. *BMC Medical Res Methodol*. (2010) 10:71. doi: 10.1186/1471-2288-10-71
35. Bridge C, Phibbs P, Kendig H, Mathews M, Cooper, B. *Home Ownership Reduces the Cost of Home-Based Care Among Old Adults*. AHURI Research and Policy Bulletin No. 132. Melbourne, VIC: Australian Housing and Urban Research Institute Limited (2010). AVAilable online at: https://www.ahuri.edu.au/research/research-and-policy-bulletins/132
36. Australian Institute of Health and Welfare. *Patterns in Use of Aged Care: 2002-03 to 2010-11, in Data Linkage Series 18*. (2014). AIHW: Canberra.
37. Faulkner D, Bennett K. *Linkages Between Housing Assistance, Residential (re)location, and Use of Community Health and Social Care by Old-Old Adults: Shelter and Non-Shelter Implications for Housing Policy Development*. Melbourne: Australian Housing and Urban Research Institute, Southern Research Centre. (2002).
38. Jorgensen M, Siette J, Georgiou A, Warland A, Westbrook J. Modeling the association between home care service use and entry into residential aged care: a cohort study using routinely collected data. *J Am Med Dir Assoc*. (2018) 19:117–21.e3. doi: 10.1016/j.jamda.2017.08.004
39. The Royal Commission into Aged Care Quality and Safety. *Background Paper 2 - Medium- and Long-Term Pressures on the System: The Changing Demographics and Dynamics of Aged Care*. (2019). Available online at: https://agedcare.royalcommission.gov.au/publications/background-paper-2-medium-and-long-term-pressures-system-changing-demographics-and-dynamics-aged-care (accessed May 20, 2021).
40. Meinow B, Wastesson JW, Kåreholt I, Kelfve S. Long-term care use during the last 2 years of life in Sweden: implications for policy to address increased population aging. *J Am Medical Directors Assoc*. (2020) 2020:3. doi: 10.1016/j.jamda.2020.01.003
41. Lagergren M, Kurube N, Saito Y. Future costs of long-term care in Japan and Sweden. *Int J Health Services*. (2017) 48:128–47. doi: 10.1177/0020731417727450
42. Australian Institute of Health and Welfare. *Pathways to Permanent Residential Aged Care in Australia: A Pathways in Aged Care (PIAC) Analysis Of People's Aged Care Program Use Before First Entry to Permanent Residential*

Aged Care in 2013–14. Cat. no. AGE 81. Canberra: AIHW. (2017). Available online at: https://www.aihw.gov.au/getmedia/71d37559-36f7-4274-9417-83977cb6e4f6/21233.pdf.aspx?inline=true (accessed May 20, 2021).
43. Visvanathan R, Amare AT, Wesselingh S, Hearn R, McKechnie S, Mussared J, et al., Prolonged wait time prior to entry to home care packages increases the risk of mortality and transition to permanent residential aged care services: findings from the registry of older South Australians (ROSA). *J Nutr Health Aging*. (2019) 23:271–80. doi: 10.1007/s12603-018-1145-y
44. Centre of Excellence in Population Ageing Research. *Housing in an Ageing Australia: Nest and Nest Egg?* CEPAR. (2019). Available online at: http://cepar.edu.au/sites/default/files/cepar-research-brief-housing-ageing-australia.pdf (accessed May 20, 2021).
45. Dijck-Heinen CJMLv, Wouters EJM, Janssen BM, Hoof Jv. A sense of home through the eyes of nursing home residents. *Int J Innov Res Sci Technol*. (2014) 1:57–69.
46. Dow B, Gibson D, Byles J. 'Current state of aged care in Australia' (English language version). *Glob Soc Security Rev*. (2018) 7:25–35.
47. Nous Group. *Wellness and Reablement: A Summary of Consultations Across the Home Care Sector. Report to the Department of Health*. (2017). Available online at: (accessed May 20, 2021).
48. Tune D. *Legislated Review of Aged Care, Commonwealth of Australia*. Department of Health (2017). Available online at: (accessed May 20, 2021).
49. Productivity Commission. *Caring for Older Australians: Overview, Report No. 53, Final Inquiry Report*. Canberra. (2011). Available online at: https://www.pc.gov.au/inquiries/completed/aged-care/report/aged-care-overview-booklet.pdf (accessed May 20, 2021).
50. Australian Association of Gerontology. *Connecting Research, Policy and Practice When Adopting a Reablement Approach. Report on a workshop held November 2017 with AAGs Collaborating Research Centres at Crown Convention Centre Perth*. (2017). Available online at: https://www.aag.asn.au/documents/item/2181 (accessed May 20, 2021).
51. Palliative Care Australia. *Palliative Care in Aged Care*. (2018). Available online at: https://palliativecare.org.au/palliative-care-in-aged-care (accessed May 20, 2021).
52. Royal Commission. *Royal Commission into Aged Care Quality and Safety, Final Report: Care, Dignity and Respect*. Canberra: Royal Commission into Aged Care Quality and Safety, Commonwealth of Australia, (2021).
53. Australian Institute of Health and Welfare. *Older Australia at a Glance*. (2018). Available online at: https://www.aihw.gov.au/reports/older-people/older-australia-at-a-glance (accessed May 20, 2021).
54. Umberson D, Chen MD, House JS, Hopkins K, Slaten E. The effect of social relationships on psychological well-being: are men and women really so different? *Am Sociol Rev*. (1996) 1996:837–57. doi: 10.2307/2096456
55. Russell D, Taylor J. Living alone and depressive symptoms: the influence of gender, physical disability, and social support among Hispanic and non-Hispanic older adults. *J Gerontol Soc Sci*. (2009) 64B:95–104. doi: 10.1093/geronb/gbn002
56. Greenfield EA, Russell D. Identifying living arrangements that heighten risk for loneliness in later life: evidence from the U.S national social life, health and aging project. *J Appl Gerontol*. (2011) 30:524–34. doi: 10.1177/0733464810364985
57. Victor C, Scambler S, Bond J, Bowling A. Loneliness in later life: preliminary findings from the Growing Older project. *Quality Ageing Older Adults*. (2002) 3:34–41. doi: 10.1108/14717794200200006
58. Byles J, Vo K, Thomas L, Mackenzie L, Kendig H. Partner status and mental and physical health of independently living men aged 70 years and older. *Australas J Ageing*. (2016) 35:143–6. doi: 10.1111/ajag.12234
59. Khadka J, Lang C, Ratcliffe J, Corlis M, Wesselingh S, Whitehead C, et al., Trends in the utilisation of aged care services in Australia, 2008–2016. *BMC Geriatr*. (2019) 19:213. doi: 10.1186/s12877-019-1209-9
60. Gordon EH, Hubbard RE. Differences in frailty in older men and women. *Med J Aust*. (2020) 212:183–8. doi: 10.5694/mja2.50466
61. Brown AJ. Older men and community aged care: barriers to access and effective models of care. *Innov Aging*. (2017) 1(Suppl.1):1033–4. doi: 10.1093/geroni/igx004.3766

