Current Environmental Health Reports (2020) 7:65–88
https://doi.org/10.1007/s40572-020-00264-7

AIR POLLUTION AND HEALTH (T NAWROT, SECTION EDITOR)

Long-Term Exposure to Residential Greenspace and Healthy Ageing: a Systematic Review

Carmen de Keijzer[1,2,3] • Mariska Bauwelinck[4,5] • Payam Dadvand[1,2,3]

Published online: 24 January 2020

Abstract

Purpose of Review We systematically reviewed the available observational evidence on the association between long-term exposure to residential outdoor greenspace and health at older age and rated the evidence as sufficient, limited, or inadequate.

Recent Findings We identified 59 studies, ranging from poor to very good quality. The health outcomes included mental health ($N = 12$, of which three were longitudinal studies and eight were rated to be of good quality), cognitive function ($N = 6$; two longitudinal studies, five of good/very good quality), physical capability ($N = 22$; five longitudinal studies, six of good/very good quality), cardiometabolic risk ($N = 9$; one longitudinal study, five of good/very good quality), morbidity ($N = 11$; three longitudinal studies, six of good/very good quality) and perceived wellbeing ($N = 9$; all cross-sectional, two of good quality). The evidence for a beneficial association with greenspace was rated limited for morbidity and inadequate for mental health, cognitive function, physical capability, cardiometabolic risk and perceived wellbeing.

Summary The reviewed studies provided inadequate/limited but suggestive evidence for a beneficial association between greater long-term greenspace exposure and healthy ageing. This review highlights the need of longitudinal studies that assess the association between long-term greenspace exposure and the trajectory of objective indicators of ageing.

Keywords Natural environment · Elderly · Health · Greenspace · Ageing · Park

Introduction

The twenty-first century is characterized by the ageing of the world's population. Between 2017 and 2050, the number of adults aged 60 years and over is projected to more than double from 962 million to approximately 2.1 billion [1]. Considering this important demographic shift, factors that support healthy ageing are increasingly important. Healthy ageing is defined by the WHO as "the process of developing and maintaining the functional ability that enables wellbeing in older age" [2] and may be partially determined by environmental factors [3–6]. In this context, healthy ageing may be supported by exposure to outdoor greenspace.

Recent studies have found that long-term exposure to greenspace was associated with improved health, including better self-perceived general health and mental health, lower risk of type II diabetes, and decreased mortality [7, 8]. The association between greenspace and health may be modified by age as some studies observed that the association was stronger among older adults [9, 10]. However, the evidence for an association between long-term exposure to greenspace and health among the older population has not been systematically reviewed yet. So far, one systematic review summarized the evidence for an association between exposure to nature-based solutions and urbanization-related health risks in the older population, including only a selection of health outcomes [11].

This article is part of the Topical Collection on *Air Pollution and Health*

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s40572-020-00264-7) contains supplementary material, which is available to authorized users.

✉ Payam Dadvand
payam.dadvand@isglobal.org

1 Instituto de Salud Global de Barcelona (ISGlobal), Barcelona Biomedical Research Park (PRBB), Doctor Aiguader 88, 08003 Barcelona, Spain

2 Universitat Pompeu Fabra (UPF), Barcelona, Spain

3 CIBER Epidemiología y Salud Pública (CIBERESP), Madrid, Spain

4 Research Foundation - Flanders (FWO), Brussels, Belgium

5 Interface Demography (ID), Department of Sociology, Vrije Universiteit Brussel, Brussels, Belgium

Therefore, the aim of this study was to systematically review the existing evidence on the association between long-term exposure to outdoor greenspace and healthy ageing. We focused solely on outdoor residential greenspace, since the evidence of the association between indoor exposure to nature and health in older adults had been reviewed recently [12].

Methods

Selection Criteria

The selection criteria applied for this review were the following: (*a*) the article was available in English and concerned an original research article of an observational study. Review articles, experimental studies and qualitative studies were excluded. (*b*) The association with a health outcome at older age was reported. We included studies on any health outcome, including physical and mental health, wellbeing, overall quality of life and outcomes concerning functioning such as cognitive and physical function. We also considered physical activity as an indicator of physical functioning as this outcome is strongly interrelated with mobility [13, 14]. However, studies on mortality and longevity were excluded, because these outcomes could not provide information on the quality of life at older age (i.e. healthy ageing). Additionally, the evidence for the association with residential greenspace exposure and mortality has been recently systematically reviewed [7]. (*c*) At least one of the exposures was a quantified measure of long-term greenspace exposure. Studies were excluded if the exposure variable did not assess long-term exposure, was not quantified (for instance, binary variables such as presence or absence of a park without an indication of the objective or perceived distance) or was not assessed as separate predictor of health (e.g. a land use mix, a built environment index or the percentage of green and open areas together). We excluded articles on gardening, since a recent review is available on the evidence of the association between gardening and health [15, 16]. (*d*) The study population consisted of older adults. While older adults are frequently defined by age 60 and older [1], studies have applied different definitions of older age. In this case, we accepted the definition of older age as given by the study. In addition, as healthy ageing is a process over time and as the age-related decline in body functions may start in middle adulthood, we included studies that include both middle-aged and older adults. Middle adulthood (or midlife) is commonly defined as starting at 40 or 45 years old. Studies including study populations with a minimum age between 35 and 40 years were considered if only a small proportion (< 10%) of the study population was < 40 years old. Last, studies were excluded if the study population only consisted of patients or other non-healthy populations (e.g. populations with dementia at baseline).

Search Strategy

We first searched freely to collect relevant articles to construct an extensive list of keywords that capture articles within the scope of our review (i.e. exposure to greenspace and healthy ageing). We created the search terms based on a combination of greenspace keywords, health keywords and age keywords. The *greenspace* keywords contained green space(s) or greenspace(s), natural environment(s), outdoor environment(s), natural outdoor environment(s), natural space(s), outdoor environment(s), open space(s), park(s), greenness, green area(s), vegetation, tree cover, VCF, land cover, greenery, garden(s), residential green, nature-based solution(s), nature contact and contact with nature. The *health* keywords included health, healthy, wellbeing or well-being, quality of life, disease(s), morbidity, life expectancy, longevity, mortality, survival, cognitive decline, physical functioning, dementia, frailty, deterioration, impairment and activity/activities of daily living. The *age* keywords encompassed older, oldest, oldest-older, middle-aged, mid-aged, mid-older, middle-to-older, elderly, senior, aged, aging, ageing, life course, geriatric, age friendly or age-friendly, retired and retirement. To narrow down the search, we excluded the keywords child, children, adolescent(s), youth and gardening.

We used this list of search terms to extract articles from both PubMed (National Library of Medicine) and Scopus. The search was conducted on March 22, 2019. The retrieved articles were inserted into the online tool Rayyan [17], which facilitates the management of the search results. Articles that clearly did not meet the selection criteria were first excluded based on the screening of the title and the abstract. Afterwards, the full texts of the remaining articles were analysed by two reviewers (CK and MB) independently to decide which articles met the selection criteria and were to be included in the review. The reviewers discussed articles that were subject of disagreement to reach a consensus on the included articles. Last, we scanned through the references of the selected articles to identify relevant additional articles.

