Cities 142 (2023) 104538

Contents lists available at ScienceDirect

Cities

journal homepage: www.elsevier.com/locate/cities

Associations of neighbourhood environmental attributes and socio-economic status with health-related quality of life in urban mid-aged and older adults: Mediation by physical activity and sedentary behaviour

Anthony Barnett [a,*], Jonathan E. Shaw [b], Erika Martino [c], Luke D. Knibbs [d,f], Govinda Poudel [a], Neville Owen [b], Ester Cerin [a,b,e]

[a] Mary Mackillop Institute for Health Research, Australian Catholic University, Melbourne, Victoria, Australia
[b] Baker Heart and Diabetes Institute, Melbourne, Victoria, Australia.
[c] Melbourne School of Population and Global Health, The University of Melbourne, Parkville, Victoria, Australia
[d] School of Public Health, Faculty of Medicine and Health, The University of Sydney, New South Wales, Australia
[e] School of Public Health, Li Ka Shing Faculty of Medicine, The University of Hong Kong, Hong Kong, China
[f] Public Health Research Analytics and Methods for Evidence, Public Health Unit, Sydney Local Health District, Camperdown, New South Wales, Australia

ARTICLE INFO

Keywords:
Neighbourhood socio-economic status
Built environment
Natural environment
Air pollution
Physical activity
Sedentary behaviour

ABSTRACT

This study examined the associations of objectively assessed physical features of the neighbourhood environment with physical and mental aspects of health-related quality of life (HRQoL) as measured by the SF-36, and the roles of physical activity and sedentary behaviour in these associations. We used data from a national sample of Australian mid-aged and older adults living in urban areas ($N = 4141$). Environmental attributes were computed for 1-km-radius areas surrounding participants' residential addresses. Neighbourhood socio-economic status (SES) and average annual concentrations of $PM_{2.5}$ were the only attributes related to HRQoL in the expected direction in the total- and direct-effect regression models. All other environmental attributes were related to HRQoL via physical activity behaviours and leisure-time sitting. The associations of most environmental features with HRQoL mediated by physical activity and sedentary behaviours were inconsistent, positive through some pathways and negative through others. This study suggests that neighbourhood SES may in part benefit HRQoL by helping promote an active lifestyle. Neighbourhood attributes defining walkability may benefit HRQoL by providing opportunities for walking and resistance training and, through these, by helping reduce leisure-time sitting. However, the same attributes also may limit opportunities for household activities and gardening and negatively impact on HRQoL through these pathways.

1. Introduction

The current trend of population ageing predicts a 34 % increase in ≥60 year-olds globally from 2020 to the end of the decade (Scott, 2021). Also, the percentage of older adults (≥65 years old) in the global population is expected to increase from 9.3 % in 2020 to 16 % in 2050 (Population Division of the United Nations, Department of Economic and Social Affairs, 2020). Hence, it is important to identify modifiable factors that can preserve mid-aged and older adults' health and HRQoL at a population level. As a high proportion of the world's population now lives in cities (Population Division of the United Nations, Department of Economic and Social Affairs, 2014), the urban neighbourhood environment is a potential source of such factors.

Several studies have investigated neighbourhood environmental correlates of mid-aged and older adults' HRQoL as assessed by versions of the Short Form Health Survey (SF), a well-validated, popular measure of HRQoL commonly used in health economics (Mortimer & Segal, 2008). Most of these have examined urban/rural environment differences (e.g., Borders et al., 2004; Byles et al., 2006; Valdivieso-Mora et al., 2018; Zhou et al., 2011), neighbourhood social capital (e.g., Apostolaki et al., 2021; Bowling et al., 2006; Luo & Menec, 2018) and/or perceived physical environment attributes (Byles et al., 2014; Chiatti et al., 2017; Stephens et al., 2020; Tomey et al., 2013; Van Dyck et al., 2015; Zhao & Chung, 2017). In contrast, few studies have examined associations of objectively assessed neighbourhood physical environment attributes (Loo et al., 2017; Parra et al., 2010) or socio-economic

* Corresponding author.
E-mail address: Anthony.Barnett@acu.edu.au (A. Barnett).

https://doi.org/10.1016/j.cities.2023.104538
Received 30 March 2023; Received in revised form 9 July 2023; Accepted 19 August 2023
Available online 1 September 2023

status (SES) (Lucumí et al., 2015; Parra et al., 2010; Tomey et al., 2013) with HRQoL.

In an Asian urban context, Loo et al. (2017) found that neighbourhood population density, access to supermarket and walkability were positively associated with physical health HRQoL (SF-36v2) measures, while land-use mix, street connectivity, access to open and green space and access to public transport were not significantly associated. Similar associations were found for the mental health component, except for population density with no significant association. Another study in Bogotá, Columbia found neighbourhood (defined as 500 m-radius area) characteristics, including public park density and transport infrastructure (presence of a Ciclovía corridor and number of TransMilenio stations) were not associated with either the physical or mental components of the HRQoL (SF-8) (Parra et al., 2010). However, those who lived in neighbourhoods with >8 % of public park area were more likely to have better self-rated health as assessed by the SF-8 than their counterparts (Parra et al., 2010). In addition, previous studies have found that neighbourhood-level SES was positively associated with the physical component of versions of the short-form survey (Lucumí et al., 2015; Tomey et al., 2013) yet mostly unrelated with the mental component (Lucumí et al., 2015; Rocha et al., 2017; Tomey et al., 2013).

Given mental health and insomnia can affect HRQoL (Kennair et al., 2022) as well as individuals' perceptions of the environment (Gotlib & Joormann, 2010; Leslie & Cerin, 2008), to establish if the neighbourhood environment impacts HRQoL, it is important that objectively assessed, rather than perceived physical environment factors, are examined in associations with HRQoL (Zhang et al., 2019). The two studies examining this issue have either focused on a limited number of attributes (Parra et al., 2010), or have failed to account for potential environmental confounders in the estimation of associations between environmental attributes and HRQoL (Loo et al., 2017). To best understand how neighbourhood environment factors impact HRQoL, capturing a wide range of inter-related environmental characteristics (aspects of the built and natural environment, air pollution and SES) is necessary, rather than focussing on one or a few.

Aspects of the built environment related to walkability (population/dwelling density, street connectivity, access to various destinations and services) are likely to be positively related to both physical and mental components of HRQoL because they support an active lifestyle and provide better access to health services and social activities (Loo et al., 2017; Stier et al., 2021). Access to the natural environment can also support active living (Barnett et al., 2017) and reduce stress (Gong et al., 2016) and, hence, should enhance HRQoL, as suggested by Parra et al. (2010). Exposure to ambient air pollution is known to harm physical and mental health (Fan et al., 2022; Hautekiet et al., 2022; Hu et al., 2021; Ju et al., 2022) and HRQoL (Hwang et al., 2020; Yamazaki et al., 2005). Finally, as noted above, higher neighbourhood-level SES has been linked to better HRQoL (Ma & McGhee, 2013). Hence, in this study, we expected it to be positively related to both physical and mental components of the SFs.

The effects of the neighbourhood environment on HRQoL are distal and, hence, statistical power to detect them is low (MacKinnon & Fairchild, 2009). Mediation analysis has greater power to detect links between the environment and HRQoL, as it estimates the associations between the environment and more proximal constructs (e.g., physical activity) that act as potential mechanisms through which the neighbourhood environment impacts HRQoL. Studies have examined mediators of environment-HRQoL or environment-QoL associations (e.g., Zhang et al., 2020; Zhang et al., in press). However, information on the mediating roles of health-related behaviours, such as physical activity and sedentary behaviours, is generally lacking. Physical activity and sedentary behaviours are potential mechanisms responsible for the effects of the neighbourhood environment on HRQoL (Cerin et al., 2016) because there is substantial evidence that some types of physical activity (Barnett et al., 2017; Cerin et al., 2017; Van Cauwenberg et al., 2018) and sedentary behaviours (Cerin, Barnett, et al., 2020) are influenced by the neighbourhood environment in older adults, and physical activity and sedentary behaviours have been found to be, respectively, positively and negatively associated with HRQoL (Bertheussen et al., 2011; Brown et al., 2003; Langhammer et al., 2018). A study on perceived environment and the mental component of the SF-36 found that self-reported active transport and leisure-time physical activity explained 11 % of the associations between the perceived neighbourhood physical activity environment and mental HRQoL (Van Dyck et al., 2015). A recent study of objectively assessed neighbourhood environment features and the World Health Organization Quality-of-Life scale (WHOQoL) found that physical activity was not a mediator of the associations between neighbourhood environment features and physical and psychological aspects of HRQoL (Zhang et al., in press). However, to our knowledge, it seems no studies have examined the mediating role of different types of physical activity and sedentary behaviours when examining associations between objectively assessed aspects of the neighbourhood environment and HRQoL as measured by the SF-36.

Based on the above, the aims of this study were 1) to examine the associations between objectively assessed physical features of the neighbourhood environment and physical and mental aspects of HRQoL as measured by the SF-36, and 2) examine the mediating effects of physical activity and sedentary behaviour in these associations. In doing so, we took into consideration the potential causal relationships between the various environmental attributes and behaviours (Cerin, Van Dyck, et al., 2020), which is important to estimate total, mediated and direct effects of the environment on HRQoL, and which has not been previously done.

As depicted in our proposed model of neighbourhood environment influences on HRQoL (Fig. 1), we hypothesised that aspects of the built environment related to walkability (population density, street connectivity, access to various destinations and services) would be positively related to both physical and mental components of HRQoL because they support an active lifestyle (i.e., more physical activity and less sedentary time) and provide better access to health services and social activities (Loo et al., 2017; Stier et al., 2021).

Access to the natural environment may also support active living (Barnett et al., 2017) and reduce stress (Gong et al., 2016) and, hence, be positively related to HRQoL. Because exposure to ambient air pollution is known to harm physical and mental health (Braithwaite et al., 2019; Fan et al., 2022; Hautekiet et al., 2022; Hu et al., 2021; Ju et al., 2022) and HRQoL (Hwang et al., 2020; Yamazaki et al., 2005), negative associations were expected between these factors. Finally, as noted above, higher neighbourhood-level SES has been linked to better HRQoL (Ma & McGhee, 2013). Hence, in this study, we expected SES to be positively related to both physical and mental components of HRQoL. We also hypothesised that most of the associations of the environment with HRQoL would be indirect and explained by physical activity and sedentary behaviours for the reasons mentioned above.