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

BRIEF RESEARCH REPORT
published: 23 June 2021
doi: 10.3389/fpubh.2021.589589

Developing the Art–Technology Intergenerational Community Program for Older Adults' Health and Social Connectedness

Jinsil Hwaryoung Seo[1]*, *Annie Sungkajun*[2] *and Brittany Garcia*[1]

[1] Soft Interaction Lab, Department of Visualization, Texas A&M University, College Station, TX, United States, [2] Creative Technologies/Graphic Design Department, Illinois State University, Normal, IL, United States

As the older adult population increases, research investigating how to support their health and well-being has become more urgent. This paper discusses the development of the art–technology intergenerational community (ATIC) program for older adults in Bryan and College Station, Texas. The program's purpose was to help improve older adult's health, well-being, and social connectedness. During the program, participants attended four sessions across 4 weeks, creating interactive art projects such as light-up cards, pop-up cards with light, interactive light painting, and interactive soft circuit ornaments. Preliminary studies allowed researchers to refine making materials by designing easy-to-follow fabricated circuit templates. Participants were able to create interactive art by using various materials such as light-emitting diodes (LEDs), copper tape, coin-cell batteries, and conductive thread. A total of 18 participants aged 60–83 participated in the ATIC program. Participants were asked to complete pre- and post-study questionnaires which assessed older adults' subjective health or well-being, feelings of intergenerational connectedness, and attitude about art and technology. Video data were captured for qualitative analysis on the art creation process, cognitive health, and social connectedness of the participants. Our findings show that those who participated in the ATIC program had improved perceptions of their own health and intergenerational relationships. There were also significant differences between pre- and post-study conditions for positive and negative affect. Qualitative results showed that the program participants were engaged in the art-making process and that creations helped to support intergenerational relationships with the student volunteers as well as their own family members.

Keywords: older adults, art, health, well-being, social connectedness

OPEN ACCESS

Edited by:
Anna Patricia Lane, Singapore University of Technology and Design, Singapore

Reviewed by:
Yuezhong Liu, Nanyang Technological University, Singapore
Caitlin McArthur, Dalhousie University, Canada

***Correspondence:**
Jinsil Hwaryoung Seo
hwaryoung@tamu.edu

Specialty section:
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

Received: *31 July 2020*
Accepted: *29 March 2021*
Published: *23 June 2021*

Citation:
Seo JH, Sungkajun A and Garcia B (2021) Developing the Art–Technology Intergenerational Community Program for Older Adults' Health and Social Connectedness. Front. Public Health 9:589589. doi: 10.3389/fpubh.2021.589589

INTRODUCTION

The health and well-being of older adults have become more important because the older adult population is growing rapidly. In 2016, 49 million people, 14.5% of the US population, were aged 65 or older, and the number is projected to climb to about 98 million (25%) by 2060 (1). As a result, the United States faces growing challenges and issues in terms of older adults' healthy aging. Much effort on research and many practical services were put in place to support that (2).

One of the collective efforts is providing art-based older adult programs. Research has shown that creative practices including dance, creative writing, music, theater, and visual arts have positive impacts on improving health, well-being, and independence of older adults (3–9). Participating in community art programs is an effective way of promoting social interaction and psychological well-being (10, 11). Creative activities for older adults have been considered to be relatively low cost and can be made easily available to seniors throughout many local facilities (12).

Most recently, interactive art and crafts, making, and coding have been introduced to the older adult population (9, 13–15). These activities contribute toward the interactive experience with artwork. In addition, there is a growing number of artists and researchers who have focused on the educational relevance of these activities as well as health-related potentials (16–18). Interactive art is a form of art that involves various levels of participant's sensory engagement with the artwork (7, 19). Some interactive arts suggest that participants' active input to finish the works allows them to become part of the artwork themselves, which in turn may stimulate older adults' cognitive functions. Coding and making activities have been popular in younger community groups (i.e., under 25). These making activities involve learning interactive concepts, figuring out functionalities, and implementing art forms that can have a significant impact on how people think and feel. These activities allow creative expression through an algorithmic thinking process (20). Through the coding and making processes, we can help older adults to set a "can-do" mindset (20) that encourages them to act and to take control of their lives.