Quality Assessment

First, we extracted the following information from the selected studies: study design, study population, sample size, exposure assessment, outcome assessment, main results and additional findings, statistical analysis, covariates and other relevant information (Table 1 and Table S1). Next, we composed 12 quality criteria to score each study (Table S2). These criteria were adapted from previous reviews on health benefits of greenspace exposure [57–59]. A score of 0, 1 or 2 points was assigned for each criterion. The two reviewers scored the articles independently and discussed points of disagreement to harmonize the scores. For each study, the points obtained for all criteria were summed up and converted into a

Table 1 Main characteristics of selected articles on long-term greenspace exposure and mental health, cognitive function and physical capability at older age

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
Mental health								
[18]	C	Adults, 45–106 years (New South Wales, Australia)	260,061	Land use (Australian Bureau of Statistics); parkland	Proportion of parkland in a 1-km buffer around the population weighted small area centroid, in quartiles	Survey: Kessler Psychological Distress Scale (K10)	Psychological distress: Kessler scores of ≥ 22 (yes/no)	+
[19]	L, 10 years	Female nurses, ≥ 54 years (USA)	38,947	Satellite images (MODIS), NDVI, 250 × 250 m, obtained in July of each follow-up year	NDVI within 250-m and 1250-m circular buffers around the residential address, in quintiles	Survey: Diagnosis by physician/clinician of depression or new use of antidepressants	Depression (yes/no)	+
[20]	C	Medicare beneficiaries, ≥ 65 years (Miami-Dade, Florida, USA)	249,405	Satellite images (NASA), NDVI, 15 m × 15 m, annual average	NDVI in County Census Blocks	Chronic Conditions Segment of the CMS' Master Beneficiary Summary File	Depression (yes/no)	+
[21]	E	Nursing home care facilities, avg. age 65 years (USA)	9186	Tree canopy map, (National Land Cover database 2011), 30 × 30 m	Percentage of tree canopy cover within 250, 500, 1000 and 3000 m donut-shaped buffers around each facility	Surveys: two questionnaires including the PHQ-9	Depression: percentage of long-term stay residents with depressive symptoms	+
[22]	C	Adults ≥ 60 years (Haidian district,	1190	(a) Street view images (Tencent Street	(a) Ratio of greenspace pixels to the total pixels	Survey: shortened Geriatric Depression	Depressive symptoms: GDS-15 score	+ (a) street view NS (b)(c)

Table 1 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
		Beijing, China)		View); (b) land cover map (GlobeLand30), 30 m × 30 m; (c) satellite images (Landsat 8), NDVI, 30 m × 30 m	per image; (b) proportion of greenspace per neighbourhood; (c) NDVI in neighbourhood	Scale-15 (GDS-15)		
[23]	C	Adults ≥ 65 years (7 cities, Korea)	11,408	Urban green per administrative area (source not reported)	Proportion of urban green area per administrative area in quartiles, in quartiles	Survey: self-reported stress and depressive symptoms	Subjective stress levels (high/low) and symptoms of depression (yes/no)	±
[24]	L, 78 years	Birth cohort, follow-up avg. age 70, 73 and 78 (UK)	328 or 1091	Open space surveys or audit maps, at each follow-up	Proportion of parks within 1500 m buffer around the home	Survey: Hospital Anxiety Depression Scale (HADS)	Depression and anxiety: HADS total score and subscores	NS
[25]	L, 7 years	Adults 57–85 years (USA)	4118	Satellite image (MODIS), NDVI, 250 m × 250 m, images of contemporaneous, summer, and annual greenness	NDVI across a 250 and 1000 m buffer around the home	Surveys: Perceived Stress (PSS-4); Hospital Anxiety and Depression (HADS-A); Center for Epidemiological Studies Depression (CESD-11) Scales	Perceived stress (PSS-4 score); anxiety symptoms (HADS-A score); depressive symptoms (CESD-11 score)	+ stress NS anxiety depression
[26]	C	Adults 45–72 years	6944	Land use maps	Greenspace proximity,	Survey: Depressive	Depressive symptoms:	NS

Table 1 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
		(Kaunas, Lithuania)		(municipality), city parks larger than 1 ha; survey: self-reported use of parks	into tertiles; Use of parks (use < 4 or ≥ 4 h/week)	symptoms CES-D10	subjects with CES-D10 score ≥ 4.0 (yes/no)	
[27]	C	Adult men 65–84 years (Caerphilly, UK)	687	Satellite images (Landsat 7), NDVI, 30 m × 30 m	Mean NDVI within a 500 m circular buffer around the individual's dwelling	Survey: Psychological distress, using the 30-item General Health Questionnaire (GHQ-30)	Psychological distress, QHQ-30 score ≥ 5 (case) or < 5 (no case)	NS
[28]	C	Adults 37–73[a] (UK)	94,879	Satellite images (Bluesky Colour Infrared imagery), NDVI, 0,5 m × 0,5 m	Mean NDVI within a 500 m catchment radius of geocoded participant's dwellings	Survey: items on depression, the Patient Health Questionnaire, and social support for mental health	Lifetime experience of major depressive disorder (yes/no)	+
[29]	C	Adults ≥ 65 years (4 cities; England)	2424	Land use map (Generalized Land Use Database), areas covered with grass and private gardens	Percentage of greenspace and private gardens in the administrative area, in quartiles.	Geriatric Mental State Examination (GMSAGE)	Depression (score ≥ 3) and anxiety (score ≥ 1).	+ Anxiety NS depression
Cognitive function								
[20]	C	Medicare beneficiaries ≥ 65 years (Miami-Dade, USA)	249,405	Satellite images (NASA), NDVI, 15 m × 15	NDVI in County Census Blocks	Chronic Conditions Segment of the CMS' Master Beneficiary	Alzheimer's disease (yes/no)	+

Table 1 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
				m, annual average		Summary File		
[30]	L 55 years	Birth Cohort follow-up avg. age 70 and 76 years (Scotland)	593 or 281	Open space surveys recording public parks, at each follow-up	Proportion of park area within a 1500 m buffer around the home for each time period	Cognitive test: Moray House Test No. 12 (MHT)	Cognitive function: MHT score changes between 11-70y and between 70-76y	+ 70–76y ears NS 11–70 years
[31]	C	Adults ≥ 50 years (Chicago, USA)	949	Geographic data from the City of Chicago	Park area in square miles in each census tract	Cognitive test: Telephone Instrument for Cognitive Status (TICS)	Cognitive function (TICS score ranging from 0 to 25)	NS
[32]	L 10 years	Civil servants 45–79 years (UK)	6506	Satellite images (MODIS), NDVI and EVI, 250 m × 25-0 m, images from each follow-up	NDVI or EVI within 500 m and 1 km buffers around the postcode centroid	Cognitive test: battery assessing reasoning, fluency and short-term memory	Cognitive function: z-score of global cognition and z-score of separate tests	+
[33]	C	Adults ≥ 65 years (4 cities; England)	2424	Land use map (Generalize-d Land Use Database), areas covered with grass and private gardens	The percentage of greenspace and private gardens in each LSOA, in quartiles	Cognitive test: The Mini-Ment-al State Examinatio-n (MMSE) and the Geriatric Mental Status (GMSAGE)	Cognitive impairment (MMSE score ≤ 25) and dementia (GMSAGE score ≥ 3)	–
[34]	C	Adults ≥ 65 years (3 cities; England)	7505	Land use map (Generalize-d Land Use Database), areas covered	The percentage of greenspace and private gardens in each LSOA	Cognitive tests: The Mini-Ment-al State Examinatio-n (MMSE)	Cognitive impairment (MMSE score ≤ 25) and dementia	- Cognition NS dementia

Table 1 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
				with grass and private gardens	divided in quintiles	and the Geriatric Mental Status (GMSAGE)	(GMSAGE score ≥ 3)	
Physical capability								
[35]	C	Adults 45–-106 years (Australia)	203,883	Land use map (Australian Bureau of Statistics land use classification for 2006), parkland	Proportion of parkland within a 1 km buffer around the population weighted small area centroid	Survey: Active Australia Survey on moderate--to-vigorous physical activities (MVPA) and walking	Physical activity: (a) weekly walking and MVPA (yes/no); (b) frequency of walking and MVPA	+
[36]	L avg. 7.5 years	Adults ≥ 45 years (Norwich, UK)	15,636	Land cover map (Centre for Ecology and Hydrology Land Cover Map of the UK, 2007), 25 m × 25 m, greenspace	Proportion of greenspace area in buffers of 800 m, 3 km and 5 km around the home, in quartiles	Survey: physical activity questionnaire (EPAQ2)	Physical activity: Weekly MET h/week, separately for total, recreational, and outdoors activities	+
[37]	L 10 years	Civil servants 50–84 years (UK)	5759	Satellite images (MODIS), NDVI and EVI, 250 m × 250 m; Land use (CORINE), natural environments ≥ 25 ha	NDVI or EVI in 500 m and 1 km around the postcode centroid; Distance (m) to natural environment	Clinical visit: walking speed test and grip strength test	Physical functioning: z-score of walking speed and z-score of grip strength	+
[38]	C	Adults ≥ 65 (Brussels, Belgium)	147,367	(1) Survey; (2) greenspace data (BRIC Brussels	(1) Dissatisfaction with greenspace; (2)	Survey: functional limitations	Suffering from functional limitations (yes/no)	NS