2. Materials and methods

2.1. Study design and participants

This study used data taken from the Australian Diabetes, Obesity and Lifestyle survey (AusDiab3, conducted in 2011-12), a population based longitudinal survey designed to examine prevalence, incidence, and determinants of diabetes in Australians 25 years and older (Dunstan et al., 2002; Tanamas et al., 2013). The third wave (AusDiab3) was chosen for the present cross-sectional analyses as it was the only wave of AusDiab with available relevant objectively-assessed environmental exposures (e.g., air pollution and built environment attributes). AusDiab3 retention rate from baseline was 44.6 % and over 97 % of participants were aged >40 years. Participant eligibility required having no major physical or intellectual disabilities, being in the target age bracket and having lived at their addresses for 6 months or longer prior to the survey. Compared to those who dropped out of the study, AusDiab3

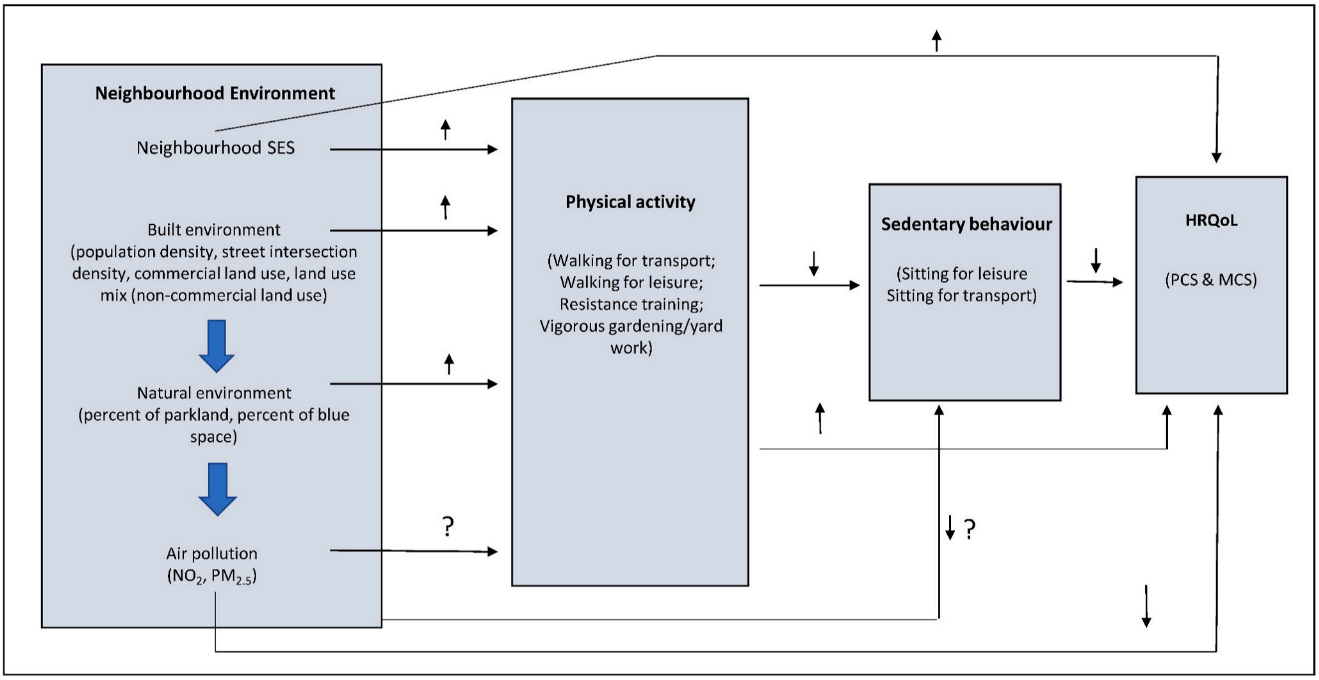

Fig. 1. Theoretical model of neighbourhood environment influences on health-related quality of life (HRQoL) via physical activity and sedentary behaviours. SES = socio-economic status, upward arrow = positive effect, downward arrow = negative effect, ? = uncertain effect, PCS & MCS = physical and mental component of HRQoL as measured by SF-36.

participants were younger ($p < .001$), more physically active ($p < .01$), less likely to smoke ($p < .01$) and had higher education attainment levels ($p < .001$) at baseline. As this study focussed on potential effects of urban neighbourhood environments of HRQoL, 473 participants who resided outside of significant urban areas were excluded from analysis, leaving an analytical sample of 4141 participants (2286 women and 1855 men) recruited from 1286 Statistical Areas 1 (SA1). With such a sample size, it was estimated that the study had 95 % power to detect small effect sizes equivalent to 1.0 % of explained outcome variance, assuming an SA1-level residual clustering effect <5 % (Cerin et al., 2016), up to 30 covariates in the regression models, and a 5 % 2-tailed significance level. The AusDiab study was approved by the Alfred Hospital Ethics Committee, Melbourne, Australia (ref. no 39/11). Participants were recruited from metropolitan and regional cities throughout Australia. Interviewer-administered surveys in English were used to collect data on HRQoL, health, health-related behaviours and socio-demographic characteristics. Written informed consent was obtained from all participants. Details of AusDiab data collection procedures are provided elsewhere (Anstey et al., 2015; Dunstan et al., 2002; Tanamas et al., 2013).

2.2. Measures

2.2.1. Health-related quality of life (outcomes)

The outcome measures were the Physical Component Summary (PCS) and Mental Component Summary (MCS) scores of the Short Form 36 Health Survey (SF-36 (v1)), a self-administered HRQoL measure (Ware, 2000). The component summaries were determined by three steps: 1) standardising the eight SF-36 scales using a *Z*-score transformation; 2) aggregating the Z-scores using the Australian Bureau of Statistics 1995 National Health Survey factor score coefficients as weights; and 3) transforming the aggregated summary scores to have a mean of 50 and standard deviation of 10 (Australian Bureau of Statistics, 1997). The structural validity and internal consistency of the eight SF-36 scales were confirmed in an Australian middle-to-old age adult sample of 41,338 participants aged 45–97 years (Bartsch et al., 2011). In the present study, the internal consistency coefficients (Cronbach's α) of the PCS and MCS were 0.843 and 0.842, respectively.

2.2.2. Environmental measures (exposures)

ArcGIS v.10.5 (ESRI, Redlands) was used to generate neighbourhood built and natural environmental measures. Untrimmed street-network buffers of 1-km radius were created. A 1-km radius corresponds to the distance adults and older adults without mobility difficulties can walk in 10–20 min (Adams et al., 2014), and the neighbourhood has been commonly defined by a 20 min walk from home (Cerin et al., 2013; Gunn et al., 2017).

Further details on all the neighbourhood environmental exposures are available elsewhere (Cerin et al., 2021, 2023; Barnett et al., 2022; Cerin et al., 2022). Briefly, four built environment and two natural environment measures were computed for each participant's residential buffer. These were population density (persons/hectare), street intersection density (intersections/km^2), percentage of buffer area devoted to commercial land use, non-commercial land use mix (an entropy measure ranging from 0 to 1 and based on residential, medical, industrial, educational and other land use data) (Frank et al., 2010), percentage of parkland and percentage of blue space (i.e., water body areas). Two ambient air pollutants were estimated using validated national-scale satellite-based land-use regression models for annual average nitrogen dioxide (NO_2, units: ppb) and fine particulate matter ≤2.5 μm in aerodynamic diameter ($PM_{2.5}$ units: μg/m^3) (Knibbs et al., 2014, 2016, 2018). Neighbourhood SES was based on the Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) (Australian Bureau of Statistics, 2011b) including information on household income, education, employment and marital status, occupational class, living arrangements, home and car ownership, housing conditions, internet access, disability, mortgage and rental costs. Sources for the above GIS data were the Australian Bureau of Statistics Mesh Block data from the 2011 Census (Australian Bureau of Statistics, 2011a), the PSMA Australia's 2012 Transport & Topography dataset (PSMA Australia Ltd.,

2012) and the national topographic spatial data for surface water features from Geoscience Australia (Crossman & Li, 2015).

2.3. Confounders and covariates

Information on confounders and covariates was collected using a self-completed survey. These variables were age, sex, educational attainment (up to secondary; trade, technician certificate; associate diploma or equivalent; Bachelor degree, post-graduate diploma), living arrangements (living alone; couple without children; couple with children; one person living with children; shared household; other arrangements), household annual income (up to $49,999; $50,000–$99,999; $100,000 and over; does not know or refusal), employment status (paid work; volunteer; neither), ethnicity (English speaking background: Yes vs. No) and residential self-selection (related to access to destinations and recreational facilities) (Cerin et al., 2021; Owen et al., 2007). For analyses purposes, the living arrangements categories one person living with children, shared household and other arrangements were collapsed due to low frequencies.

2.4. Mediators

We hypothesised that physical activity and sedentary behaviours may be potential mediators of the effects of the neighbourhood environment on HRQoL (Siceloff et al., 2014; Van Dyck et al., 2015). For this study, we used items adapted from Australian Institute of Health and Welfare (2003) measuring last-week frequencies of walking for transport, walking for recreation, vigorous gardening and resistance training. Examined sedentary behaviour mediators were last-week sitting for transport (hours/day) and leisure-time sitting (hours/day), which were developed for AusDiab3. These sedentary behaviour measures were validated against objectively measured sitting time (Clark et al., 2015). In this study, leisure time sitting included television viewing and leisure-time computer time.

2.5. Data analytic plan

Descriptive statistics, including percentage of missing values, were computed for all variables and presented in tabular form. Cross-sectional total, direct and indirect effects of neighbourhood environment attributes on HRQoL were estimated using generalised additive mixed models (GAMMs; package 'mgcv' version 1.8.22 (Wood, 2017) in R) with random intercepts at the SA1 level (Wood, 2017). As this is a cross-sectional study, the term 'effect', used in mediation analyses, does not imply evidence of causation and needs to be interpreted with caution considering the likely presence of unmeasured confounders. Minimal sufficient sets of confounders for the GAMMs estimating exposure-outcome, exposure-mediators and mediators-outcome relationships were determined using a directed acyclic graph (DAG) (Textor et al., 2016) (Fig. S1), which was based on published evidence and the authors' expert opinion on causal effects among the variables. Potential multicollinearity was assessed by computing the Variance Inflation Factor (VIF) for each variable included in the GAMMs. All VIFs were smaller than 3, indicating no collinearity issues (Sheather, 2009).

To test aspects of the proposed model of neighbourhood environmental influences on HRQoL (Fig. 1), analyses were conducted in several steps. First, the total effects of environmental attributes on the two components of HRQoL were estimated. In doing so, the curvilinearity of associations were also tested by comparing the Akaike Information Criteria (AIC) values of GAMMs with linear vs. curvilinear regression terms (smooth terms) for each environmental attribute. A 5 unit or larger difference in AIC values (smaller AIC for the GAMM with a smooth term) was considered sufficient evidence of curvilinearity. Then the direct and mediated effects of the environmental attributes on HRQoL were estimated, i.e., the extent to which the effects of an environmental attribute on HRQoL were explained (i.e., mediated) by physical activity and sedentary behaviours. This included the estimation of confounder-adjusted associations of: (1) a specific environmental attribute with other environmental attributes in the pathway between the specific attribute and HRQoL (not reported as published elsewhere; Cerin et al., 2021); (2) environmental attributes with physical activity and sedentary behaviour measures; (3) physical activity with sedentary behaviour measures; and (4) physical activity and sedentary behaviour measures with HRQoL. The joint-significance test was used to establish mediation, whereby a variable is considered to be a mediator if it is significantly related to the exposure as well as the outcome after adjustment for the exposure (MacKinnon et al., 2002). Detailed information about the models is given in the Supplementary Material (Tables S1–S7). Estimates of total and direct effects of all neighbourhood environmental attributes on HRQoL were presented in tabular form. Statistically significant total, direct and behaviour-mediated effects of environmental attributes on HRQoL were also presented graphically as a simplified path diagram.