Healthy aging is not an individual older adult's problem to take care of; it requires family and community-based support. Families provide foundational affective bonds and share responsibilities, such as caregiving and intergenerational transfers of knowledge and wealth. Research indicates that there are positive correlations between intergenerational or familial support and subjective well-being and mental health among older adults (21–23). However, more than one-third of adults aged 45 and older feel lonely, and nearly one-fourth of adults aged 65 and older are considered to be socially isolated in the United States (24). The risk of social isolation and loneliness has increased because it is closely related to living alone, the loss of family or friends, chronic illness, and hearing loss (25, 26). Therefore, a community-based effort for supporting intergenerational relationships and social interaction is critical.

We drew inspiration from the potential opportunities of interactive art and craft practice and started a small art workshop in the cities of Bryan and College Station, Texas. As more older adults showed interests and participated in our events, our program became a regular weekly program at multiple locations. In the early workshops, we introduced interactive art and craft technology to participating older adults in local assisted living and nursing homes. Participants integrated a paper-based electronic circuit into various art forms (e.g., painting, drawing, and sewing) and created interactive art. From preliminary studies, we learned that such programs could hold great potential to engage older adults and significantly improve their daily lives (9, 27). We also learned that technical support for this kind of program is critical because if materials are not accessible, participants will not produce meaningful experiences. Therefore, we adjusted materials and developed paper templates focusing on usability. In addition, we actively invited college students to assist and work with older adults in our workshops. This way, participants were able to overcome technical barriers and created what they wanted with the assistance of the students. This became a framework of our program and led to the present study. This article examines how participating in the art–technology intergenerational community (ATIC) program may impact an individual older adult's health, well-being, and social connectedness.

BACKGROUND

We find the foundation of our practice from Erikson's psychosocial human development theory and continuity theory. Art activities are known for supporting older adults who have difficulties expressing themselves and can enhance individuation, which is important to well-being in older adults (28). According to art therapists, supporting and encouraging making art is effective when working with older adults. Studies with older adults and art have centered around dementia, restricted ability to communicate, and lifelong mental illness. Art therapy is most effective when older adults understand what is considered healthy and adaptive during the life stage they are in (29). Cohen et al. (30) conducted a study with older adults in art programs investigating emotional and health benefits; results showed that participants improved both emotionally and physically. Erikson's theory of psychosocial human development addresses adult development, specifically the need to seek ego integrity. In each developmental stage, a person has conflict that they must overcome to move to the next stage. The final stage is when individuals realize that their life has had meaning despite failures, and they feel a need to share this wisdom with others. Through this, the older individual will feel a sense of connection with younger generations. Chapin Stephenson stated that by participating in art activities, older adults stay involved, connected, and exhilarated (29).

Like Erikson's psychosocial human development theory, continuity theory focuses on an individual's ability to link things from the past to changes in their future. With regard to older adults, the premise of continuity theory is that adaptation to change is done by using strategies to maintain continuity in their lives, both internal and external. Internal continuity refers to the forming of personal links between new experiences and previous ones, and external continuity refers to interacting with familiar people and living in familiar environments (31). Art allows older adults to maintain continuity by providing a visual link for them to explore past and present experiences (32). These theories guide us to develop the ATIC program that focuses on participants' perspective health and connecting with younger generation through art activities.

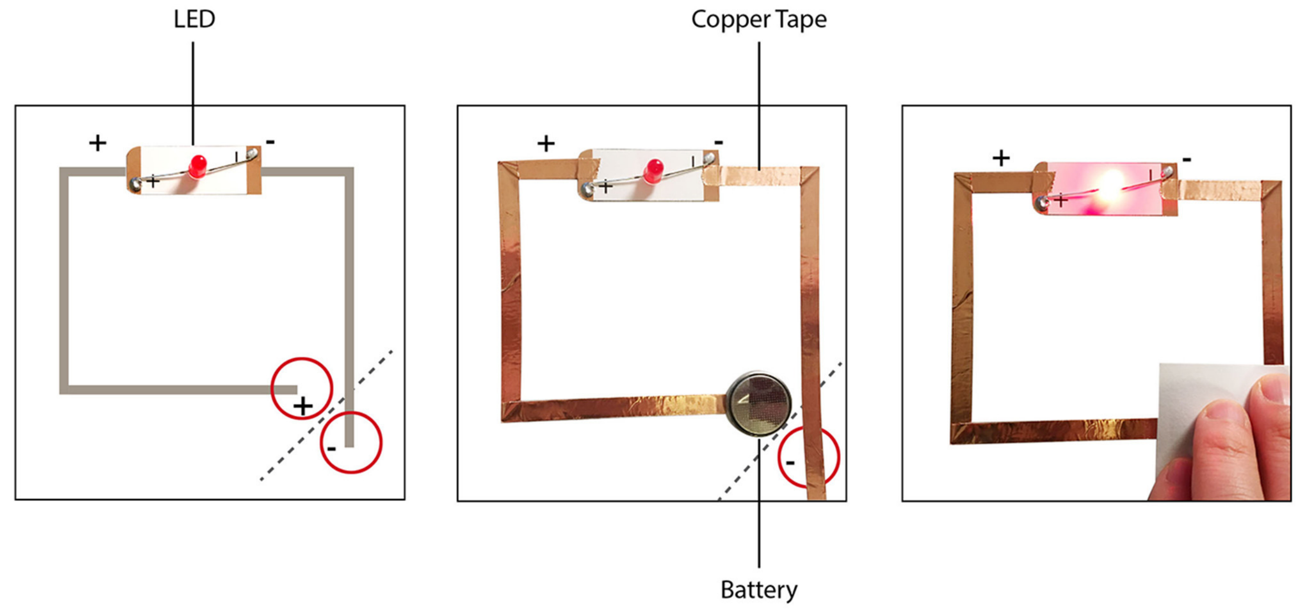


FIGURE 1 | Paper circuit template.