Table 1 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
				Urbis database)	greenspace area in 500 m buffer around the centroid of the statistical ward, in quintiles			
[39]	C	Men ≥ 67 years (Caerphilly, Wales)	1010	Satellite images (Landmap true colour aerial photograph), NDVI, 0.5 m × 0.5 m	NDVI and variation (high/low) of NDVI in a 400 m buffer around the postcode centroid	Survey: self-reported physical activity of 22 activities	Physical activity: regular participation (yes/no)	+ greenspace NS variation
[40]	C	Adults 45–74 years (Norwich, England)	4732	Quality audit of greenspaces (≥ 2 ha); GIS-assessed accessibility, geolocated locations and sizes of the greenspaces	(a) Distance based accessibility measure; (b) size--adjusted accessibility measure; (c) size and quality accessibility measure	Survey: self-reported physical activity	Physical activity: hours of recreational activity per week	NS
[41]	C	Overweight women 52–62 years (Pittsburg, USA)	158	Southwestern Pennsylvania Commission databases	Park within a 1500-m buffer around the home (yes/no)	Pedometer	Physical activity: Average steps per day	NS
[42]	C	Adults (low income) ≥ 40 years (Singapore)	1972	Spatial data (Singapore Land Authority)	Straight line distance from residential housing to a public park	Survey	Physical inactivity: walking < 30 min/day, sports activities < 1/week	NS

Table 1 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
[43]	C	Adults 65–-100 years (Rayside, Scotland)	547	Land cover/use map (Centre for research on environment, society and health)	Percentage of greenspace in the census ward	Accelerometer (7-day period), 7-day activity diary	Physical activity: accelerometry counts of activity per day	NS
[44]	C	Adults ≥ 65 years (Portland, Oregon, USA)	546	Regional Land Information System database (planning agency Metro)	Euclidian distance from the residence to the nearest park/-greenspace	Survey: Yale Physical Activity Scale	Physical activity: total, leisure or brisk weekly walking time	+ brisk NS total or leisure
[45]	C	Adults ≥ 60 years (Sao Paulo, Brazil)	1190	Green area per resident (Department of environmental planning of the municipality of Sao Paulo)	Total green area (m^2) per resident in administrative regions, categorized as ≥ 9, 4–9 and < 4	Clinic visit: Timed Up and Go Test (TUGT) and survey	Occurrence of falls (yes/no); functional mobility (TUGT score ≥ 12.47 s)	NS
[46]	C	Adults ≥ 65 years (Porto, Portugal)	532	City council digital maps	Shortest street route from home to the nearest park entrance	EPIPorto Physical Activity Questionnaire	Leisure time physical activity: minutes/day and daily (yes/no)	NS
[47]	L	3 cohorts avg. age 64, 79 and 83 years (Scotland)	700, (271, 119, 310)	Land use maps (Scotland's Greenspace Map; EEA Urban Atlas)	Proportion of natural greenspace in the administrative area	ActivPAL activity monitor (7-day period)	Percentage of waking time spent sedentary	NS
[48]	C	African American women 55–84 years (Bryan,	80	Satellite images (Digital Orthophoto Quad), classified as	Density of greenspace, greenery, and street greenery in 800 m and	Survey: modified Community Healthy Activities Model	Physical activity: Caloric expenditure/week/kg in all	+ Greenery NS other indicators

Table 1 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
		Texas, USA)		greenery and non--greenery	1600 m around the home; distance to greenspace	Program for Seniors (CHAMPS) question-naire	physical activities	
[49]	L 0.5 years	Adults 66–97 years (Washington Baltimore, USA)	726	Land use maps (local park agencies and parcel-level land use data)	Number of parks within 1 km buffer around the home and distance to closest park	Accelerometer (7-day period) and CHAMPS question-naire	Physical activity: moderate/-vigorous physical activity and self-reported walking (minutes/-day)	+ accelerometer NS walking
[50]	C	Women 35[a]–74 years (USA)	50,884	Land cover maps (US National Land Cover database), vegetation, 30 m × 30 m	Proportion of area covered by greenspace in 250 m and 500 m buffers around the home, in tertiles	Survey: physical activity	Physical activity: ≥ 67.1 MET hours/week of physical and recreational activities (yes/no)	+
[51]	C	Adults ≥ 65 years (Augsburg, Germany)	1711	Geocodes of greenspaces (City of Augsburg), greenspaces of > 0.5 ha	Distances to nearest greenspace from home, in < 200, 200–400, 400–800 and ≥ 800 m	Surveys: (a) physical constitution item; (b) Health Assessment Questionnaire Disability Index (HAQ-DI)	Physical constitution (fair or poor, yes/no); Disability (HAQ-DI ≥ 1, yes/no)	NS
[52]	C	Adults 40–65 years (Brisbane, Australia)	10,286	Land cover map (aerial photography by the local council), tree coverage and parks,	Tree coverage within a 1 km buffer around the home; distance to park from home	Survey: single item taken from the Active Australia Survey	Walking: minutes/-week: < 30, ≥ 30–90, ≥ 90–150, ≥ 150–300 and ≥ 300 min.	+ tree cover NS distance

Table 1 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
				grid points of 2.4 m^2				
[53]	C	Adults ≥ 65 years (Taichung, Taiwan)	274	Urban planning map (Taichung City Government)	Number of parks in a 600 m buffer around the home; distance from home to park	Survey: (1) International Physical Activity Questionnaire; (2) Amenities for physical activity	(1) Physical activity in the past 7 days (METs-min/week); (2) place of physical activity	+
[54]	C	Adults ≥ 45 years (Shanghai, China)	1043	Regional land use data (Land and Resources Bureau)	Distance from the home to parkland	Pedometer	Physical activity: total steps of walking	+
[55]	L	Adults aged ≥ 65 years (Hong Kong, China)	3240	Satellite images (IKONOS), NDVI	Proportion of vegetation in a 300-m radial buffer	Survey items + clinic visit: grip strength and walking speed	Frailty: transition states (deteriorated, stable or improved) over study period	+
[56]	C	Adults ≥ 65 years (Birmingham, UK)	173	Spatial data (Birmingham City Council)	Percentage of greenspace in a 2 km Euclidean buffer	GPS tracked walking levels in a 2 km buffer around the home (3–8-day period)	Physical activity: outdoor walking minutes/day.	+

Results are presented as + (a statistically significant, beneficial association was found between long-term greenspace exposure and the outcome), − (a statistically significant, detrimental association was found between long-term greenspace exposure and the outcome), or NS (no statistically significant association was found between long-term greenspace exposure and the outcome)

Design: *L* longitudinal, *C* cross-sectional, *E* ecological, *Q* quartile

[a] Less than 10% of the study population was aged 40 and younger

percentage of the maximum score. The quality of the study was assessed based on this percentage with ≥ 81% as *very good quality*, between 61 and 80% as *good quality*, between 41 and 60% as *fair quality*, between 21 and 40% as *poor quality* and ≤ 20% as *very poor quality* [59, 60].

Evaluation of the Evidence

To evaluate the strength of the overall evidence for the relationship between the exposure and outcome, we classified the evidence per outcome as (a) sufficient, (b) limited, (c) inadequate evidence for an association or (d) evidence for lack of association. The level of evidence was rated based on the guidelines suggested by the International Agency for Research on Cancer (IARC) and adapted by other reviews similar to this review [60, 61]. *Sufficient evidence* was considered if most of the studies, including good quality studies, observed an association. *Limited evidence* included several independent good quality studies that reported an association, but the evidence was not yet conclusive. *Inadequate evidence* was considered if the association was reported by one or more studies, but the studies were of insufficient quality, there were an inadequate number of studies, the findings lacked consistency and/or there was a lack of statistical power. Last, *evidence for lack of association* included several good quality studies that consistently observed no relationship.