Over 16 % of cases had missing data on at least one variable and data were at least missing at random (see Supplementary Material). Consequently, 20 imputed datasets were created for the regression analysis as recommended by Ruben (1987) and van Buuren (2018). Multiple imputations by chained equations were performed using the package 'mice' (Van Buuren & Groothuis-Oudshoorn, 2011) in R version 4.0.0 (R Core Team, 2020). Analyses were conducted on multiple imputed data as well as on complete cases. As the findings between the two sets of analyses did not differ substantially, we report only those conducted on multiple imputed data. The complete case analyses are available on request from the corresponding author.

3. Results

Table 1 reports the sample descriptive statistics. Participants' mean age was 61.1 years with a range from 34 to 97 years. Females comprised 55 % of the sample. Educational attainment and annual household income categories were relatively evenly spread. In terms of HRQoL, the averages of both PCS (48.3 ± 8.9) and MCS (53.4 ± 9.7) T-scores were close to adult population averages (i.e., T-score of 50). However, the MCS tended to be higher than PCS. With regard to physical activity, leisure-time walking and resistance training were the activities with the highest and lowest rate of participation, respectively. On average, participants tended to accumulate fewer hours of sitting for transport than for leisure or other purposes (Table 1).

Table 2 reports the total and direct effects of neighbourhood environmental characteristics on HRQoL. Neighbourhood SES (IRSAD) and annual average $PM_{2.5}$ concentrations showed significant positive and negative total and direct effects respectively on the physical component of HRQoL (Table 2). No other significant total or direct associations were observed.

Mediation analyses identified a substantial number of indirect effects of all examined neighbourhood environment attributes on both components of HRQoL through various physical activity measures and sitting for leisure but not sitting for transport (Fig. 2; Tables S9–S14). When controlling for environmental confounders, neighbourhood SES showed positive indirect effects on both components of HRQoL via resistance training and sitting for leisure. Data suggested that residents of higher SES areas were more likely to engage in resistance training and, consequently, sit less for leisure. Less sitting for leisure was, in turn, positively related to both HRQoL components. Furthermore, neighbourhood SES was negatively related to frequency of resistance training in those who engaged in this activity which, in turn, was associated with more sitting for leisure. This pathway also had a positive indirect effect on HRQoL due to sitting for leisure being negatively associated with both HRQoL components. Notably, the negative total effect of neighbourhood SES on sitting for leisure was fully explained by engagement in resistance training, as evidenced by the lack of a statistically significant direct effect.

Population density showed negative and positive indirect effects on

Table 1
Participant and neighbourhood environment characteristics ($N = 4141$).

Characteristics	Statistics	Characteristics	Statistics
Socio-demographic and other individual and household characteristics			
Age, years, M ± SD	61.1 ± 11.4	Sex, female, %	55.2 %
Educational attainment, %		Smoking history, %	
Up to secondary	32.7 %	Current smoker	7.0 %
Trade, technician certificate	29.1 %	Previous smoker	35.9 %
Associate diploma & equivalent	14.5 %	Non-smoker	54.5 %
Bachelor degree, post-graduate diploma	23.1 %	Missing data	2.6 %
Missing data	0.6 %	Household income, annual, %	
Living arrangements, %		Up to $49,999	32.9 %
Couple without children	48.2 %	$50,000–$99,999	26.8 %
Couple with children	26.8 %	$100,000 and over	28.9 %
Other	22.4 %	Does not know or refusal	8.8 %
Missing data	2.5 %	Missing data	2.7 %
Residential self-selection – access to destinations, M ± SD	2.9 ± 1.3	Residential self-selection – access to recreational facilities, M ± SD	3.1 ± 1.5
Missing data	7.8 %	Missing data	7.8 %
Work or volunteer, %		English speaking background, %	89.9 %
Neither	30.4 %		
Paid work	52.2 %		
Volunteer	15.1 %		
Missing data	2.3 %		
Neighbourhood environment characteristics, M ± SD			
Neighbourhood SES (IRSAD, range 1–10)	6.4 ± 2.7	% Blue space (1 km buffer)	0.2 ± 2.0
% Commercial land (1 km buffer)	2.5 ± 6.1	% Parkland (1 km buffer)	11.6 ± 12.5
Population density (/ha)	17.4 ± 10.0	Land use mix (entropy score)[a]	0.35 ± 0.16
Air pollution - NO_2 (ppb)	5.5 ± 2.1	Street intersection density (/km^2)	62.2 ± 32.2
Air pollution - $PM_{2.5}$ (μg/m^3)	6.3 ± 1.7		
Physical activity and sedentary behaviour			
Transportation walking		Leisure-time walking	
Times per week, M ± SD	1.4 ± 3.5	Times per week, M ± SD	2.4 ± 2.5
Prevalence, %	29.1	Prevalence, %	61.6
Missing data, %	2.7	Missing data, %	3.0
Vigorous gardening		Resistance training	
Times per week, M ± SD	0.8 ± 1.5	Times per week, M ± SD	0.9 ± 2.3
Prevalence, %	37.1	Prevalence, %	25.5
Missing data, %	2.6	Missing data, %	2.6
Sitting for transport, h/day, M ± SD	0.8 ± 0.8	Leisure-time sitting, h/day, M ± SD	2.6 ± 1.6
Missing data, %	2.7	Missing data, %	2.8
Sitting (other purposes), h/day, M ± SD	3.4 ± 2.4		
Missing data, %	2.9		
Health-related variables			
Tobacco-smoking status, %		Heart problems/stroke (past), %	8.7
Current smoker	7.0	Missing data, %	1.0
Previous smoker	35.9		
Non-smoker	54.5		
Missing data	2.6		
Health related quality of life outcomes			
SF36 - Physical Component Score (T-Score)	48.3 ± 8.9	SF36 - Mental Component Score (T-Score)	53.4 ± 9.7
Missing data	0.1 %	Missing data	0.1 %

Note. M, mean; SD, standard deviation; SES, socio-economic status; IRSAD, Index of Relative Socio-economic Advantage and Disadvantage; ha, hectare; NO_2, nitrogen dioxide; ppb, particles per billion; $PM_{2.5}$, particulate matter with a diameter of 2.5 μm or less.

[a] Land use mix includes residential, medical, educational, industrial and other land uses. It is expressed as an entropy score ranging from 0 to 1.

both HRQoL components through different pathways. Positive indirect effects were observed through engagement in resistance training and walking for transport because these two activities were positively related to population density as well as negatively related to sitting for leisure (which was likely detrimental to HRQoL) (Fig. 2). While the total and direct effects of population density on resistance training were similar (Fig. 2; Table S9), those related to walking for transport differed substantially (Fig. 2; Table S10), indicating that the positive association of population density with walking for transport, but not that with resistance training, may be due to environmental factors accompanying densification (i.e., availability of commercial destinations, better street connectivity, more mixed land use). The negative indirect effects of population density were channelled through frequency of vigorous gardening/yard work and sitting for leisure. This is because, after adjusting for physical activity, population density was positively related to sitting for leisure. Furthermore, population density was negatively related to frequency of vigorous gardening/yard work which, in turn, was negatively related to sitting for leisure. As for walking for transport, the total effect of population density on gardening/yard work was fully accounted for by other environmental attributes resulting from densification as no significant direct effect was observed (Fig. 2; Table S12).

Street intersection density also displayed contrasting indirect effects, two of which were also via engagement in walking for transport and frequency of vigorous gardening/yard work. A third pathway emerged through engagement in walking for recreation, which was positively related to the PCS directly and to PCS and MCS indirectly through sitting for leisure. The remaining built environment features showed consistent indirect effects on HRQoL. Percentage of commercial land use displayed positive indirect effects on both HRQoL components via engagement in walking for transport and vigorous gardening/yard work frequency through sitting for leisure. In contrast, non-commercial land use mix had a negative indirect effect on HRQoL via gardening/yard work frequency. Specifically, this environmental measure was negatively related to gardening/yard work frequency, which was, in turn, negatively related to sitting for leisure contributing to poorer HRQoL. The negative total effect of non-commercial land on gardening/yard work frequency was explained by other environmental attributes in the pathway (air pollution) as the direct effect was not statistically significant (Fig. 2; Table S12).

Both percentage of parkland and percentage of blue space displayed positive and negative indirect effects on HRQoL. For parkland, the former were channelled through engagement in resistance training and sitting for leisure, while the latter were channelled through engagement in walking for recreation and sitting for leisure. For percentage of blue space, the positive indirect effect was due to this environmental attribute being negatively related to sitting for leisure, while negative effects were due to the negative associations of the neighbourhood attribute with engagement in walking for transport and frequency of vigorous gardening/yard work which were, in turn, negatively related to sitting for leisure.

Finally, positive indirect effects on HRQoL were found for both air pollution indicators (NO_2 and $PM_{2.5}$). These were due to them being positively related to engagement in walking for transport, which was negatively associated with sitting for leisure, and the latter negatively associated with both components of HRQoL. The fact that $PM_{2.5}$ showed a significant negative total effect but non-significant direct effect on sitting for leisure, after adjustment for engagement in walking for transport (Fig. 2), indicates that walking for transport mediated in full the association between $PM_{2.5}$ and sitting for leisure.

Table 2
Total and direct effects of neighbourhood environmental characteristics on health-related quality of life (HRQoL).

Environmental characteristic (units)	Effect	Physical component score (HRQoL)			Mental component score (HRQoL)		
		b	95 % CI	*p*-Value	b	95 % CI	p-Value
Population density (persons/ha)	Total	−0.004	−0.032, 0.025	0.812	−0.023	−0.055, 0.010	0.167
	Direct	−0.004	−0.046, 0.038	0.856	−0.030	−0.079, 0.018	0.220
Street intersection density (intersections/km^2)	Total	0.0004	−0.010, 0.011	0.947	0.003	−0.009, 0.015	0.603
	Direct	0.002	−0.009, 0.013	0.746	0.004	−0.009, 0.016	0.577
Percentage of commercial land use	Total	−0.003	−0.049, 0.042	0.885	0.009	−0.044, 0.063	0.733
	Direct	−0.003	−0.049, 0.043	0.902	0.026	−0.042, 0.020	0.358
Non-commercial land use mix (entropy score)[a]	Total	0.365	−1.482, 2.213	0.699	−0.921	−2.987, 1.144	0.382
	Direct	1.008	−1.101, 3.116	0.349	−0.427	−2.871, 2.016	0.732
Percentage of parkland	Total	0.009	−0.017, 0.035	0.496	−0.010	−0.041, 0.020	0.506
	Direct	−0.002	−0.027, 0.0238	0.888	−0.011	−0.042, 0.020	0.492
Percentage of blue space	Total	0.052	−0.081, 0.186	0.444	0.060	−0.094, 0.215	0.445
	Direct	0.030	−0.101, 0.161	0.655	0.037	−0.116, 0.190	0.637
Neighbourhood SES (IRSAD)	Total	**0.202**	**0.092, 0.312**	**<0.001**	0.049	−0.079, 0.177	0.455
	Direct	**0.175**	**0.059, 0.292**	**0.003**	0.037	−0.099, 0.172	0.597
Air pollution - NO_2 (ppb)	Total	0.015	−0.169, 0.199	0.869	−0.040	−0.249, 0.169	0.707
	Direct	0.024	−0.160, 0.207	0.801	0.013	−0.200, 0.225	0.907
Air pollution - $PM_{2.5}$ (μg/m^3)	Total	**−0.218**	**−0.393, −0.044**	**0.014**	−0.050	−0.257, 0.157	0.639
	Direct	**−0.223**	**−0.398, −0.048**	**0.012**	−0.035	−0.241, 0.172	0.743

Note. Physical and Mental Component Scores (T-Score) as derived from the SF-36; ha, hectare; IRSAD, Index of Relative Socio-economic Advantage and Disadvantage; ppb, particles per billion; NO_2, air pollution nitrogen dioxide; ppb, particles per billion; $PM_{2.5}$, particulate matter with a diameter of 2.5 μm or less; *b*, regression coefficients; CI, confidence intervals. Associations significant at the 0.05 probability level are in bold. Covariates entered in the regression models are reported in Table S1 (Supplementary Material).