MATERIAL: THE ATIC PROGRAM

The ATIC program consists of four sessions over the span of 4 weeks, with each session taking 1 h. The program focuses on encouraging participants to engage in art and technology creations with undergraduate volunteers. Each week, participants worked on a new project, gaining an understanding on how interactive techniques can be utilized in their art. The workshop includes four activities: *light-up cards*, *pop-up cards with light*, *interactive light painting*, and *interactive soft circuit ornaments*. The activities incorporated basic forms of art, such as painting, drawing, paper folding, and sewing. In the workshop, participants work very closely with undergraduate volunteers who work as assistants and collaborators in each session. Workshop participants shared their hobbies, moments in their lives, and personal interests.

Custom Materials Development

Through previous studies conducted, we learned how difficult it was for older adults to handle small electronics, as well as hesitant to handle them. Despite the parts being very simple and not enough to cause harm, the question "Will I get shocked?" was still commonplace. In order not only to make these parts accessible but also to make the participants feel comfortable, we chose to fabricate our own paper circuit template for light-emitting diodes (LEDs) using cardstock paper (**Figure 1**).

These templates allowed participants to know where to place the LEDs, based on their position, and also helped to match the positive and negative sides so as to avoid error. Lines indicated where to place the copper tape, while a circle helped to show where to place the coin-cell batteries provided. On the corners of the templates, a dashed line showed participants where to fold, in order to create the interaction, creating a connection point between the copper tapes to the battery (**Figure 1**).

Four Curated Activity Sessions

Activity 1: Light-Up Cards

Materials: LEDs, paper, copper tape, coin-cell battery

After participants filled out the pre-study questionnaire, we introduced creating light-up cards. A simple fold connection was utilized so that it could act as a "switch" to turn the light on, while also preserving the battery power. The circuitry portion of the cards was then placed into folded pieces of paper, so that the light would be able to shine through and allow them to create their art, while incorporating the light into their designs. Due to the card's free form, participants were creative with their design choices, ranging from utilizing the lights as noses for drawn dogs or to light up a drawn emergency vehicle in a get well soon card for a family member (**Figure 2**). At the end of the session, participants presented their works and commented on each other's card.

Activity 2: Pop-Up Cards With Light

Materials: LEDs, paper, copper tape, coin-cell battery

For the second week of our program, we chose to continue a similar circuit procedure, incorporating the art of kirigami (the cutting and folding of paper) in order to create pop-up designs. Simple pop-up templates, such as circles and butterflies, were provided to give them a base for their design. However, they were also free to create their own and explore other options after they finished a template. Participants had to make decisions on how to incorporate their chosen color of light into their design. The light within the pop-up card acted as a backlit glow for their designs. Most of the participants remembered the use of copper tape and which way the LED

FIGURE 2 | Light-up cards and pop-up cards created by participants.

and battery should face. The template designs (butterflies, hearts, and a simple circle) guided participants' final pop-up cards. The butterfly design allowed them to either reference real butterfly wing designs or to create their own. The heart design was often used to show sentiments of love for family and friends (**Figure 2**).

Activity 3: Interactive Light Painting

Materials: LEDs, watercolor paint, copper tape, coin-cell battery, paper

The third activity was to create watercolor paintings that incorporated the same simple light circuits they have learned. Participants were welcome to be experimental with their circuitry or use pre-made circuit diagrams with sample designs they could paint. Sample designs included dandelions to rainbows. A live demonstration was shown to explain the process of water coloring to those who had no prior experience. Participants who were experienced painters helped and gave advice to beginners, showing unique techniques such as "watercolor splattering," a process to create splashes of dotted color randomly across the page. Most participants experimented with painting certain areas, whereas some chose to begin with the background. **Figure 3** includes some light-up paintings done by the workshop participants.

Activity 4: Interactive Soft Circuit Ornament

Materials: Felt, conductive thread, thread, coin-cell battery, LEDs, battery pack

In our last activity, we introduced the participants to a sewing project where they created soft, light-up objects out of felt. In the prior activities, they used copper tape as connection points between their LEDs and the battery. For this soft circuit, we introduced conductive threads in order to sew the connections between the LEDs and the provided battery packs. The materials provided for this activity were pre-cut fabric objects, using a laser cutter, that included shapes such as flowers, birds, a child, dogs, and cats. We also provided base shapes such as rectangles and circles that allowed participants to be creative for the usability of the artwork. Some saw that the rectangular-shaped bases could be effective as light-up bookmarks, while another participant thought to create a wristband for their daughter. Most participants used the light to illuminate specific objects they had sewn into their base, such as flowers, or in order to illustrate a scene that they had created (**Figure 3**).

FIGURE 3 | Light-up paintings and soft ornaments created by participants.

METHODS

The goal of our work is to understand how community activities involving art and technology with older adults and undergraduate students could improve older adults' subjective health or well-being and social connectedness.

Study Description

Our study consisted of a pre-study questionnaire, four workshop sessions (ATIC program), and a post-study questionnaire. The workshops were held at two locations: the Art Council of Brazos Valley and Southwood Community Center in College Station, Texas. Each workshop session was an hour long and consisted of a short briefing on the art topic, a Q&A period, and then the art activity itself. Data from these sessions were gathered via video recording and questionnaire. Each session was recorded so that dialogue and actions could be coded objectively. Questionnaires were given out twice, once at the very beginning of the study and once at the very end of the 4 weeks. The intent for these types of data collection was to record the baseline, the process, and the outcome. The questionnaire includes questions about older adults' subjective health or well-being, their feeling of intergenerational connectedness, and their attitude about art and technology. Questions were collected from standard measures including self-reported health, positive and negative affect, art and technology interest, self-efficacy, and intergenerational relationships. We composed several standard questions using associate scales (33–36).