Results

Study Selection

Using our search terms, 2704 unique articles were found by searching PubMed and Scopus (Figure 1). A total of 2489 articles were excluded based on the title and the abstract. Of the remaining 215 full texts, 50 articles were found to meet the selection criteria and were included in the review. Based on the reference lists of these articles, we identified nine additional articles to be included in the review, resulting in a total of 59 articles.

Study Characteristics and Findings

The majority of the identified studies on the association between long-term greenspace exposure and health at older age were of cross-sectional design ($N = 44$). The remaining studies were of ecological ($N = 1$) and longitudinal design ($N = 14$). The studies were conducted in 15 different countries, with 18 studies from the UK and 15 from the USA. Around half of the studies focused solely on the older population (i.e. minimum age was 60 years or older), while the other half also included middle-aged adults. All studies included an objective assessment of long-term residential exposure to greenspace, using spatial data obtained from satellite images, land use or cover maps, administrative data or street view images. Most studies ($N = 37$) were based on only one indicator of greenspace exposure; only seven studies provided various indicators of exposure to greenspace (e.g. by obtaining different vegetation indices or by using different sources of spatial data) [22, 32, 37, 48, 50, 52, 62], four considered the quality of the greenspace [38, 62–64], and three included the use of greenspace in the analyses [26, 65, 66].

The included studies investigated the association between long-term greenspace exposure and various health outcomes. We categorized the studies by health outcome and presented the main characteristics of each study in Tables 1, 2 and Figure 1 (additional information is presented in Table S1). The studies included the following six categories of health: mental health, cognitive function, physical capability, morbidity, cardiometabolic risk factors and perceived wellbeing. The categories were based on the biomarkers of healthy ageing as proposed by an expert panel [82, 83]. If a study reported the association between the exposure to greenspace for more than one health outcome falling into different categories, the study was rated repeatedly for each corresponding category.

The results of the quality assessment are presented in Table S3. A short description of the characteristics, results of the studies and evaluation of the evidence is given below per outcome category.

Mental Health We identified 12 studies on the association between long-term greenspace exposure and mental health, including three longitudinal studies [19, 24, 25], eight cross-sectional studies [18, 20, 22, 23, 26–29] and one ecological study [21]. Most studies focused on depression [21–25, 28, 29], stress [18, 23, 25, 27], and/or anxiety symptoms [24–26], mainly assessed with a questionnaire, and in two studies, the outcome was based on the diagnosis of depression (yes/no), obtained from a health administration database [20] or self-reported [19].

Eight out of the 12 studies found that greater long-term exposure to greenspace was associated with a lower risk of stress, depression and anxiety. Furthermore, one study found a non-linear association and three studies did not find any statistically significant association. As the three studies that did not observe any association were considered to be of good quality, we considered the evidence for a beneficial association between greenspace exposure and mental health to be inadequate.

Cognitive Function There were six articles on cognitive function, including diagnosis with Alzheimer's disease obtained from a health administration database [20] and assessment of cognitive function by cognitive tests [30–34].

Table 2 Main characteristics of selected articles on long-term greenspace exposure and morbidity, cardiometabolic risk factors and perceived wellbeing at older age

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
Morbidity								
[67]	C	Adults ≥45 years (Australia)	267,072	Land use map (Australian Bureau of Statistics land use classification for 2006), parkland	Proportion of parkland in a 1 km buffer around the population weighted small area centroid	Survey	Diabetes: self-reported diagnosis of diabetes (yes/no)	±
[68]	C	Adults ≥45 years (Australia)	267,072	Land use map (Australian Bureau of Statistics land use classification for 2006), parkland	Proportion of parkland in a 1-km buffer around the population weighted small area centroid	Survey	Skin cancer: self-reported diagnosis of (non-) melanoma skin cancer	+
[69]	C	Medicare beneficiaries ≥65 years (Miami-Dade, USA)	249,405	Satellite images (NASA), NDVI, 15 m × 15 m, annual average	Average annual NDVI in County Census Blocks	Chronic Conditions Segment of the CMS' Master Beneficiary Summary File	Chronic health conditions: (a) total number (range of 0–27); (b) diabetes (yes/no)	+
[70]	L 4 years	Adults 45–84 years (British Columbia, Canada)	380,738	Satellite images (source not reported), NDVI, yearly and seasonal estimates over follow-up	NDVI across 100 m buffers around residential postcode centroids	Health administration databases (ICD codes)	Incident diabetes (yes/no)	+
[71]	L 14 years	Adults 40–79 years (East Anglia, England)	23,865	Land cover (Land Cover Map 2007 UK), 25 m × 25 m	Proportion of greenspace area within circular buffers of 800 m	Different sources: GP records, hospital data, survey	Incident type II diabetes (yes/no)	+

Table 2 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
					around the home			
[72]	C	Adults ≥40 years (Longzihu district, Bengbu, China)	1944	Satellite images (MODIS), NDVI, 250 m × 250 m, annual average	Annual average NDVI at residential location, in quartiles	Clinic visit and medical records	CVD: CHD, stroke (yes/no)	+
[42]	C	Adults (low income) ≥40 years (Singapore)	1972	Spatial data (Singapore Land Authority)	Distance from residential housing to a public park	Survey	Self-reported medical history of diabetes and heart attack (yes/no)	NS
[73]	C	Adults ≥60 years (Sao Paulo, Brazil)	1333	2010 census, administrative area data	Greenspace per inhabitant (green area per m^2), in quartiles	Survey	CVD: self-reported medical diagnosis of CVD (yes/no)	+
[65]	L	Adults 45–72 years (Kaunas, Lithuania)	5112	Spatial land cover data (municipality), city parks ≥1 ha	Distance to nearest park based on the home address, in tertiles	Medical records	CVD: Non-fatal (acute MI, unstable angine pectoris, and stroke); total	+ total NS non-fatal
[74]	C	Adults ≥65 years (Miami-Dade, Florida, USA)	249,405	Satellite images (ASTER, NASA), NDVI, 15 × 15 m	Mean census block-level NDVI, in tertiles	Chronic Conditions Segment of CMS' Master Beneficiary Summary File	CVD: acute myocardial infarction (AMI), ischemic heart disease (IHD), heart failure (HF), or atrial fibrillation (AF) (yes/no)	+
[63]	C	Adults ≥60 years	700	Geospatial data (Wuhan	Accessibility score (based on distance	Survey: self-reported	Cardiocerebral vascular (CCVD),	+

Table 2 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
		(Wuhan, China)		Land Resources and Planning Information Center)	to a park and park-area/-population ratio), as low, medium--low, medium--high and high	chronic disease	joint (JD), digestive (DD), endocrine (ED), urological (UD), nervous system (NSD) and respiratory (RD) diseases (yes/no)	
Cardiometabolic risk factors								
[75]	C	Adults 45–-106 years (New South Wales, Australia)	246,920	Land use (Australian Bureau of Statistics); parkland (no private gardens or agricultural land)	Proportion of parkland in a 1-km buffer around the population weighted small area centroid	Survey: self-reported height and weight	Weight status: BMI < 18.5 (under), 18.5–24.9 (normal), 25–29.9 (over) or ≥ 30 (obese)	NS
[76]	C	Women 60–87 years (USA)	23,435	Satellite images (MODIS), NDVI, 250 m × 250 m, summer image	NDVI at the address (pixel value) and 1250 m buffer in sensitivity analyses	Survey: self-reported height and weight	Weight status: self-reported BMI	±
[72]	C	Adults ≥ 40 years (Longzihu district, Bengbu, China)	1944	Satellite images (MODIS), NDVI, 250 m × 250 m, annual average	Annual average NDVI at residential location, low (1st quartile) vs moderate to high (2nd to 4th quartile)	Clinic visit: blood pressure or self-reported diagnosis of hypertension	Hypertension (yes/no)	+
[42]	C		1972	Spatial data (Singapore		Health screening;	Medical history of	NS