[a] Non-commercial land use mix includes residential, medical, educational, industrial and other land uses; the indicator is expressed as an entropy score ranging from 0 to 1.

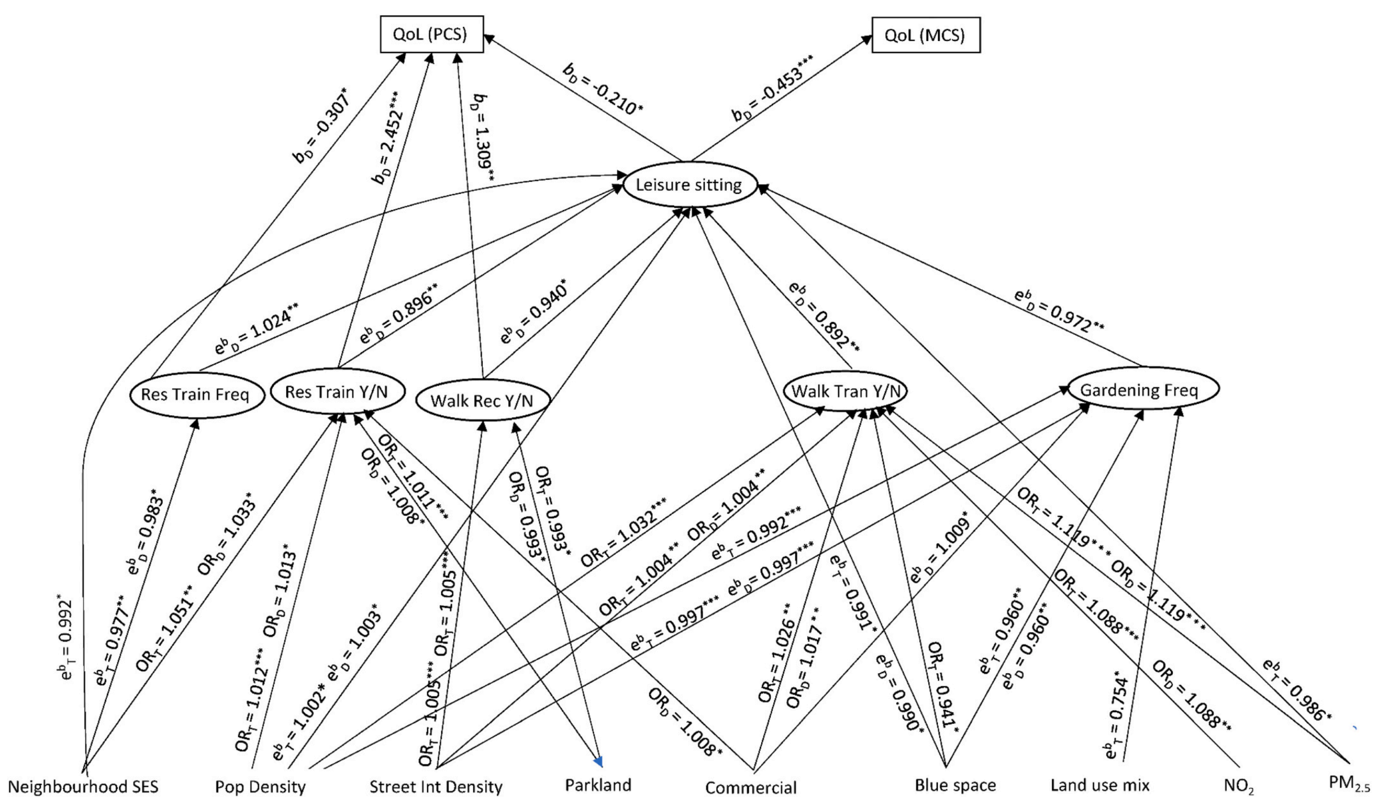

Fig. 2. Indirect effects of neighbourhood environmental attributes on the physical (PCS) and mental components (MCS) of health-related quality of life (SF-36). Subscript T = estimate of total effect, subscript D = estimate of direct effect, b = regression coefficient, e^b = exponentiated regression coefficient, OR = odds ratio. Res Train Freq = Resistance training frequency, Res Train Y/N = Engagement in resistance training, Walk Rec Y/N = Engagement in walking for recreation, Walk Trans Y/N = Engagement in walking for transport, Gardening Freq = Vigorous gardening/yard work frequency, Leisure sitting = Sitting for leisure, **p* < .05, **p < .01, ****p* < .001.

4. Discussion

The purpose of this study was to examine the validity of a model of neighbourhood environmental correlates of HRQoL by estimating associations of neighbourhood physical attributes and SES with HRQoL and the mediating roles of physical activity and sedentary behaviour in these associations in a cohort of Australian mid-aged and older adults. While only $PM_{2.5}$ and neighbourhood SES (IRSAD) showed significant total and direct associations with PCS, all environmental attributes were indirectly significantly associated with HRQoL via sitting for leisure and/or physical activity. The lack of total and direct associations can be attributed to some environmental attributes having contrasting effects on different domains of physical activity (e.g., parkland being positively associated with resistance training and negatively associated with leisure-time walking) or environmental attributes being distal influencing factors with respect to HRQoL (e.g., street intersection density). The data generally supported the validity of the proposed model, although the hypothesised associations were not always in the expected direction. These findings are discussed in detail below.

4.1. Neighbourhood SES

Neighbourhood SES was the only neighbourhood attribute that showed a total and direct positive association with HRQoL, and only with PCS (Table 2). As noted earlier, prior studies have also found that neighbourhood-level SES was positively associated with the physical component of versions of the SF (Lucumí et al., 2015; Tomey et al., 2013) and mostly unrelated with the mental component (Lucumí et al., 2015; Rocha et al., 2017; Tomey et al., 2013). People living in lower SES neighbourhoods typically have poorer physical health as well as poorer perceptions of the same, irrespective of their health status (Rocha et al., 2017). Disadvantaged neighbourhoods may also lack facilities, services and social norms promoting a healthy lifestyle (Macintyre et al., 2002; Pickett & Pearl, 2001).

The reason for not finding a significant total or direct effect between neighbourhood SES and the MCS is unclear. However, in the current study, neighbourhood SES was indirectly, positively associated with both HRQoL components via resistance training and sitting for leisure (Fig. 2). Mid-aged and older adults tend to accumulate sitting for leisure mainly through TV viewing (Compernolle et al., 2021), which has been associated with poor physical and mental health (Compernolle et al., 2021; Gardner et al., 2014) and lower individual-level (Gardner et al., 2014) and neighbourhood-level SES (Coogan et al., 2012). This study also suggests that some of the time spent sitting for leisure (e.g., TV viewing) can be potentially displaced by leisure-time physical activity (Gardner et al., 2014) and this may benefit both physical and mental health. Furthermore, we found that participation in resistance training may directly benefit the physical component of HRQoL, i.e., irrespective of its effects on PCS via sitting for leisure. Resistance training improves muscle strength and the capacity to perform activities of daily living, which are likely to improve HRQoL (Hart & Buck, 2019; Levinger et al., 2007).

Interestingly, while, in our study, participants from higher SES areas were more likely to partake in resistance training, they were less likely to undertake it frequently, which was somewhat unexpectedly associated with them having lower scores on the PCS. These findings were similar to those in a study of a nationally representative Australian adult sample (Freeston et al., 2017) which found that residents of more socially advantaged areas were more likely to participate in resistance training but, among those who participated in this type of activity, residents of less advantaged areas tended to have a higher weekly frequency of participation. Residents of higher SES areas may have access to and be interested and be able to afford participating in a greater variety of leisure-time physical activities compared to their counterparts who may only participate in one activity, such as resistance training (Kamphuis et al., 2008).

4.2. Neighbourhood built environment

Although no significant total or direct effects of neighbourhood built environment features on HRQoL were observed, all examined features were indirectly related to PCS and MCS via physical activity and leisure-time sitting. The indirect associations of population and street intersection density with HRQoL were inconsistent, while those of commercial land use and non-commercial land use mix were, respectively, positive and negative. Overall, our study suggests that urban design features that define neighbourhood walkability (density, access to services and street connectivity) are distal factors influencing HRQoL by promoting or hindering lifestyle behaviours that are beneficial (physical activity) or detrimental (sitting) to health. These complex and contrasting distal pathways of influence may explain why previous studies reported conflicting findings on built environmental correlates of HRQoL as measured by the SF (Loo et al., 2017; Parra et al., 2010). We discuss the specific findings of our study below.

As observed for neighbourhood SES, population density was indirectly positively related to both PCS and MCS via its positive association with engagement in resistance training, which was predictive of less leisure-time sitting. Dense neighbourhoods may encourage participation in resistance training because they provide more physical and social resources for such activities (e.g., indoor recreational facilities and fitness clubs/groups) (Cerin, Barnett, et al., 2020). However, unlike neighbourhood SES, population density was also directly positively associated with leisure-time sitting and, hence, showed negative effects on both PCS and MCS through this pathway. That population density can potentially promote as well as hinder an active lifestyle in ageing populations has been observed in recent studies. For example, Belgian older adults showed positive direct associations of residential density with both accelerometry-assessed moderate-to-vigorous physical activity and sedentary time (Cerin, Van Dyck, et al., 2020). This finding was attributed to more dense environments providing more opportunities for incidental and structured physical activities in the neighbourhood and, at the same time, fewer opportunities for household and gardening activities due to the smaller size of dwellings and the lack of private gardens (Cerin, Van Dyck, et al., 2020).

Unsurprisingly, population density, as well as street intersection density and percentage of commercial land use, were positively associated with both PCS and MCS via engagement in walking for transport and leisure-time sitting. The various operationalisations of these environmental attributes that have been used to define neighbourhood walkability indices (Cerin et al., 2010; Frank et al., 2010; Leslie et al., 2007) showed consistent positive associations with older adults' walking for transport (Cerin et al., 2017). Engagement in walking for transport, as a proxy for engagement in various activities in the neighbourhood, may displace some TV viewing and other home-based leisure-time sedentary activities. In fact, a longitudinal study conducted in Belgian mid-aged and older adults reported that declines in active transport were accompanied by increases in leisure-time sitting (Van Dyck et al., 2016).