Program Participants

We recruited older adults, aged 60 and up, who had not been diagnosed with any age-related mental illnesses and who lived independently and did not require any form of third-party caregiver. Recruitments were conducted through the Texas A&M mailing list for retired faculty and staff. In addition, participants were able to register for the program at the workshop venues. Because the ATIC program requires a small group setting to provide individual support and active participation, we recruited 8–10 participants per workshop. Eighteen participants (15 females and three males, aged 60–83) who finished at least three sessions were included in the study data.

In the ATIC program, undergraduate volunteers took critical roles as a workshop assistant, team member, collaborator, and younger friend. They particularly supported one-on-one communication and social engagement. Nine students participated in the program: four students from the art department and five students from different departments (psychology, biomedical science, and chemistry). All of them were interested in either working with older adults or making pieces of art. Some students utilized this opportunity for developing social interaction skills for their future career.

Data Collection and Analysis

We collected both quantitative and qualitative data to measure how art and technology activities could improve participants' subjective health or well-being and social connectedness. The questionnaire included questions from standardized psychological measures for self-reported health, mood, perceived control, functional health, well-being, art interest, and technology self-efficacy. We compared pre- and post-responses on measures at time 1 (before the intervention) to time 2 (after the intervention).

We utilized a self-reported health measure to assess perceptions of current health. Participants responded to questions such as "How would you rate your health at the present time" and "How much do health problems limit your daily activities"; questions were scaled on a 5-point Likert scale. To assess older adults' sense of control, participants responded to three statements taken from a standard six-item measure of confidence (34). Participants were asked on a scale of 1 (strongly agree) to 5 (strongly disagree) to indicate their level of agreement with statements such as "I can do just about anything I set my mind to," "If I want something, I go out and get it," and "I am a go-getter." To assess older adults' sense of overall well-being, participants completed the Subjective Well-being Scale [SWLS; (35)]. The scale consists of five items examining how satisfied the individual is with his or her life, with response options on a 7-point scale (ranging from strongly disagree to strongly agree), for a total positive score of 30. Older adults' interest in art was assessed by using a single-item question (e.g., "How likely would you be to engage in other art/technology workshops") to be answered on a Likert scale from 1 (very unlikely) to 5 (very likely). Older adults' confidence in their ability to use technology was assessed by using a single-item question (e.g., "I am confident with my ability to learn and use technology") to be answered on a Likert scale from 1 (strongly disagree) to 5 (strongly agree). To assess older adults' sense of intergenerational connectedness, participants completed a questionnaire from the Family Exchange Study (36) designed to assess support given, support received, and family support beliefs.

Finally, to assess current mood, participants completed a measure of positive and negative affect [Positive and Negative Affect Schedule (PANAS); (33)], in which participants were asked to rate the extent to which 20 different adjectives (10 positive and 10 negative) describe how they are feeling at the current time, using a 5-point scale (1 = not at all; 5 = extremely). The positive affect words were *interested*, *cheerful*, *energetic*, *excited*, *inspired*, *strong*, *confident*, *loved*, and *enthusiastic*, and the negative affect words were *distressed*, *incapable*, *miserable*, *nervous*, *scared*, *hostile*, *dissatisfied*, *irritable*, *pathetic*, and *afraid*. For analysis, pre- and post- study questionnaire data were entered into a spreadsheet, and a statistical analysis program, SPSS, was used to run paired-sample *t*-tests. The positive and negative affect words were scored and averaged from participant scores for the words.

The qualitative data were generated by asking pre-prepared open-ended questions during the workshop sessions. A total of 17 h of video recordings were collected. The videos were coded using the MAXQDA qualitative analysis application. A team of researchers conducted open coding as a first step for video analysis by focusing on individual participant speaker turns with other participants. A speaker turn was defined as consisting of a discourse excerpt (one or more conversational turns). The team met again and discussed arising categories such as the art process, participant health or well-being, and social connectedness. Researchers had multiple rounds of meetings to determine a proper coding scheme. From these discussions, researchers agreed upon three overarching codes: the *art creation process* was to note the process each participant went through when creating their art, *cognitive health* was to analyze the participants' mental well-being, and *social connectedness* was the moments where participants were making social connections to other participants and researchers.

RESULTS AND DISCUSSION

Participants' Backgrounds and Interests

This paper discusses the ATIC program for older adults; the purpose is to help improve older adult's health, well-being, and social connectedness. For this study, previous art experience was not required, but 12 participants had art-related hobbies including painting, sewing, crafting, silk screening, weaving, gardening, and jewelry making. There were six participants who did not have much experience with being artistic, but they wanted to try in the workshop. However, these participants still had the mindset that they were not good at making art. They often said, "I am bad at painting" (S19-06) and "I'm a horrible drawer" (S19-19).

Many participants decided to participate in the ATIC program to make art and meet other people. Participant *S19-03* commented, "I just want to take some art and meet some people too!" Similar notions were shared by *S19-02*, "I wanted to try something new." Some also participated in the workshop to connect with their grandchildren who study art, such as S19-28.

Quantitative Results

Paired-sample *t*-tests were conducted using SPSS to analyze the data collected, which can be found in **Table 1**.

Qualitative Results

From the qualitative analysis process, we categorized codes into three areas: *art creation process*, *cognitive health*, and *social connectedness*. The following presents themes that emerged from the workshop programs' video data.

TABLE 1 | Quantitative *t*-test results.

		Mean	SD	*t*	*df*	*p*
Subjective health	Pre	4.08	0.73	−4.014	17	0.001
	Post	4.56	0.59			
Self-efficacy	Pre	5.84	0.80	−2.22	17	0.04
	Post	6.04	0.69			
Positive affect	Pre	3.83	0.65	−2.70	18	0.015
	Post	4.03	0.67			
Negative affect	Pre	1.19	0.24	2.695	17	0.015
	Post	1.08	0.176			
Intergenerational connectedness	Pre	5.78	1.00	−2.72	17	0.015
	Post	6.17	0.71			

Art Creation Process

The workshop participants were very active in the process of art making. They followed the instructions very well and supported each other by providing feedback, helping in design choices, and sharing materials. Participants also supported each other to make more interesting or polished works.