Table 2 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
		Adults (low income) ≥ 40 years (Singapore)		Land Authority)	Distance from home to a public park	medical history, weight, height	hypertension or high cholesterol; overweight (BMI ≥ 23)	
[77]	L 18 years	Women > 66 years (Portland, Oregon, USA)	2003	Land cover map (Landsat TM data), (publicly accessible) greenspaces	Distance to greenspaces from home over time, in deciles	Clinic visit: weight and height	Weight status: BMI continuous and categorized	NS
[78]	C	Adults 38[a]–73 years (UK)	333,183	Satellite images (Bluesky Colour Infrared imagery), NDVI, 0.5 m × 0.5 m	NDVI in a 500 m buffer around the home: per IQR increase and in quartiles	Clinic visit: height, weight, waist circumference (WC), and whole body fat (WBF)	Weight status: BMI (kg/m^2), WC (cm) and WBF (kg); obesity (BMI ≥ 30 kg/m^2, yes/no)	+
[79]	C	Adults 38[a]–73 years (UK)	429,334	Satellite images (Bluesky Colour Infrared imagery), NDVI, 0.5 m × 0.5 m	NDVI in a 500 m buffer around the home	Clinic visit: diastolic blood pressure (DBP) and systolic blood pressure (SBP); self-reported hypertension	DBP and SBP (continuous); hypertension prevalence (yes/no)	±
[50]	C	Women 35[a]–74 years (USA)	50,884	Land cover maps (US National Land Cover database), vegetation, 30 m × 30 m	Proportion of area covered by vegetation in 250 m and 500 m buffers around the home, in tertiles	Clinic visit: height and weight	Weight status: BMI > 30 (yes/no)	+
[54]	C		1043					+

Table 2 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
		Adults ≥ 45 years (Shanghai, China)		Regional land use data (Land and Resources Bureau)	Distance from the home to parkland	Clinic visits: weight and height	Weight status: BMI: continuous and overweight (BMI ≥ 24, yes/no)	
Perceived wellbeing								
[38]	C	Adults ≥ 65 (Brussels, Belgium)	147,367	(1) Survey; (2) Greenspace data (BRIC Brussels Urbis database)	(1) Dissatisfaction with greenspace; (2) greenspace area in 500 m buffer around the centroid of the statistical ward, in quintiles.	Survey: self-rated health	Poor self-rated health (yes/no)	NS
[80]	C	Adults 55–75 years (Helsinki, Finland)	844	Land cover map (CORINE)	Proportion of greenspace in the administrative unit, 500 m buffer, home range model, and Individualized Residential Exposure Model (IREM)	Survey: self-reported perceived wellbeing	Wellbeing: overall health; ability to function; quality of life; state of happiness at the moment	+ IREM NS other indicators
[66]	C	Adults 50–99 years (USA)	1515	(a) Spatial data (source not reported); (b) Survey	(a) Geocoded distance to the park; (b) perceived walking distance to	Survey: Rand Medical Outcomes Study (MOS) 20-Item	Mean score of perceived physical health	NS

Table 2 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
					the park (yes/no)	Short Form (SF-20)		
[81]	C	Adults 45–75 years (Essen, Germany)	4480	Satellite images (Landsat 5), NDVI, 30 m × 30 m, obtained in July	NDVI in a 100 m and 1 km buffer around the home	Survey: perceived health status	Poor self-rated health status (yes/no)	+
[64]	C	Adults ≥ 60 years (Colombia)	1863	GIS databases (Cadastre Department and the Sports and Recreation Institute of Bogotá)	Proportion of public park within a 500 m buffer around neighbourhood centroid, in tertiles	Survey: Short Form-8 and perceived health status	Health-related quality of life: SF-8 physical health score; SF-8 mental health score; self-rated health status (good/poor)	+ self-rated health NS SF-8 scores
[26]	C	Adults 45–72 years (Kaunas, Lithuania)	6944	(1) Spatial land covering datasets (municipality), city parks ≥1 ha; (2) Survey	(1) Greenspace proximity, into tertiles; (2) Use of parks (< 4 or ≥ 4 h/week)	Surveys: Perceived general health status	Perceived health: very poor or poor (yes/no)	NS
[51]	C	Adults ≥ 65 years (Augsburg, Germany)	1711	Geocodes of greenspaces (City of Augsburg), greenspaces of > 0.5 ha	Distances to green space from home, in < 200, 200–400, 400–800 and ≥ 800 m	Surveys: European Quality of Life questionnaire (EQ-5D)	Health-related quality of life (EQ-5D ≥ 1, yes/no)	NS
[54]	C	Adults ≥ 45 years (Shanghai, China)	1043	Regional land use data (Land and Resources Bureau)	Distance from the home to parkland	Survey: health status questionnaire	Health status: self-reported health status score (range 1–5)	NS
[62]	C	Adults ≥ 65 years (Hong Kong, China)	909	Environmental audits and extant GIS data (Census and	Park area in 400 m and 800 m buffers around the	Survey: Quality of Life (QoL)	QoL standardized scores (ranging from 4 to	NS

Table 2 (continued)

Reference	D	Study pop., age (country)	Number	Greenspace data source	Greenspace indicator	Outcome assessment	Outcome	Main result(s)
				Statistics, Lands, and Planning Departments of Hong Kong); Environmental audits	home; Number of parks, trees, aesthetics, visibility, greenery/natural sights	questionnaire by the WHO	20) for 4 domains: physical QoL, physiological QoL, social QoL, environmental QoL	

Results are presented as + (a statistically significant, beneficial association was found between long-term greenspace exposure and the outcome), − (a statistically significant, detrimental association was found between long-term greenspace exposure and the outcome), or NS (no statistically significant association was found between long-term greenspace exposure and the outcome)

Design: L = longitudinal, C = cross-sectional, E = ecological, *Q* quartile

[a] Less than 10% of the study population was aged 40 and younger

The two longitudinal studies found a beneficial association between greenspace exposure and cognitive decline over the follow-up period [30, 32]. However, the findings of the four cross-sectional studies were mixed; one study found that greater greenspace exposure was associated with lower odds of Alzheimer's disease [20], but, in contrast, two cross-sectional studies found that higher availability of greenspace was associated with an increased risk of dementia and/or cognitive impairment [33, 34], while another cross-sectional study did not find any association between proximity to park and cognitive function [31]. As the findings were inconsistent and the number of studies low, we considered the evidence for a beneficial association between greenspace exposure and cognitive function at older age to be inadequate.

Physical Capability The association with physical functioning was assessed in 22 studies, including 17 cross-sectional [35, 38–48, 50–54, 56] and four longitudinal studies [36, 37, 49, 55].

Most studies focused on physical activity ($N = 17$) assessed by self-reported physical activity levels [35, 36, 39, 40, 42, 44, 46, 48, 50, 52, 53] or objectively measured physical activity using an accelerometer or pedometer [41, 43, 47, 49, 54, 56]. The findings for an association between long-term greenspace exposure and physical activity were mixed; 11 studies observed a beneficial association between greenspace exposure and an outcome of physical activity, but six studies did not. In addition, only four studies were of good quality. Therefore, the evidence for an association between long-term greenspace exposure and physical activity was rated to be inadequate.

The five other studies focused on physical capability assessed by physical tests (e.g. walking speed, grip strength, and timed up and go) [37, 45] or self-reported functional limitations, frailty, or disability [38, 51, 55]. Two studies were longitudinal [37, 55] and three cross-sectional [38, 45, 51]. The two studies of good or very good quality found a beneficial association between long-term greenspace exposure and physical functioning, but the three studies rated of fair quality observed no significant association. Considering these mixed findings and the small number of studies, the evidence for a beneficial association between long-term greenspace and physical capability was considered to be inadequate.

Morbidity We identified 11 studies on the risk of disease, including eight cross-sectional [42, 63, 67–69, 72–74] and three longitudinal studies [65, 70, 71]. A wide range of diseases including diabetes [42, 67, 70, 71], skin cancer [68], cardiovascular disease [42, 65, 72–74] and cardiocerebral vascular, joint, digestive, endocrine, urological, nervous system and respiratory diseases [63] were assessed. Six studies had objective data on the outcomes [65, 69–72, 74], while five studies were based solely on self-reported disease [42, 63, 67, 68, 73].