One of the neighbourhood walkability components included in this study – street intersection density was also positively related to HRQoL through engagement in recreational walking which, in turn, was directly positively associated with PCS and indirectly associated with both HRQoL components through leisure-time sitting. The observed association between this environmental feature and walking for recreation is in line with the findings of a systematic review and meta-analysis on environmental correlates of leisure-time physical activity in older adults (Van Cauwenberg et al., 2018), suggesting that street intersection density may promote walking for recreation in ageing populations by providing easy access to places for socialising and other various facilities in the neighbourhood. As to the positive associations between walking for recreation and aspects of HRQoL, they have been reported in many studies (Han et al., 2021). However, these studies did not investigate the mediating role of leisure-time sitting.

Neighbourhood walkability features, including population density, street intersection density and non-commercial land use mix, were also indirectly negatively associated with HRQoL via frequency of vigorous gardening and leisure-time sitting. As dense urban environments with mixed land use are likely to have small or no gardens, it is not surprising that their residents report minimal or no vigorous gardening/yard work. It is also not surprising that minimal or no participation in gardening resulted in more sitting for leisure in this older demographic. However, the positive, albeit weak, association of commercial land use with gardening frequency found in the present study was not expected because areas with a high prevalence of commercial facilities typically do not have gardens.

4.3. Neighbourhood natural environment

Despite the inconsistent findings in the literature (Loo et al., 2017; Parra et al., 2010), we hypothesised that access to parkland would be associated with better HRQoL directly (e.g., by reducing stress) and indirectly (by promoting leisure-time physical activity). Our hypotheses were only partially confirmed. Specifically, parkland was indirectly, positively associated with PCS via engagement in resistance training, but, in contrast, was indirectly, negatively associated with PCS via engagement in walking for recreation (with and without mediation by leisure-time sitting). A recent systematic review on the impact of types of physical activity in green urban space on adult health and behaviours (Grigoletto et al., 2021) noted that, worldwide, an increasing number of parks have outdoor fitness equipment. This may explain the observed link between parkland and engagement in resistance training. The negative association between parkland and recreational walking is more puzzling. In their systematic review and meta-analysis, Van Cauwenberg and colleagues reported a positive association between parks/open spaces and overall leisure-time physical activity rather than walking for recreation in older adults (Van Cauwenberg et al., 2018). They also noted that access to services was the strongest environmental correlate of walking for recreation. Older adults may prefer walking in safe areas with good visibility and tend to avoid isolated trails in parks (Moran et al., 2014). If percentage of parkland in a neighbourhood is a proxy for lack of visibility and isolation, it is not surprising that it was weakly negatively related to walking for recreation. Also, parks are only one of the common locations where older people walk for recreation (Barnett et al., 2015).

Blue space in the neighbourhood is the other natural environmental attribute examined in the present study. We hypothesised it would be positively related to HRQoL directly (by reducing stress) and through lifestyle behaviours (by promoting an active lifestyle) (White et al., 2020). As expected, blue space was indirectly positively associated with PCS and MCS via its negative association with sitting for leisure. However, it was indirectly negatively associated with both components of HRQoL via of its negative associations with walking for transport and vigorous gardening frequency. These findings may be in part due to the way access to blue space was operationalised. A high percentage of blue space in a 1-km buffer around a residential address implies that there is less space for other land uses, such as commercial or residential. This would result in a negative association of this particular measure of blue space with walking for transport as well as gardening. Recent studies that examined the relationship between blue space and HRQoL and similar constructs tended to use distance to blue space and blue space use as exposures. For example, in Ireland, people living within 2 km of blue spaces reported significantly more life satisfaction than people living further than 5 km away (Brereton et al., 2008). Subsequent research in Canada (Pearson et al., 2019), China (Helbich et al., 2019), England (Alcock et al., 2020; Garrett, Clitherrow, et al., 2019) and the Netherlands (De Vries et al., 2016) found living near the coast or inland water bodies was associated with better mental health. With regard to PCS and MCS (SF-12v2), blue space use in two German cities was a better indicator of health outcomes than perceived walking distance to the blue space (Völker et al., 2018). Furthermore, a study of Hong Kong (mainly older) residents found that those with a view of blue space from home were more likely to report good general health, while intentional exposure was linked to greater odds of high wellbeing (Garrett, White, et al., 2019).

4.4. Air pollution

Average annual $PM_{2.5}$ concentrations were negatively associated with PCS but not MCS in the total and direct effect models. This was not the case for NO_2, which was unrelated to HRQoL. Surprisingly, both NO_2 and $PM_{2.5}$ were indirectly and positively associated with PCS and MCS via engagement in walking for transport and sitting for leisure. $PM_{2.5}$ was also indirectly and positively associated with PCS and MCS via sitting for leisure only (Fig. 2). In contrast, a study in Belgium (Hautekiet et al., 2022) found that an interquartile range (IQR) increment of either $PM_{2.5}$ or NO_2 long-term exposure was associated with higher odds of poor self-rated health. Also, a recent study based on the multi-site European Community Respiratory Health survey found higher NO_2, $PM_{2.5}$ and PM_{10} were associated with lower MCS (Boudier et al., 2022).

The difference between our findings and those from these European studies might be attributed to methodological differences in exposure assessment or the levels of air pollution in the two continents. The average annual concentrations of $PM_{2.5}$ and NO_2 in the present study were >50 % lower than those reported in Europe. For example, while the annual average concentration of $PM_{2.5}$ in our study was 6.3 $\mu g/m^3$, in 2020, 96 % of the European Union urban population were exposed to levels of $PM_{2.5}$ above the health-based guideline level set by the World Health Organization (European Environment Agency, 2022) which is 15 $\mu g/m^3$. It is possible that the levels and/or variability of $PM_{2.5}$ and NO_2 in our sample group is insufficient to have a clear effect on both components of HRQoL. Moreover, the positive associations of $PM_{2.5}$ and NO_2 with walking for transport suggest that, in our study, these measures might be proxies of access to destinations such as food outlets and retail, which were not accurately captured by our measures of access to services – namely, percentage of commercial land use and non-commercial land use mix. The same reasoning applies to the observed associations of these air pollutants with leisure-time sitting in the present study.

4.5. Strength and limitations

A strength of this study was the use of objective rather than perceived measures of the neighbourhood environment allowing a more robust assessment of potential causal relationships, given that perceptions of the environment and HRQoL are both influenced by poor mental health (Gotlib and Joormann, 2010; Kennair et al., 2022; Leslie & Cerin, 2008; Zhang et al., 2019). Another strength was the use of DAGs to determine minimal sufficient sets of confounders for the regression models estimating exposure-outcome, exposure-mediators and mediators-outcome associations based on a theoretical model of neighbourhood environmental influences on HRQoL that considered plausible causal effects among environmental attributes as well as lifestyle behaviours. Furthermore, this study accounted for neighbourhood self-selection by adjusting the regression models for physical activity-related reasons for living in a specific neighbourhood.

Study limitations include the cross-sectional nature of the available data, which limits the ability to estimate causal effects. The sample was not representative of the Australian urban population of mid-aged and older adults in terms of health because the third wave of AusDiab included relatively healthy individuals. Specifically, they were more physically active, less likely to smoke and more highly educated than those who dropped out from the study (Barnett et al., 2022; Cerin et al., 2021). This may have resulted in underestimated associations between environmental attributes and HRQoL. We relied on self-report measures of physical activity and sedentary behaviours which are known to be less accurate than device-based measures (Prince et al., 2020). Accuracy is especially a problem among people with cognitive difficulties, such as those arising from ageing-related cognitive decline (Shephard, 2003). These measures did not distinguish activities undertaken within the neighbourhood from those that were undertaken outside the neighbourhood of residence. Finally, the objective measures of access to a variety of services (percentage of commercial land and non-commercial land use mix) were not sufficiently specific to capture the presence of destinations important for daily living and, hence, HRQoL.

5. Conclusions and practical implications

We examined neighbourhood environmental correlates of HRQoL as measured by the SF-36 and the mediating roles of physical activity and sedentary behaviours in a national sample of Australian mid-aged and older adults. Only neighbourhood SES and average annual $PM_{2.5}$ concentrations showed significant total and direct associations with PCS in the expected direction. All other environmental attributes were related to the physical and mental components of HRQoL via physical activity behaviours and leisure-time sitting. Most environmental features had both positive and negative associations with physical activity and/or sedentary behaviours leading to null total associations with HRQoL.

Overall, neighbourhood SES appears to have beneficial effects on HRQoL by helping promote an active lifestyle and through other mechanisms that were not captured in this study. Built environment attributes defining neighbourhood walkability appear to have beneficial effects on HRQoL by promoting walking and resistance training and, through these, by helping decrease leisure-time sitting. However, some of these attributes may also lead to more sitting in mid-aged and older adults by limiting opportunities for household and gardening activities. Access to natural features may also promote some activities (e.g., resistance training, less sitting) and hinder others (gardening). These findings highlight the importance of examining the potential effects of the neighbourhood environment on the HRQoL through mediation analyses encompassing key inter-related neighbourhood environmental attributes (aspects of the built and natural environment and air pollution) and a variety of lifestyle behaviours theoretically linked to specific environmental features and HRQoL.

From an urban planning policy perspective, this study suggests that the creation of dense neighbourhoods typified by good access to commercial destinations and a well-connected street network may be beneficial to mid-aged and older adults' HRQoL by encouraging walking and participation in resistance training. The potentially negative effects of dense, walkable neighbourhoods on physical activity accrued through gardening appear to be limited in size and, probably, relevant to geographical contexts and cultures where gardening may contribute to a substantial amount of daily physical activity, such as Australia or the UK. The establishment of urban community gardens may help address this particular shortcoming of urban densification. That neighbourhood natural features (parkland and blue spaces) showed mixed associations with physical activity suggests that, to maximise their beneficial effects on HRQoL, they need to an integral part of dense, destination-rich neighbourhoods so that residents have a wide range of options that support an active lifestyle. Finally, our study suggests that urban planning and transportation policies that reduce ambient air pollution (e.g., establishment of low-emission zones, smart traffic lights, an efficient and affordable public transport network, urban gardens) are needed to enhance older residents' HRQoL.

CRediT authorship contribution statement

Anthony Barnett: Conceptualization, Methodology, Formal analysis, Writing – original draft, Funding acquisition. **Jonathan E. Shaw:** Investigation, Writing – review & editing, Funding acquisition. **Erika Martino:** Software, Writing – review & editing. **Luke D. Knibbs:** Methodology, Software, Writing – review & editing. **Govinda Poudel:** Writing – review & editing. **Neville Owen:** Investigation, Writing – review & editing, Funding acquisition. **Ester Cerin:** Conceptualization, Investigation, Methodology, Formal analysis, Writing – original draft, Funding acquisition.

Declaration of competing interest

None.

Data availability

Data that support the findings of this study are available on request under a license agreement. Written applications can be made to the AusDiab Steering Committee (Dianna.Magliano@baker.edu.au).