Making Artworks for Loved Ones

Many participants used the workshop as an opportunity to create something for their loved ones: family members and close friends. In the process of making, participants often shared stories about the person who they were making the art for to others in the workshop.

> "Today is my daughter's birthday. She has two cats. So I made a card from the cats. She will love it." (S19-20)
> "My friend got a big surgery recently. I want to make a card for her." (S19-23)

Providing Feedback on Experimentation and Iteration

The art creation processes became experimental and iterative. Participants tried different colors and materials, seeking other participants' and student volunteers' opinions about their artwork. Participants started with suggesting colors and simple ideas while actively participating in brainstorming ideas and finding complex solutions for electronic circuits with other participants and student volunteers.

> "Where are you going to put the light" (S03) "I thought it was gonna like go in the middle and light up the whole thing but ... I could put the light under like that tree? Like right there. I don't know, maybe. I don't know, I don't think it matters." (S19-01)
> "You can always move it around and then tape it down where you like it." (S03) "Oh okay!" (S19-01)
> "I'm just not seeing the butterflies maybe we just need to come up with something else." (S19-14) "Butterflies will be great. What about this design?" (S05) "Oh, I like that." (S19-14)

Sharing Personal Knowledge and Skills

Some experienced participants actively helped other participants who had never done any art projects before. During the painting and sewing sessions, skilled participants were able to display their knowledge and skills, which were transferred among the group.

> "So the trick about working with watercolor is having a blow dryer because you really need to get it dry before you move on. This is not my first time" (S19-33)
> "Oh I lost my thread." (S19-07) "You can tie a thread about the needle." (S19-03)

Cognitive Health

The workshop program created positive impacts on participants' cognitive health. Even though all our participants were healthy and independently living, their participation in the art program made them more active and engaged with various cognitive processes.

Creativity

The workshop program was designed to evoke creativity in older adults. Participants thought technology-based art making was very thought provoking and unique. Their projects started from examples and templates, but participants integrated their personal stories and experiences into the projects.

> "You know, I never thought about putting those kinds of things together. That's just, wow! That's interesting." (S19-07)

Keeping Their Mind Active

The electronic circuit component made participants intellectually engaged. To create their work, participants had to remember the positive and negative sides of an LED and move their circuit around their works (i.e., painting, card, and soft ornament). This process could be cognitively demanding and improve one's thinking ability.

> "What I'm gonna do is I'm gonna put my light here and I'm going to put my positive side right there and I'm gonna run my thread right there." (S19-23)
> "Can I make this side negative? How can I connect it to negative? ... Okay that just made my life a bit easier." (S19-33)

Excitement and Happiness

Maintaining a good mood enhances cognitive function in older adults. Happiness and mood could support the quality of life of older adults (37). Throughout the workshop program, there were lots of laughs and many excitements expressed by the participants and student volunteers.

> "That's what I miss about work is all the laughter you know? We just laugh so much." (S19-31)
> "Hah! My light works!" (S19-05) "Oh it looks good! I like it." (S19-08)

Social Connectedness

Participating in social activities has been suggested to lower the risk of some health problems and improve well-being (38). In the ATIC program, participants were connected with other older adults and volunteer students (**Figure 4**).

FIGURE 4 | Participants working collaboratively in the ATIC program.

Sharing Personal Stories

Through multiple sessions of the workshop, participants became close and shared personal stories about themselves, family members, and friends with other participants, researchers, and student volunteers.

> "My hobbies are embroidery, I recently won a contest by embroidering a denim jacket." (S19-01)
> "Today I have to leave early because I have to go to my friend's wedding. He is 92 years old. This is a special wedding for a 92 year old man." (S19-02)

Planning Beyond the Workshop

We found that while participants worked together, developing social networks continued after the workshop.

> "We're gonna have to find some other class we can take together" (S19-21) "No kidding y'all I was just thinking that. I would like to get all y'all's emails." (S19-24) "A family reunion, a class reunion." (S19-24).

Intergenerational Relationship

Workshop participants reported that they usually communicate with their children or grandchildren via text message, FaceTime, or Skype. They sometimes send them birthday cards. In the beginning of the workshop, their perception about new technology around younger generations was negative, because they thought technology did not support more face-to-face relationships in society.

The workshop program led participants to reconnect with their children or grandchildren via their art creations.

> "I have a granddaughter that's 12 and she just loves to make her own cards and she does very complicated and they're folded. I would like to show her what I made here." (S19-14)

Something unique about this program is that undergraduate students participated in the workshop with older adults. Student volunteers worked as workshop assistants as well as collaborators. In the beginning of the workshop, they talked only about workshop projects and materials.

> "Would you help me find images of butterflies?" (S19-02)

"How can we draw an ambulance?" (S19-05)

In the later sessions, the workshop became an intergenerational art club to share many things: university life, career, job search, favorite movies, favorite books, hobbies, and so on.