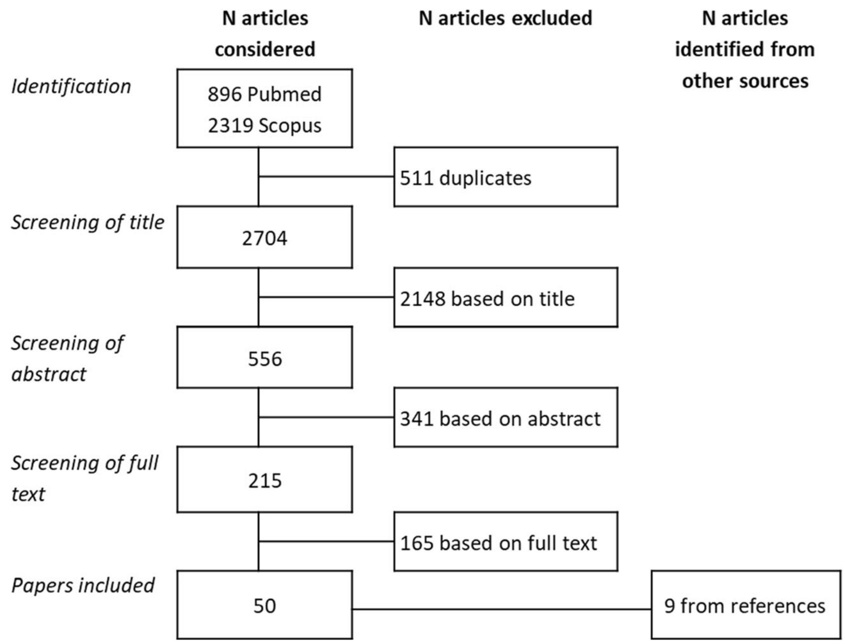

Fig. 1 Selection process of the articles

Nine of the 11 studies found a beneficial association between long-term greenspace exposure and the risk of disease among older adults. In addition, one study found a non-linear relationship and one study observed no association at all. Based on the consistent findings of the studies, including six of good or very good quality, we considered there was limited evidence for a beneficial association between long-term greenspace exposure and the risk of disease.

Cardiometabolic Risk Factors There were nine articles that investigated the association between long-term greenspace exposure and cardiometabolic risk factors, including weight status [42, 50, 54, 75–78], hypertension [42, 72, 79] and/or cholesterol levels [42]. Only one study had a longitudinal design [77] and the other eight studies used cross-sectional data [42, 50, 54, 72, 75, 76, 78, 79]. Most studies obtained the outcome data from objective measurements [42, 50, 54, 72, 77–79], but two studies used self-reported height and weight [75, 76].

The findings were mixed. Among the seven studies on the association between long-term greenspace exposure and weight status, three observed a significant beneficial association, one a non-linear association, and three did not observe a significant association. Considering the association with hypertension, one study observed a beneficial association, one observed a non-linear association, and one did not observe an association with hypertension. Only one study investigated the association with cholesterol levels but did not observe a significant association. Considering the small number of studies and the mixed results, we considered the evidence for an association between greenspace and cardiometabolic risk factors to be inadequate.

Perceived Wellbeing The association between long-term greenspace exposure and self-perceived wellbeing was assessed in nine cross-sectional studies, including self-rated health status [26, 38, 54, 64, 66, 81], self-reported wellbeing [80] and (health-related) quality of life [51, 62]. Six of the nine studies did not find any significant association, while three found a beneficial association. Only two studies were rated to be of good quality; we therefore considered the evidence for an association between long-term greenspace exposure and perceived wellbeing to be inadequate.

Discussion

Limitations of Available Evidence

Though this review included 59 studies on various health outcomes, we were limited by a small number of studies per health outcome. In addition, the studies were heterogeneous in study design, exposure assessment, statistical methodology and study population samples which complicated comparison and interpretation of the different results. Altogether, conducting a meta-analysis for our reviewed associations was not feasible.

Study Design Overall, a small part of our reviewed studies had longitudinal design, while majority of the studies were cross-sectional. Reverse causality cannot be ruled out when using cross-sectional data as the outcome may precede the exposure. Furthermore, cross-sectional studies are prone to self-selection bias when, for instance, less healthy adults move to neighbourhoods with more greenspace available. Nevertheless, 16 of the 44 cross-sectional studies took into account the residential history of the participants by selecting only study participants who had not moved recently or by adjusting for length of residency. Longitudinal studies are less prone to reverse causation and self-selection bias and by providing trajectories of health status or incidence of disease over the time, they are more capable of evaluating the effects of greenspace exposure on the ageing process.

Exposure Assessment All studies included in this review obtained an objective indicator of greenspace exposure, mainly based on satellite-based indices of greenspace or land use or cover maps. In addition, all studies assessed the greenspace exposure at the residential location. However, in several studies, the risk of exposure misclassification could not be ruled out as the residential location was not based on the residential address, but on, for instance, the postcode centroid or administrative area. Furthermore, none of the studies assessed the exposure to greenspace at another location than home, while older adults may also spend a part of their time outside of their direct neighbourhood.

Ideally, to assess the exposure to greenspace, different aspects should be assessed such as the physical and visual access, the actual use and the quality of greenspace. Moreover, the type of vegetation and the richness of biodiversity in greenspaces are potentially relevant. However, among the studies included in this review, most studies only used a single greenspace indicator. Only a few studies included a comparison between various indicators of greenspace exposure or considered the quality or use of a greenspace. Therefore, the type or specific characteristics of greenspace that may be most supportive of healthy ageing are still largely unknown.

Outcome Assessment The review identified studies on the association of long-term greenspace exposure with a wide range of health outcomes, including outcomes of mental health, cognitive function, physical capability, cardiometabolic risk factors, morbidity and perceived wellbeing. Cognitive function and physical capability are key indicators of healthy ageing [82]. This review identified six studies on cognitive function, of which only two had a longitudinal design. Regarding physical capability, the assessment of locomotor function, strength, balance and dexterity have been proposed to be most indicative of age-related physical capability [82], but this review only identified two studies that measured walking speed and grip strength. The studies on physiological function included in this review focused on cardiometabolic risk factors and the assessed outcomes were weight status, hypertension and cholesterol level. However, several important biomarkers of age-related physiological function such as lung function or glucose homeostasis have not been explored [82]. Additional relevant biomarkers of healthy ageing may be indicators of endocrine function, sensory functions and immune function [82], but we did not identify studies looking at the association of long-term greenspace exposure with these outcomes. Similarly, the potential impact of greenspace exposure on telomere length or other markers of cellular ageing remains as an open question to be evaluated by future studies.

Mechanisms

Long-term exposure to greenspace may be supportive of healthy ageing through various pathways. First, more greenspace in the residential environment could lead to less feelings of loneliness, more social support and improved social cohesion in the neighbourhood [84, 85], which are important contributors to health at older age [3]. Second, greenspace may be a resource for psychological restoration [86]. Exposure to greenspace has been associated with reduced stress [87] and providing the opportunity to restore directed attention [88–90], which may benefit cognitive ageing. Third, older adults living in areas with higher access to greenspace have shown higher physical activity levels [39] and a reduced decline in physical activity [36], while physical activity plays a significant role in maintaining functioning and health at older age [91, 92]. Last, increased exposure to greenspace has been associated with lower exposure to environmental stressors such as air pollution, noise and heat [93], which are detrimental to health at older age [70, 94, 95].

Few of the studies in this review conducted formal examination of these potential mechanisms. We were unable to compare these results due to the low number of studies and the heterogeneity in applied statistical methods. Consequently, this review could not provide sufficient information to further understand the pathways (Table S1).