Acknowledgements

The AusDiab study, initiated and coordinated by the International Diabetes Institute, and subsequently coordinated by the Baker Heart and Diabetes Institute, gratefully acknowledges the support and assistance given by: B Atkins, B Balkau, E Barr, A Cameron, S Chadban, M de Courten, D Dunstan, A Kavanagh, D Magliano, S Murray, N Owen, K Polkinghorne, T Welborn, P Zimmet and all the study participants. Also, for funding or logistical support, we are grateful to: National Health and Medical Research Council (NHMRC grants 233200 and 1007544), Australian Government Department of Health and Ageing, Abbott Australasia Pty Ltd., Alphapharm Pty Ltd., Amgen Australia, AstraZeneca, Bristol-Myers Squibb, City Health Centre-Diabetes Service-Canberra, Department of Health and Community Services - Northern Territory, Department of Health and Human Services – Tasmania, Department of Health – New South Wales, Department of Health – Western Australia, Department of Health – South Australia, Department of Human Services – Victoria, Diabetes Australia, Diabetes Australia Northern Territory, Eli Lilly Australia, Estate of the Late Edward Wilson, GlaxoSmithKline, Jack Brockhoff Foundation, Janssen-Cilag, Kidney Health Australia, Marian & FH Flack Trust, Menzies Research Institute, Merck Sharp & Dohme, Novartis Pharmaceuticals, Novo Nordisk Pharmaceuticals, Pfizer Pty Ltd., Pratt Foundation, Queensland Health, Roche Diagnostics Australia, Royal Prince Alfred Hospital, Sydney, Sanofi Aventis, sanofi-synthelabo, and the Victorian Government's OIS Program. We also acknowledge the support from the Australian Research Council Centre of Excellence in Population Ageing Research. We are grateful to Mr. David H. Lee for contributing to the computation of environmental data.

Funding source declaration

This work was supported by a program grant ("The environment, active living and cognitive health: building the evidence base") from the Australian Catholic University [grant number ACURF18]. Jonathan E. Shaw is supported by a National Health and Medical Research Council (NHMRC) Investigator Grant [grant number 1173952].

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cities.2023.104538.

References

Adams, M. A., Frank, L. D., Schipperijn, J., Smith, G., Chapman, J., Christiansen, L. B., … Sallis, J. F. (2014). International variation in neighborhood walkability, transit, and recreation environments using geographic information systems: The IPEN adult study. *International Journal of Health Geographics, 13*(1), 43. https://doi.org/10.1186/1476-072X-13-43

Alcock, I., White, M. W., Pahl, S., Duarte-Davidson, R., & Fleming, L. E. (2020). Associations between pro-environmental behaviour and neighbourhood nature, nature visit frequency and nature appreciation: Evidence from a nationally representative survey in England. *Environment International, 136*, Article 105441. https://doi.org/10.1016/j.envint.2019.105441

Anstey, K. J., Sargent-Cox, K., Eramudugolla, R., Magliano, D. J., & Shaw, J. E. (2015). Association of cognitive function with glucose tolerance and trajectories of glucose tolerance over 12 years in the AusDiab study. *Alzheimer's Research & Therapy, 7*, 48. https://doi.org/10.1186/s13195-015-0131-4

Apostolaki, I., Pepa, A., Vlassopoulos, A., & Kapsokefalou, M. (2021). Social capital and self-perceived quality of life-interrelated predictors of mediterranean diet adherence in older adults. *Nutrients, 13*(9), 3100. https://doi.org/10.3390/nu13093100

Australian Bureau of Statistics. (1997). *National Health Survey, SF-36 population norms Australia*. Canberra: Australian Bureau of Statistics.

Australian Bureau of Statistics. (2011a). *Australian statistical geography standard (ASGS) volume 1 - Main structure and greater capital city statistical areas (cat no. 1270.0.55.001)*. Canberra: Australian Bureau of Statistics.

Australian Bureau of Statistics. (2011b). *Census of population and housing: Socio-Economic Indexes for Areas (SEIFA)*. Canberra: Australian Bureau of Statistics.

Australian Institute of Health and Welfare. (2003). *The active Australia survey: A guide and manual for implementation, analysis and reporting*. Canberra: Australian Institute of Health and Welfare.

Barnett, A., Cerin, E., Cheung, M. C., & Chan, W. M. (2015). An in-depth pilot study on patterns, destinations, and purposes of walking in Hong Kong older adults. *Journal of Aging and Physical Activity, 23*(1), 144–152.

Barnett, A., Martino, E., Knibbs, L. D., Shaw, J. E., Dunstan, D. W., Magliano, D. J., … Cerin, E. (2022). The neighbourhood environment and profiles of the metabolic syndrome. *Environmental Health, 21*(1), 80. https://doi.org/10.1186/s12940-022-00894-4

Barnett, D. W., Barnett, A., Nathan, A., Van Cauwenberg, J., Cerin, E., & on behalf of the Council on Environment and Physical Activity (CEPA) – Older Adults working group. (2017). Built environmental correlates of older adults' total physical activity and walking: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 103. https://doi.org/10.1186/s12966-017-0558-z

Bartsch, L. J., Butterworth, P., Byles, J. E., Mitchell, P., Shaw, J., & Anstey, K. J. (2011). Examining the SF-36 in an older population: Analysis of data and presentation of Australian adult reference scores from the Dynamic Analyses to Optimise Ageing (DYNOPTA) project. *Quality of Life Research, 20*(8), 1227–1236. https://doi.org/10.1007/s11136-011-9864-0

Bertheussen, G. F., Romundstad, P. R., Landmark, T., Kaasa, S., Dale, O., & Helbostad, J. L. (2011). Associations between physical activity and physical and mental health—A HUNT 3 study. *Medicine and Science in Sports and Exercise, 43*(7), 1220–1228. https://doi.org/10.1249/MSS.0b013e318206c66e (PMID:21131869).

Borders, T. F., Aday, L. A., & Xu, K. T. (2004). Factors associated with health-related quality of life among an older population in a largely rural western region. *Journal of Rural Health, 20*(1), 67–75. https://doi.org/10.1111/j.1748-0361.2004.tb00009.x

Boudier, A., Markevych, J., Jacquemin, B., Abramson, M. J., Accordini, S., Forsberg, B., … Siroux, V. (2022). Long-term air pollution exposure, greenspace and health-related quality of life in the ECRHS study. *Science of the Total Environment, 849*, Article 157693. https://doi.org/10.1016/j.scitotenv.2022.157693

Bowling, A., Barber, J., Morris, R., & Ebrahim, S. (2006). Do perceptions of neighbourhood environment influence health? Baseline findings from a British survey of aging. *Journal of Epidemiology & Community Health, 60*(6), 476–483.

Braithwaite, I., Zhang, S., Kirkbride, J. B., Osborn, D. P. J., & Hayes, J. F. (2019). Air pollution (particulate matter) exposure and associations with depression, anxiety, bipolar, psychosis and suicide risk: A systematic review and meta-analysis. *Environmental Health Perspectives, 127*(12), Article 126002. https://doi.org/10.1289/EHP4595

Brereton, F. J., Clinch, J. P., & Ferreira, S. (2008). Happiness, geography and the environment. *Ecological Economics, 65*(2), 386–396. https://doi.org/10.1016/j.ecolecon.2007.07.008

Brown, D. W., Balluz, L. S., Heath, G. W., Moriarty, D. G., Ford, E. S., Giles, W. H., & Mokdad, A. H. (2003). Associations between recommended levels of physical activity and health-related quality of life. Findings from the 2001 Behavioral Risk Factor Surveillance System (BRFSS) survey. *Preventive Medicine, 37*(5), 520–528. https://doi.org/10.1016/S0091-7435(03)00179-8

Byles, J., Powers, J., Chojenta, C., & Warner-Smith, P. (2006). Older women in Australia: Ageing in urban, rural and remote environments. *Australasian Journal on Ageing, 25*(3), 151–157. https://doi.org/10.1111/j.1741-6612.2006.00171.x

Byles, J. E., Mackenzie, L., Redman, S., Parkinson, L., Leigh, L., & Curryer, C. (2014). Supporting housing and neighbourhoods for healthy ageing: Findings from the Housing and Independent Living Study (HAIL). *Australasian Journal of Ageing, 33*(1), 29–35. https://doi.org/10.1111/j.1741-6612.2012.00646.x

Cerin, E., Barnett, A., Shaw, J. E., Martino, E., Knibbs, L. D., Tham, R., … Anstey, K. J. (2021). From urban neighbourhood environments to cognitive health: a cross-sectional analysis of the role of physical activity and sedentary behaviours. *BMC Public Health, 21*(1), 2320. https://doi.org/10.1186/s12889-021-12375-3

Cerin, E, Barnett, A, Shaw, J. E., Martino, E, Knibbs, L. D., Tham, R., … Anstey, K. J. (2022). Urban neighbourhood environments, cardiometabolic health and cognitive function: a national cross-sectional study of middle-aged and older adults in Australia. *Toxics, 10*(1), 23. https://doi.org/10.3390/toxics10010023

Cerin, E., Barnett, A., Wu, Y. T., Martino, E., Shaw, J. E., Knibbs, L. D., … Anstey, K. J. (2023). Do neighbourhood traffic-related air pollution and socio-economic status moderate the associations of the neighbourhood physical environment with cognitive function? Findings from the AusDiab study. *Science of the Total Environment, 858*(Pt 3), Article 160028. https://doi.org/10.1016/j.scitotenv.2022.160028

Cerin, E., Barnett, A., Zhang, C. J. P., Lai, P. C., Sit, C. H. P., & Lee, R. S. Y. (2020). How urban densification shapes walking behaviours in older community dwellers: A cross-sectional analysis of potential pathways of influence. *International Journal of Health Geography, 19*(1), 14. https://doi.org/10.1186/s12942-020-00210-8

Cerin, E., Conway, T. L., Cain, K. L., Kerr, J., De Bourdeaudhuij, I., Owen, N., … Sallis, J. F. (2013). Sharing good NEWS across the world: Developing comparable scores across 12 countries for the Neighborhood Environment Walkability Scale (NEWS). *BMC Public Health, 13*, 309. https://doi.org/10.1186/1471-2458-13-309

Cerin, E., Nathan, A., van Cauwenberg, J., Barnett, D. W., Barnett, A., & on behalf of the Council on Environment and Physical Activity (CEPA) – Older Adults working group. (2017). The neighbourhood physical environment and active travel in older adults: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 14*(1), 15. https://doi.org/10.1186/s12966-017-0471-5

Cerin, E., Sit, C. H., Cheung, M. C., Ho, S. Y., Lee, L. C., & Chan, W. M. (2010). Reliable and valid NEWS for Chinese seniors: Measuring perceived neighborhood attributes related to walking. *International Journal of Behavioral Nutrition and Physical Activity, 7*, 84. https://doi.org/10.1186/1479-5868-7-84

Cerin, E., Sit, C. H., Zhang, C. J., Barnett, A., Cheung, M. M., Lai, P. C., … Lee, R. S. (2016). Neighbourhood environment, physical activity, quality of life and depressive symptoms in Hong Kong older adults: A protocol for an observational study. *BMJ Open, 6*(1), Article e010384.