DISCUSSION AND CONCLUSION

We created an intergenerational program for older adults that involves art- and technology-based activities, called ATIC. In the ATIC program, older adults created personalized greeting cards, pop-up cards, paintings, and soft ornaments using custom-designed paper-circuit templates. This program was supported by college student volunteers who worked as workshop assistants and collaborators. Quantitative results revealed that there were significant differences in the scores (subjective health, self-efficacy, and participants' perception about the younger generation) between pre- and post-study conditions. When comparing pre- and post-study results for subjective health, they showed an increase; these results coincide with the results of those participating in art therapy and art education in that improved cognition is observed in older adults by providing a dynamic learning opportunity for them to engage their cognitive motor and social abilities (39). Results from pre- and post-study self-efficacy scores also show significant differences as well; therefore, by participating in the ATIC program, older adults' self-efficacy increased. This is similar to other studies investigating older adults and self-efficacy while attending art therapy or art workshops (39). Positive affect showed significant pre- and post-study results; however, the scores for negative affect significantly decreased. These two findings support the notion that by participating in the ATIC program, older adults have the possibility to improve positive affect while decreasing negative affect (40). In terms of the participants' perception about the younger generation, their views also improved, meaning that the older adults' views on the younger generation went from a negative outlook to positive. By working with undergraduate volunteers, the older adults were able to share experiences while creating art. This kind of stimulation, which is in line with Erikson's theory (29), allows older adults to reflect on their past and share these memories with the undergraduate workers, in turn causing their views of different generations to change.

These findings were also supported by qualitative results. The participants were very engaged in the ATIC art-making process. Their creations reflected their love to strengthen existing relationships with younger generations. Participants became more connected to their children and grandchildren, extended family, and close friends and expanded their relationships to the student volunteers. The workshop participants shared their knowledge and life experiences with volunteer students and others, creating a support system among the participants. Participants utilized various art supplies that were provided, which helped to enhance their ability for creativity. Findings such as these are common among other art studies such as Cantu and Fleuriet (41), which showed that art creation in art programs can promote well-being.

Overall, the ATIC program was effective in improving subjective health and social/intergenerational connectedness in older adults. This program could be modularized and disseminated to other community facilities including art centers, senior community centers, and assisted living homes to support older adults' health and social connectedness. After the study was ended, our team shared all workshop materials on our website (http://softinteraction.com/) and continued to support local community programs. Activity directors at local programs for older adults have access to them and can integrate the program into their activity programs. Our team will make sure materials are updated and be easily accessible by program directors. We will also visit the local community center once a month and invite student volunteers to engage with older adults.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Texas A&M University. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

JS is the PI in this research and contributed to design/run the workshop program, data collection, data analysis, and write the final report. AS contributed to prepare/fabricate workshop materials and run the workshop, and write the final report. BG contributed for quantitative and qualitative data analyses and editing the final report. All authors contributed to the article and approved the submitted version.

FUNDING

The work was funded by Research Grant #16-968162, in the Art Program from NEA (National Endowment for the Arts).

ACKNOWLEDGMENTS

The authors would like to thank the National Endowment for the Arts and Department of Visualization at Texas A&M University.

REFERENCES

1. CDC. *Promoting Health for Older Adults: CDC Works to Help Older Adults Remain Active and Independents as Long as Possible.* (2019). Retrieved from: https://www.cdc.gov/chronicdisease/resources/publications/factsheets/promoting-health-for-older-adults.htm (accessed July 01, 2020).
2. Siegler EL, Lama SD, Knight MG, Laureano E, Reid MC. Community-based supports and services for older adults: a primer