Conclusions

In this review of observational studies on the association between long-term exposure to outdoor greenspace and healthy ageing, we identified 59 studies on outcomes of mental health, cognitive function, physical capability, morbidity, cardiometabolic risk factors and perceived wellbeing at older age. Overall, although the available evidence for a beneficial association between greenspace exposure and the aforementioned outcomes is still limited/inadequate, they are suggestive for the existence of such associations and call for future studies to establish the associations.

Recommendations

The findings of the articles included in this review call for future studies, especially studies that (a) use a longitudinal design that provide insight in the process of ageing; (b) objectively assess healthy ageing by using, for instance, repeated measures of biomarkers of healthy ageing [82]; (c) assess the exposure to greenspace repeatedly over the study period and include various aspects of greenspace exposure; and (d) investigate the underlying pathways for the association between greenspace and health at older age.

Funding Information Mariska Bauwelinck is funded by an individual PhD grant supported by the Research Foundation-Flanders (FWO) (grant number 11A9718N) and a Gustave Boël-Sofina Fellowship (grant number V422218N). PD [RYC-2012-10995] is funded by Ramón y Cajal fellowships awarded by the Spanish Ministry of Economy and Competitiveness. The funders have not been involved in any part of the study design or reporting.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance

1. United Nations. World population ageing 2017: highlights; 2017. ISBN 978-92-1-151551-0.
2. World Health Organization. World report on ageing and health; 2015. ISBN 978 92 4 069479 8.
3. Clarke PJ, Nieuwenhuijsen ER. Environments for healthy ageing: a critical review. Maturitas. 2009;64:14–9.
4. Yen IH, Michael YL, Perdue L. Neighborhood environment in studies of health of older adults: a systematic review. Am J Prev Med. 2009;37:455–63.
5. Burton EJ, Mitchell L, Stride CB. Good places for ageing in place: development of objective built environment measures for investigating links with older people's wellbeing. BMC Public Health. 2011;11:839.
6. Tuckett AG, Banchoff AW, Winter SJ, King AC. The built environment and older adults: a literature review and an applied approach to engaging older adults in built environment improvements for health. Int J Older People Nursing. 2018. https://doi.org/10.1111/opn.12171.
7. Gascon M, Triguero-Mas M, Martínez D, Dadvand P, Rojas-Rueda D, Plasència A, et al. Residential green spaces and mortality: a systematic review. Environ Int. 2016;86:60–7.
8. Twohig-Bennett C, Jones A. The health benefits of the great outdoors: a systematic review and meta-analysis of greenspace exposure and health outcomes. Environ Res. 2018. https://doi.org/10.1016/j.envres.2018.06.030.
9. de Vries S, Verheij RA, Groenewegen PP, Spreeuwenberg P. Natural environments—healthy environments? An exploratory analysis of the relationship between greenspace and health. Environ Plann A. 2003;35:1717–31.
10. Astell-Burt T, Mitchell R, Hartig T. The association between green space and mental health varies across the lifecourse. A longitudinal study. J Epidemiol Commun H. 2014;68:578–83.
11. Kabisch N, van den Bosch M, Lafortezza R. The health benefits of nature-based solutions to urbanization challenges for children and the elderly - a systematic review. Environ Res. 2017;159:362–73.
12. Yeo NL, Elliott LR, Bethel A, White MP, Dean SG, Garside R. Indoor nature interventions for health and wellbeing of older adults in residential settings: a systematic review. Gerontologist. 2019. https://doi.org/10.1093/geront/gnz019.
13. DiPietro L. Physical activity in aging: changes in patterns and their relationship to health and function. J Gerontol Ser A. 2001;56:13–22.
14. Visser M, Pluijm SMF, Stel VS, Bosscher RJ, Deeg DJH. Physical activity as a determinant of change in mobility performance: the longitudinal aging study Amsterdam. J Am Geriatr Soc. 2002;50:1774–81.
15. Soga M, Gaston KJ, Yamaura Y. Gardening is beneficial for health: a meta-analysis. Prev Med Rep. 2017. https://doi.org/10.1016/j.pmedr.2016.11.007.
16. Wang D, MacMillan T. The benefits of gardening for older adults: a systematic review of the literature. Act Adapt Aging. 2013;37:153–81.
17. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan—a web and mobile app for systematic reviews. Syst Rev. 2016;5:210.
18. Astell-Burt T, Feng X, Kolt GS. Mental health benefits of neighbourhood green space are stronger among physically active adults in middle-to-older age: evidence from 260,061 Australians. Prev Med (Baltim). 2013;57:601–6.
19. Banay RF, James P, Hart JE, Kubzansky LD, Spiegelman D, Okereke OI, et al. Greenness and depression incidence among older women. Environ Health Perspect. 2019;127:27001.
20. Brown SC, Perrino T, Lombard J, et al. Health disparities in the relationship of neighborhood greenness to mental health outcomes in 249,405 U.S. Medicare beneficiaries. Int J Environ Res Public Health. 2018. https://doi.org/10.3390/ijerph15030430.
21. Browning MHEM, Lee K, Wolf KL. Tree cover shows an inverse relationship with depressive symptoms in elderly residents living in U.S. nursing homes. Urban For Urban Green. 2019;41:23–32.
22. Helbich M, Yao Y, Liu Y, Zhang J, Liu P, Wang R. Using deep learning to examine street view green and blue spaces and their associations with geriatric depression in Beijing, China. Environ Int. 2019;126:107–17.
23. Lee HJ, Lee DK. Do Sociodemographic factors and urban green space affect mental health outcomes among the urban elderly population? Int J Environ Res Public Health. 2019. https://doi.org/10.3390/ijerph16050789.
24. Pearce J, Cherrie M, Shortt N, Deary I, Thompson CW. Life course of place: a longitudinal study of mental health and place. Trans Inst Br Geogr. 2018;43:555–72.
25. 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.
26. Reklaitiene R, Grazuleviciene R, Dedele A, Virviciute D, Vensloviene J, Tamosiunas A, et al. The relationship of green space, depressive symptoms and perceived general health in urban population. Scand J Public Health. 2014;42:669–76.
27. Sarkar C, Gallacher J, Webster C. Urban built environment configuration and psychological distress in older men: results from the Caerphilly study. BMC Public Health. 2013;13:695.
28. Sarkar C, Webster C, Gallacher J. Residential greenness and prevalence of major depressive disorders: a cross-sectional, observational, associational study of 94 879 adult UK biobank participants. Lancet Planet Health. 2018;2:e162–73.