Cerin, E., Van Dyck, D., Zhang, C. J. P., Van Cauwenberg, J., Lai, P. C., & Barnett, A. (2020). Urban environments and objectively-assessed physical activity and sedentary time in older Belgian and Chinese community dwellers: Potential pathways of influence and the moderating role of physical function. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 73. https://doi.org/10.1186/s12966-020-00979-8

Chiatti, C., Westerlund, Y., & Ståhl, A. (2017). Access to public mobility services and health in old age: A cross-sectional study in three Swedish cities. *Journal of Transport & Health, 7*, 218–226. https://doi.org/10.1016/j.jth.2017.09.001

Clark, B. K., Lynch, B. M., Winkler, E. A., Gardiner, P. A., Healy, G. N., Dunstan, D. W., & Owen, N. (2015). Validity of a multi context sitting questionnaire across demographically diverse population groups: AusDiab3. *International Journal of Behavioral Nutrition and Physical Activity, 12*, 148. https://doi.org/10.1186/s12966-015-0309-y

Compernolle, S., De Bourdeaudhuij, I., Cardon, G., & Van Dyck, D. (2021). Sex-specific typologies of older adults' sedentary behaviors and their associations with health-related and socio-demographic factors: A latent profile analysis. *BMC Geriatrics, 21*(1), 66. https://doi.org/10.1186/s12877-021-02011-5

Coogan, P. F., White, L. F., Evans, S. R., Palmer, J. R., & Rosenberg, L. (2012). The influence of neighborhood socioeconomic status and walkability on TV viewing time. *Journal of Physical Activity & Health, 9*(8), 1074–1079. https://doi.org/10.1123/jpah.9.8.1074

Crossman, S., & Li, O. (2015). *Surface hydrology polygons (national)*. Canberra: Geoscience Australia.

De Vries, S., ten Have, M., van Dorsselaer, S., van Wezep, M., Hermans, T., & de Graaf, R. (2016). Local availability of green and blue space and prevalence of common mental disorders in the Netherlands. *BJPsych Open, 2*(6), 366–372. https://doi.org/10.1192/bjpo.bp.115.002469

Dunstan, D. W., Zimmet, P. Z., Welborn, T. A., Cameron, A. J., Shaw, J. E., de Courten, M, … McCarthy, DJ. (2002). The Australian Diabetes, Obesity and Lifestyle Study (AusDiab) - Methods and response rates. *Diabetes Research and Clinical Practice, 57*, 119–129. https://doi.org/10.1016/S0168-8227(02)00025-6.diab

European Environment Agency. (2022). Air quality in Europe. https://www.eea.europa.eu/publications/air-quality-in-europe-2022#:~:text=Air%20pollution%20is%20a%20major,by%20the%20World%20Health%20Organization.

Fan, H., Wang, Y., Wang, Y., & Coyte, P. C. (2022). The impact of environmental pollution on the physical health of middle-aged and older adults in China. *Environmental Science Pollution Research International, 29*(3), 4219–4231. https://doi.org/10.1007/s11356-021-15832-z

Frank, L. D., Sallis, J. F., Saelens, B. E., Leary, L., Cain, K., Conway, T. L., & Hess, P. M. (2010). Development of a walkability index: Application to the neighbourhood quality of life study. *British Journal of Sports Medicine, 44*, 924–933. https://doi.org/10.1136/bjsm.2009.058701

Freeston, J., Gale, J., Mavros, Y., Bennie, J. A., Pedisic, Z., Bauman, A. E., & Stamatakis, E. (2017). Associations between multiple indicators of socio-economic status and muscle-strengthening activity participation in a nationally representative population sample of Australian adults. *Preventive Medicine, 102*, 44–48. https://doi.org/10.1016/j.ypmed.2017.06.020

Gardner, B., Iliffe, S., Fox, K. R., Jefferis, B. J., & Hamer, M. (2014). Sociodemographic, behavioural and health factors associated with changes in older adults' TV viewing over 2 years. *International Journal of Behavioral Nutrition and Physical Activity, 11*(1), 102. https://doi.org/10.1186/s12966-014-0102-3

Garrett, J. K., Clitherrow, T. J., White, M. P., Elliot, L. R., Wheeler, B. W., & Fleming, L. E. (2019). Coastal proximity and mental health among urban adults in England: The moderating effect of household income. *Health & Place, 59*, Article 102200. https://doi.org/10.1016/j.healthplace.2019.102200

Garrett, J. K., White, M. P., Huang, J., Ng, S., Hui, Z., Leung, C., … Wong, M. C. S. (2019). Urban blue space and health and wellbeing in Hong Kong: Results from a survey of older adults. *Health & Place, 55*, 100–110. https://doi.org/10.1016/j.healthplace.2018.11.003

Gong, Y., Palmer, S., Gallacher, J., Marsden, T., & Fone, D. (2016). A systematic review of the relationship between objective measurements of the urban environment and psychological distress. *Environment International, 96*, 48–57. https://doi.org/10.1016/j.envint.2016.08.019

Gotlib, I. H., & Joormann, J. (2010). Cognition and depression: Current status and future directions. *Annual Review of Clinical Psychology, 6*, 285–312. https://doi.org/10.1146/annurev.clinpsy.121208.131305

Grigoletto, A., Mauro, M., Maietta Latessa, P., Iannuzzi, V., Gori, D., Campa, F., … Toselli, S. (2021). Impact of different types of physical activity in green urban space on adult health and behaviors: A systematic review. *European Journal of Investigation