for clinicians. *J Geriatr.* (2015) 2015:1–6. doi: 10.1155/2015/678625
3. Abraham R. *When Words Have Lost Their Meaning: Alzheimer's Patients Communicate Through Art*. Westport, CT: Praeger Publishers/Greenwood Publishing Group (2005).
4. Kerr C. The psychosocial significance of creativity in the elderly. *Art Therapy.* (1999) 16:37–41. doi: 10.1080/07421656.1999.10759349
5. Orr P. Treating the whole person: a combination of medical and psychiatric treatment for older adults. *Art Therapy.* (1997) 14:200–5. doi: 10.1080/07421656.1987.10759282
6. Ravid-Horesh RH. A temporary guest: the use of art therapy in life review with an elderly woman. *Arts Psychother.* (2004) 31:303–19. doi: 10.1016/j.aip.2004.07.001
7. Sezaki S, Bloomgarden J. Home-based art therapy for older adults. *Art Therapy.* (2000) 17:283–90. doi: 10.1080/07421656.2000.10129756
8. Stewart EG. Art therapy and neuroscience blend: working with patients who have dementia. *Art Therapy.* (2004) 21:148–55. doi: 10.1080/07421656.2004.10129499
9. Seo JH, Geraci L, Sanchez T. Exploring the impact of creative expression through interactive art making on older adults' well-being. *Dig Creat.* (2016) 27:358–68. doi: 10.1080/14626268.2016.1251946
10. Phinney A, Moody EM, Small JA. The effect of a community-engaged arts program on older adults' well-being. *Can J Aging.* (2014) 33:336–45. doi: 10.1017/S071498081400018X
11. Lipe AW, Ward KC, Watson AT, Manley K, Keen R, Kelly J, et al. The effects of an arts intervention program in a community mental health setting: a collaborative approach. *Arts Psychother.* (2012) 39:25–30. doi: 10.1016/j.aip.2011.11.002
12. Cheever T, Taylor A, Finkelstein R, Edwards E, Thomas L, Bradt J, et al. NIH/Kennedy Center workshop on music and the brain: finding harmony. *Neuron.* (2018) 97:1214–8. doi: 10.1016/j.neuron.2018.02.004
13. Nap HH, De Greef HP. Self-efficacy and stress in senior computer interaction. In: *Proceedings of the 28th Annual European Conference on Cognitive Ergonomics*. Delft (2010). p. 227–30.
14. Jelen B, Freeman A, Narayanan M, Sanders KM, Clawson J, Siek KA. Craftec: engaging older adults in making through a craft-based toolkit system. In: *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction*. (2019). p. 577—87.
15. Richards OK. Exploring the empowerment of older adult creative groups using maker technology. In: *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. Denver, CO (2017). p. 166–71.
16. Schiphorst T, Seo J. *Tendrils. ACM Tangible Embodied Interface (TEI)'10 Art and Design Explorations*. New York, NY; Madeira: Association for Computing Machinery (2011).
17. Waller D. *Group Interactive Art Therapy: Its Use in Training and Treatment*. New York, NY: Routledge (2014).
18. Turner J, Greenawalt K, Goodwin S, Rathie E, Orsega-Smith E. The development and implementation of the art of happiness intervention for community-dwelling older adults. *Educ Gerontol.* (2017) 43:630–40. doi: 10.1080/03601277.2017.1380894
19. Heo Y, Bang H. Memoirs. *Leonardo*. (2011) 44:366–7. doi: 10.1162/LEON_a_00220
20. Dougherty D, Conrad A. *Free to Make: How the Maker Movement is Changing Our Schools, Our Jobs, Our Minds*. Berkeley, CA: North Atlantic Books (2016). p. 22.
21. Tian Q. Intergeneration social support affects the subjective well-being of the elderly: mediator roles of self-esteem and loneliness. *J Health Psychol.* (2014) 21:1137–44. doi: 10.1177/1359105314547245
22. Lu N, Lou VWQ, Zuo D, Chi I. Intergenerational relationships and self-rated health trajectories among older adults in rural China: does gender matter? *Res Aging.* (2017) 39:322–44. doi: 10.1177/0164027515611183
23. Reisig CN, Fees BS. Older adults' perceptions of well-being after intergenerational experiences with youth. *J Intergener Relatsh.* (2006) 4:7–22. doi: 10.1300/J194v04n04_02
24. National Academies of Sciences, Engineering, and Medicine. *Social Isolation and Loneliness in Older Adults: Opportunities for the Health Care System*. Washington, DC: The National Academies Press (2020).
25. Shankar A, McMunn A, Banks J, Steptoe A. Loneliness, social isolation, and behavioral and biological health indicators in older adults. *Health Psychol.* (2011) 30:377. doi: 10.1037/a0022826
26. Steptoe A, Shankar A, Demakakos P, Wardle J. Social isolation, loneliness, and all-cause mortality in older men and women. *Proc Natl Acad Sci USA.* (2013) 110:5797–801. doi: 10.1073/pnas.1219686110
27. Seo JH, Copeland BM, Sungkajun A, Chang Gonzalez KI, Mathews N. Re-powering senior citizens with interactive art making: case study with independent older adults. In: *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems*. Montreal, QC (2018). p. 1–6.
28. Roswiyani R, Kwakkenbos L, Spijker J, Witteman CL. The effectiveness of combining visual art activities and physical exercise for older adults on well-being or quality of life and mood: a scoping review. *J Appl Gerontol.* (2019) 38:1784–804. doi: 10.1177/0733464817743332
29. Chapin Stephenson R. Promoting well-being and gerotranscendence in an art therapy program for older adults. *Art Therapy.* (2013) 30:151–8. doi: 10.1080/07421656.2014.846206
30. Cohen GD, Perlstein S, Chapline J, Kelly J, Firth KM, Simmens S. The impact of professionally conducted cultural programs on the physical health, mental health, and social functioning of older adults. *Gerontologist.* (2006) 46:726–34. doi: 10.1093/geront/46.6.726
31. Payson M. *Biological and Social Theories of Aging. Occupational Therapy with Elders-eBook: Strategies for the Occupational Therapy Assistant*. St. Louis, MO: Elsevier (2017). 20 p.
32. Stephenson RC. Promoting self-expression through art therapy. *Generations.* (2006) 30:24—6.
33. Watson D, Clark LA, Tellegen A. Development and validation of brief measures of positive and negative affect: the PANAS scales. *J Person Soc Psychol.* (1988) 54:1063. doi: 10.1037/0022-3514.54.6.1063
34. Atchley RC. *Continuity and Adaptation in Aging. Creating Positive Experiences*. Baltimore, MD: Johns Hopkins University (1999).
35. Diener ED, Emmons RA, Larsen RJ, Griffin S. The satisfaction with life scale. *J Person Assess.* (1985) 49:71–5. doi: 10.1207/s15327752jpa4901_13
36. Birditt KS, Tighe LA, Fingerman KL, Zarit SH. Intergenerational relationship quality across three generations. *J Gerontol Psychol Sci Soc Sci.* (2012) 67:627–38. doi: 10.1093/geronb/gbs050
37. Little J. *Happiness Equalis Good Cognitive Health in Seniors*. (2013). Retrieved from: https://www.sunriseseniorliving.com/blog/march-2013/happiness-equals-good-cognitive-health-in-seniors.aspx#:~:text=Many%20people%20seek%20out%20happiness,skills%20by%20boosting%20their%20moods (accessed July 01, 2020).
38. Everard KM, Lach HW, Fisher EB, Baum MC. Relationship of activity and social support to the functional health of older adults. *J Gerontol Psychol Sci Soc Sci.* (2000) 55:S208–12. doi: 10.1093/geronb/55.4.S208
39. Alders A. Perceived self-efficacy and its role in education-related cognitive performance in Latino American elderly. *J Latin Educ.* (2011) 10:299–319. doi: 10.1080/15348431.2011.605680
40. Bennington R, Backos A, Harrison J, Reader AE, Carolan R. Art therapy in art museums: promoting social connectedness and psychological well-being of older adults. *Arts Psychother.* (2016) 49:34–43. doi: 10.1016/j.aip.2016.05.013
41. Cantu AG, Fleuriet KJ. "Making the ordinary more extraordinary": exploring creativity as a health promotion practice among older adults in a community-based professionally taught arts program. *J Holistic Nurs.* (2018) 36:123–33. doi: 10.1177/0898010117697863

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Frontiers
Avenue du Tribunal-Fédéral 34
1005 Lausanne | Switzerland

Visit us: www.frontiersin.org
Contact us: frontiersin.org/about/contact