in Health, Psychology and Education, 11(1), 263–275. https://doi.org/10.3390/ejihpe11010020
Gunn, L. D., King, T. L., Mavoa, S., Lamb, K., Giles-Corti, B., & Kavanagh, A. (2017). Identifying destination distances that support walking trips in local neighborhoods. *Journal of Transport and Health, 5*, 33–141. https://doi.org/10.1016/j.jth.2016.08.009
Han, A., Kim, J., & Kim, J. (2021). A study of leisure walking intensity levels on mental health and health perception of older adults. *Gerontology and Geriatric Medicine, 7*. https://doi.org/10.1177/2333721421999316, 2333721421999316.
Hart, P. D., & Buck, D. J. (2019). The effect of resistance training on health-related quality of life in older adults: Systematic review and meta-analysis. *Health Promotion Perspectives, 9*(1), 1–12. https://doi.org/10.15171/hpp.2019.01
Hautekiet, P., Saenen, N. D., Demarest, S., Keune, H., Pelgrims, I., Van der Heyden, J., … Nawrot, T. S. (2022). Air pollution in association with mental and self-rated health and the mediating effect of physical activity. *Environmental Health, 21*(1), 29. https://doi.org/10.1186/s12940-022-00839-x
Helbich, M., Yao, Y., Liu, Y., Zhang, J., Liu, P., & Wang, R. (2019). Using deep learning to examine street view green and blue spaces and their associations with geriatric depression in Beijing, China. *Environment International, 126*, 107–117. https://doi.org/10.1016/j.envint.2019.02.013
Hu, Q., Feng, Y., & Xu, M. (2021). Are there heterogeneous impacts of air pollution on mental health? *Frontiers in Public Health, 9*, Article 780022. https://doi.org/10.3389/fpubh.2021.780022
Hwang, M. J., Kim, J. H., & Cheong, H. K. (2020). Short-term impacts of ambient air pollution on health-related quality of life: A Korea health panel survey study. *International Journal Environmental Research and Public Health, 17*(23), 9128. https://doi.org/10.3390/ijerph17239128
Ju, K., Lu, L., Chen, T., Duan, Z., Chen, D., Liao, W., … Wang, W. (2022). Does long-term exposure to air pollution impair physical and mental health in the middle-aged and older adults?- a causal empirical analysis based on a longitudinal nationwide cohort in China. *Science of Total Environment, 827*, Article 154312. https://doi.org/10.1016/j.scitotenv.2022.154312
Kamphuis, C. B., Van Lenthe, F. J., Giskes, K., Huisman, M., Brug, J., & Mackenbach, J. P. (2008). Socioeconomic status, environmental and individual factors, and sports participation. *Medicine & Science of Sports and Exercise, 40*(1), 71–81. https://doi.org/10.1249/mss.0b013e318158e467
Kennair, L. E. O., Hagen, R., Hjemdal, O., Havnen, A., Ryum, T., & Solem, S. (2022). Depression, anxiety, insomnia, and quality of life in a representative community sample of older adults living at home. *Frontiers in Psychology, 13*, Article 811082. https://doi.org/10.3389/fpsyg.2022.811082
Knibbs, L. D., Coorey, C. P., Bechle, M. J., Cowie, C. T., Dirgawati, M., Heyworth, J. S, … Hewson, M. G. (2016). Independent validation of national satellite-based land-use regression models for nitrogen dioxide using passive samplers. *Environmental Science & Technology, 50*(22), 12331–12338. https://doi.org/10.1021/acs.est.6b03428.40
Knibbs, L. D., Hewson, M. G., Bechle, M. J., Marshall, J. D., & Barnett, A. G. (2014). A national satellite-based land-use regression model for air pollution exposure assessment in Australia. *Environment Research, 135*, 204–211. https://doi.org/10.1016/j.envres.2014.09.011.41
Knibbs, L. D., van Donkelaar, A., Martin, R. V., Bechle, M. J., Brauer, M., Cohen, D. D., … Barnett, A. G. (2018). Satellite-based land-use regression for continental-scale long-term ambient PM2.5 exposure assessment in Australia. *Environmental Science & Technology, 52*(21), 12445–12455. https://doi.org/10.1021/acs.est.8b02328
Langhammer, B., Bergland, A., & Rydwik, E. (2018). The importance of physical activity exercise among older people. *BioMed Research International, 2018*, 7856823. https://doi.org/10.1155/2018/7856823
Leslie, E., & Cerin, E. (2008). Are perceptions of the local environment related to neighbourhood satisfaction and mental health in adults? *Preventive Medicine, 47*(3), 273–278. https://doi.org/10.1016/j.ypmed.2008.01.014
Leslie, E., Coffee, N., Frank, L., Owen, N., Bauman, A., & Hugo, G. (2007). Walkability of local communities: Using geographic information systems to objectively assess relevant environmental attributes. *Health & Place, 13*(1), 111–122. https://doi.org/10.1016/j.healthplace.2005.11.001
Levinger, I., Goodman, C., Hare, D. L., Jerums, G., & Selig, S. (2007). The effect of resistance training on functional capacity and quality of life in individuals with high and low numbers of metabolic risk factors. *Diabetes Care, 30*(9), 2205–2210.
Loo, B. P. Y., Lam, W. W. Y., Mahendran, R., & Katagiri, K. (2017). How is the neighborhood environment related to the health of seniors living in Hong Kong, Singapore, and Tokyo? Some insights for promoting aging in place. *Annals of the American Association of Geographers, 107*(4), 812–828. https://doi.org/10.1080/24694452.2016.1271306
Lucumí, D. I., Gomez, L. F., Brownson, R. C., & Parra, D. C. (2015). Social capital, socioeconomic status, and health-related quality of life among older adults in Bogotá (Colombia). *Journal of Aging and Health, 27*(4), 730–750. https://doi.org/10.1177/0898264314556616
Luo, H., & Menec, V. (2018). Social capital and health among older Chinese immigrants: A cross-sectional analysis of a sample in a Canadian prairie city. *Journal of Cross-Cultural Gerontology, 33*, 65–81. https://doi.org/10.1007/s10823-017-9342-4
Ma, X., & McGhee, S. M. (2013). A cross-sectional study on socioeconomic status and health-related quality of life among elderly Chinese. *BMJ Open, 3*, Article e002418. https://doi.org/10.1136/bmjopen-2012-002418
Macintyre, S., Ellaway, A., & Cummins, S. (2002). Place effects on health: How can we conceptualise, operationalise and measure them? *Social Science & Medicine, 55*(1), 125–139. https://doi.org/10.1016/S0277-9536(01)00214-3
MacKinnon, D. P., & Fairchild, A. J. (2009). Current directions in mediation analysis. *Current Directions in Psychological Science, 18*(1), 16–20. https://doi.org/10.1111/j.1467-8721.2009.01598.x
MacKinnon, D. P., Lockwood, C. M., Hoffman, J. M., West, S. G., & Sheets, V. (2002). A comparison of methods to test mediation and other intervening variable effects. *Psychological Methods, 7*(1), 83–104. https://doi.org/10.1037/1082-989x.7
Moran, M., Van Cauwenberg, J., Hercky-Linnewiel, R., Cerin, E., Deforche, B., & Plaut, P. (2014). Understanding the relationships between the physical environment and physical activity in older adults: A systematic review of qualitative studies. *International Journal of Behavioral Nutrition and Physical Activity, 11*, 79. https://doi.org/10.1186/1479-5868-11-79
Mortimer, D., & Segal, L. (2008). Comparing the incomparable? A systematic review of competing techniques for converting descriptive measures of health status into QALY-weights. *Medical Decision Making, 28*(1), 66–89. https://doi.org/10.1177/0272989X07309642
Owen, N., Cerin, E., Leslie, E., duToit, L., Coffee, N., Frank, L. D., … Sallis, J. F. (2007). Neighborhood walkability and the walking behavior of Australian adults. *American Journal of Preventive Medicine, 33*(5), 387–395. https://doi.org/10.1016/j.amepre.2007.07.025
Parra, D. C., Gomez, L. F., Sarmiento, O. L., Buchner, D., Brownson, R., Schimd, T., … Lobelo, F. (2010). Perceived and objective neighborhood environment attributes and health related quality of life among the elderly in Bogotá, Colombia. *Social Science and Medicine, 70*(7), 1070–1076. https://doi.org/10.1016/j.socscimed.2009.12.024
Pearson, A. L., Shortridge, A., Delamater, P. L., Horton, T. H., Dahlin, K., Rzotkiewicz, A., & Marchiori, M. J. (2019). Effects of freshwater blue spaces may be beneficial for mental health: A first, ecological study in the North American Great Lakes region. *PLoS One, 14*(8), Article e0221977. https://doi.org/10.1371/journal.pone.0221977
Pickett, K. E., & Pearl, M. (2001). Multilevel analyses of neighbourhood socioeconomic context and health outcomes: A critical review. *Journal of Epidemiology and Community Health, 55*(2), 111–122. https://doi.org/10.1136/jech.55.2.111
Population Division of the United Nations Department of Economic and Social Affairs (UN DESA). (2020). World population ageing 2020. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/files/documents/2020/Sep/un_pop_2020_pf_ageing_10_key_messages.pdf.
Population Division of the United Nations, Department of Economic and Social Affairs (UN DESA) United Nations, & Department of Economic and Social Affairs, Population Division. (2014). *Urban and rural population by age and sex, 1980–2015*. New York: United Nations. https://esa.un.org/unpd/popdev/urpas/urpas2014.aspx.
Prince, S. A., Cardilli, L., Reed, J. L., Saunders, T. J., Kite, C., Douillette, K., … Buckley, J. P. (2020). A comparison of self-reported and device measured sedentary behaviour in adults: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity, 17*(1), 1–17. https://doi.org/10.1186/S12966-020-00938-3
PSMA Australia Ltd. (2012). *PSMA street network*.
R Core Team. (2020). *R. A language and environment for statistical computing.* Vienna, Austria: R Foundation for Statistical computing.
Rocha, V., Ribeiro, A. I., Severo, M., Barros, H., & Fraga, S. (2017). Neighbourhood socioeconomic deprivation and health-related quality of life: A multilevel analysis. *PLoS One, 12*(12), Article e0188736. https://doi.org/10.1371/journal.pone.0188736
Ruben, D. B. (1987). *Multiple imputation for non-response in surveys.* New York, NY: Wiley J & Sons.
Scott, M. (2021). Planning for age-friendly cities. *Planning Theory & Practice, 22*(3), 457–492. https://doi.org/10.1080/14649357.2021.1930423
Sheather, S. (2009). *A modern approach to regression with R.* New York, NY: Springer.
Shephard, R. J. (2003). Limits to the measurement of habitual physical activity by questionnaires. *British Journal of Sports Medicine, 37*(3), 197–206. https://doi.org/10.1136/BJSM.37.3.197
Siceloff, E. R., Coulon, S. M., & Wilson, D. K. (2014). Physical activity as a mediator linking neighborhood environmental supports and obesity in African Americans in the path trial. *Health Psychology, 33*(5), 481–489.
Stephens, C., Allen, J., Keating, N., Szabó, Á., & Alpass, F. (2020). Neighborhood environments and intrinsic capacity interact to affect the health-related quality of life of older people in New Zealand. *Maturitas, 139*, 1–5. https://doi.org/10.1016/j.maturitas.2020.05.008
Stier, A. J., Schertz, K. E., Rim, N. W., Cardenas-Iniguez, C., Lahey, B. B., Bettencourt, L. M. A., & Berman, M. G. (2021). Evidence and theory for lower rates of depression in larger US urban areas. *Proceedings of the National Academy of Sciences of the United States of America, 118*(31), Article e2022472118. https://doi.org/10.1073/pnas.2022472118
Tanamas, S. K., Magliano, D. J., Lynch, B. M., Sethi, P., Willenberg, L., Polkinghorne, K. R., … Shaw, J. E. (2013). *AusDiab 2012: The Australian Diabetes, Obesity and Lifestyle Study*. Melbourne, Australia: Baker: Heart and Diabetes Institute.
Textor, J., van der Zander, B., Gilthorpe, M. S., Liskiewicz, M., & Ellison, G. T. (2016). Robust causal inference using directed acyclic graphs: The R package "dagitty". *International Journal of Epidemiology, 45*(6), 1887–1894. https://doi.org/10.1093/ije/dyw341
Tomey, K., Diez Roux, A. V., Clarke, P., & Seeman, T. (2013). Associations between neighborhood characteristics and self-rated health: A cross-sectional investigation in the Multi-Ethnic Study of Atherosclerosis (MESA) cohort. *Health & Place, 24*, 267–274. https://doi.org/10.1016/j.healthplace.2013.10.001
Valdivieso-Mora, E., Ivanisevic, M., Shaw, L. A., Garnier-Villarreal, M., Green, Z. D., Salazar-Villanea, M., … Johnson, D. K. (2018). Health-related quality of life of older adults in Costa Rica as measured by the Short-Form-36 Health Survey. *Gerontology and Geriatric Medicine, 4*. https://doi.org/10.1177/2333721418782812, 2333721418782812.
Van Buuren, S. (2018). *Flexible imputation of missing data* (2 ed.). Boca Raton, Florida: Chapman & Hall.

Van Buuren, S., & Groothuis-Oudshoorn, K. (2011). mice: Multivariate imputation by chained equations in R. *Journal of Statistical Software, 45*(3), 1–67. https://doi.org/10.18637/jss.v045.i03

Van Cauwenberg, J., Nathan, A., Barnett, A., Barnett, D. W., Cerin, E., & on behalf of the Council on Environment and Physical Activity (CEPA)-Older Adults Working Group. (2018). Relationships between neighbourhood physical environmental attributes and older adults' leisure-time physical activity: A systematic review and meta-analysis. *Sports Medicine, 48*(7), 1635–1660. https://doi.org/10.1007/s40279-018-0917-1

Van Dyck, D., Cardon, G., & De Bourdeaudhuij, I. (2016). Longitudinal changes in physical activity and sedentary time in adults around retirement age: What is the moderating role of retirement status, gender and educational level? *BMC Public Health, 16*(1), 1125. https://doi.org/10.1186/s12889-016-3792-4

Van Dyck, D., Teychenne, M., McNaughton, S. A., De Bourdeaudhuij, I., & Salmon, J. (2015). Relationship of the perceived social and physical environment with mental health-related quality of life in middle-aged and older adults: Mediating effects of physical activity. *PLoS One, 10*(3), Article e0120475. https://doi.org/10.1371/journal.pone.0120475

Völker, S., Heiler, A., Pollmann, T., Claßen, T., Hornberg, C., & Kistemann, T. (2018). Do perceived walking distance to and use of urban blue spaces affect self-reported physical and mental health? *Urban Forestry & Urban Greening, 29*, 1–9. https://doi.org/10.1016/j.ufug.2017.10.014

Ware, J. (2000). SF-36 health survey update. *Spine, 25*(24), 3130–3139.

White, M. P., Elliot, L. R., Gascon, M., Roberts, B., & Fleming, L. E. (2020). Blue space, health and well-being: A narrative overview and synthesis of potential benefits. *Environmental Research, 191*, 10169. https://doi.org/10.1016/j.envres.2020.110169

Wood, S. N. (2017). *Generalised additive models: An introduction with R* (2nd ed.). Bocan Raton, FL: Chapman & Hall/CRC.

Yamazaki, S., Nitta, H., Murakami, Y., & Fukuhara, S. (2005). Association between ambient air pollution and health-related quality of life in Japan: Ecological study. *International Journal of Environmental Health Research, 15*(5), 383–391. https://doi.org/10.1080/09603120500292279

Zhang, C. J. P., Barnett, A., Ming, W.-K., Lai, P.-C., Lee, R. S. Y., & Cerin, E. (2023). How urban environments affect quality of life in older socio-demographic groups: the role of physical activity behaviour. In R. W. Marans, R. J. Stimson, & N. J. Webster (Eds.), *Handbook of quality of life research: Place and space perspectives*. Cheltenham, U.K.: Edward Elgar Publishing (Forthcoming).

Zhang, C. J. P., Barnett, A., Sit, C. H. P., Lai, P.-c., Johnston, J. M., Lee, R. S. Y., & Cerin, E. (2019). To what extent does physical activity explain the associations between neighborhood environment and depressive symptoms in older adults living in an Asian metropolis? *Mental Health and Physical Activity, 16*, 96–104. https://doi.org/10.1016/j.mhpa.2018.11.005

Zhang, F., Li, D., & Chan, A. P. C. (2020). Diverse contributions of multiple mediators to impact of perceived neighborhood environment on the overall quality of life of community-dwelling seniors: A cross-sectional study in Nanjing, China. *Habitat International, 104*, Article 102253. https://doi.org/10.1016/j.habitatint.2020.102253

Zhao, Y., & Chung, P. K. (2017). Neighborhood environment walkability and health-related quality of life among older adults in Hong Kong. *Archives of Gerontology and Geriatrics, 73*, 182–186. https://doi.org/10.1016/j.archger.2017.08.003

Zhou, B., Chen, K., Wang, J., Wang, H., Zhang, S., & Zheng, W. (2011). Quality of life and related factors in the older rural and urban Chinese populations in Zhejiang province. *Journal of Applied Gerontology, 30*(2), 199–225. https://doi.org/10.1177/0733464810361346