29. Wu Y-T, Prina AM, Jones A, Matthews FE, Brayne C. Older people, the natural environment and common mental disorders: cross-sectional results from the cognitive function and ageing study. BMJ Open. 2015;5:e007936.
30. Cherrie MPC, Shortt NK, Mitchell RJ, Taylor AM, Redmond P, Thompson CW, et al. Green space and cognitive ageing: a retrospective life course analysis in the Lothian birth cohort 1936. Soc Sci Med. 2018;196:56–65.
31. Clarke PJ, Ailshire JA, House JS, Morenoff JD, King K, Melendez R, et al. Cognitive function in the community setting: the neighbourhood as a source of "cognitive reserve"? J Epidemiol Community Health. 2012;66:730–6.
32.• de Keijzer C, Tonne C, Basagaña X, Valentín A, Singh-Manoux A, Alonso J, et al. Residential surrounding greenness and cognitive decline: a 10-year follow-up of the whitehall II cohort. Environ Health Perspect. 2018. https://doi.org/10.1289/EHP2875 **This study was one of the first longitudinal studies on the association between greenspace exposure and cognitive decline at middle and older age. Cognitive functioning is considered to be one of the main indicators of healthy ageing.**
33. Wu Y-T, Prina AM, Jones AP, Barnes LE, Matthews FE, Brayne C. Community environment, cognitive impairment and dementia in later life: results from the cognitive function and ageing study. Age Ageing. 2015;44:1005–11.
34. Wu Y-T, Prina AM, Jones A, Matthews FE, Brayne C. The built environment and cognitive disorders: results from the cognitive function and ageing study II. Am J Prev Med. 2017;53:25–32.
35. 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.
36. Dalton AM, Wareham N, Griffin S, Jones AP. Neighbourhood greenspace is associated with a slower decline in physical activity in older adults: a prospective cohort study. SSM - Popul Health. 2016;2:683–91.
37. de Keijzer C, Tonne C, Sabia S, Basagaña X, Valentín A, Singh-Manoux A, et al. Green and blue spaces and physical functioning in older adults: longitudinal analyses of the Whitehall II study. Environ Int. 2019;122:346–56.
38. Dujardin C, Lorant V, Thomas I. Self-assessed health of elderly people in Brussels: does the built environment matter? Health Place. 2014;27:59–67.
39. 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;11:1–11.
40. Hillsdon M, Panter J, Foster C, Jones A. The relationship between access and quality of urban green space with population physical activity. Public Health. 2006. https://doi.org/10.1016/j.puhe.2006.10.007.
41. King WC, Belle SH, Brach JS, Simkin-Silverman LR, Soska T, Kriska AM. Objective measures of neighborhood environment and physical activity in older women. Am J Prev Med. 2005;28:461–9.
42. Lim KK, Kwan YH, Tan CS, Low LL, Chua AP, Lee WY, et al. The association between distance to public amenities and cardiovascular risk factors among lower income Singaporeans. Prev Med Rep. 2017;8:116–21.
43. McMurdo MET, Argo I, Crombie IK, Feng Z, Sniehotta FF, Vadiveloo T, et al. Social, environmental and psychological factors associated with objective physical activity levels in the over 65s. PLoS One. 2012;7:e31878.
44. 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.
45. Nascimento CF d, Duarte YAO, Lebrao ML, Chiavegatto Filho ADP. Individual and neighborhood factors associated with functional mobility and falls in elderly residents of Sao Paulo, Brazil: a multilevel analysis. J Aging Health. 2018;30:118–39.
46. Ribeiro AI, Pires A, Carvalho MS, Pina MF. Distance to parks and non-residential destinations influences physical activity of older people, but crime doesn't: a cross-sectional study in a southern European city. BMC Public Health. 2015;15:593.
47. Shaw RJ, Cukic I, Deary IJ, Gale CR, Chastin SFM, Dall PM, et al. The influence of neighbourhoods and the social environment on sedentary behaviour in older adults in three prospective cohorts. Int J Environ Res Public Health. 2017. https://doi.org/10.3390/ijerph14060557.
48. Shin W-H, Kweon B-S, Shin W-J. The distance effects of environmental variables on older African American women's physical activity in Texas. Landsc Urban Plan. 2011;103:217–29.
49. 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.
50. Villeneuve PJ, Jerrett M, Su JG, Weichenthal S, Sandler DP. Association of residential greenness with obesity and physical activity in a US cohort of women. Environ Res. 2018;160:372–84.
51. Vogt S, Mielck A, Berger U, Grill E, Peters A, Döring A, et al. Neighborhood and healthy aging in a German city: distances to green space and senior service centers and their associations with physical constitution, disability, and health-related quality of life. Eur J Ageing. 2015;12:273–83.
52. Wilson L-AM, Giles-Corti B, Burton NW, Giskes K, Haynes M, Turrell G. The association between objectively measured neighborhood features and walking in middle-aged adults. Am J Health Promot. 2011;25:e12–21.
53. Yeh C-Y, Chang C-K, Yang F-A. Applying a treatment effects model to investigate public amenity effect on physical activity of the elderly. J Aging Soc Policy. 2018;30:72–86.
54. Ying Z, Ning LD, Xin L. Relationship between built environment, physical activity, adiposity, and health in adults aged 46-80 in Shanghai, China. J Phys Act Health. 2015;12:569–78.
55. Yu R, Wang D, Leung J, Lau K, Kwok T, Woo J. Is neighborhood green space associated with less frailty? Evidence From the Mr and Ms Os (Hong Kong) Study. J Am Med Dir Assoc. 2018. https://doi.org/10.1016/j.jamda.2017.12.015.
56. Zandieh R, Flacke J, Martinez J, Jones P, van Maarseveen M. Do inequalities in neighborhood walkability drive disparities in older adults' outdoor walking? Int J Environ Res Public Health. 2017. https://doi.org/10.3390/ijerph14070740.
57. Gascon M, Zijlema W, Vert C, White MP, Nieuwenhuijsen MJ. Outdoor blue spaces, human health and well-being: a systematic review of quantitative studies. Int J Hyg Environ Health. 2017;220:1207–21.
58. de Keijzer C, Gascon M, Nieuwenhuijsen MJ, Dadvand P. Long-term green space exposure and cognition across the life course: a systematic review. Curr Environ Health Rep. 2016;3:468–77.
59. Lachowycz K, Jones AP. Greenspace and obesity: a systematic review of the evidence. Obes Rev. 2011;12:e183–9.
60. Gascon M, Triguero-Mas M, Martínez D, Dadvand P, Forns J, Plasència A, et al. Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. Int J Environ Res Public Health. 2015;12:4354–79.
61. Gascon M, Morales E, Sunyer J, Vrijheid M. Effects of persistent organic pollutants on the developing respiratory and immune systems: a systematic review. Environ Int. 2013;52:51–65.
62. Zhang CJP, Barnett A, Johnston JM, Lai P-C, Lee RSY, Sit CHP, et al. Objectively-measured neighbourhood attributes as correlates and moderators of quality of life in older adults with different living arrangements: the ALECS cross-sectional study. Int J Environ Res Public Health. 2019. https://doi.org/10.3390/ijerph16050876.

63. Xie B, An Z, Zheng Y, Li Z. Healthy aging with parks: association between park accessibility and the health status of older adults in urban China. Sustain Cities Soc. 2018;43:476–86.
64. 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 Bogotá, Colombia. Soc Sci Med. 2010;70:1070–6.
65.• Tamosiunas A, Grazuleviciene R, Luksiene D, et al. Accessibility and use of urban green spaces, and cardiovascular health: findings from a Kaunas cohort study. Environ Health. 2014;13:20 **This study scored the highest quality rating in this systematic review. What especially stood out was the use of objective greenspace indicators and an indicator of the use of greenspace to assess greenspace exposure.**
66. Mowen A, Orsega-Smith E, Payne L, Ainsworth B, Godbey G. The role of park proximity and social support in shaping park visitation, physical activity, and perceived health among older adults. J Phys Act Health. 2007;4:167–79.
67. Astell-Burt T, Feng X, Kolt GS. Is neighborhood green space associated with a lower risk of type 2 diabetes? Evidence from 267,072 Australians. Diabetes Care. 2014;37:197–201.
68. Astell-Burt FX, Kolt GS. Neighbourhood green space and the odds of having skin cancer: multilevel evidence of survey data from 267072 Australians. J Epidemiol Community Health. 2014;68:370–4.
69. Brown SC, Lombard J, Wang K, Byrne MM, Toro M, Plater-Zyberk E, et al. Neighborhood greenness and chronic health conditions in Medicare beneficiaries. Am J Prev Med. 2016;51:78–89.
70. Clark C, Sbihi H, Tamburic L, Brauer M, Frank LD, Davies HW. Association of long-term exposure to transportation noise and traffic-related air pollution with the incidence of diabetes: a prospective cohort study. Environ Health Perspect. 2017;125:87025.
71. Dalton AM, Jones AP, Sharp SJ, Cooper AJM, Griffin S, Wareham NJ. Residential neighbourhood greenspace is associated with reduced risk of incident diabetes in older people: a prospective cohort study. BMC Public Health. 2016;16:1171.
72. 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.
73. Massa KHC, Pabayo R, Lebrão ML, Chiavegatto Filho ADP. Environmental factors and cardiovascular diseases: the association of income inequality and green spaces in elderly residents of São Paulo, Brazil. BMJ Open. 2016;6:e011850.
74. Wang K, Lombard J, Rundek T, et al. Relationship of neighborhood greenness to heart disease in 249 405 US Medicare beneficiaries. J Am Heart Assoc. 2019;8:e010258.
75. Astell-Burt T, Feng X, Kolt GS. Greener neighborhoods, slimmer people? Evidence from 246,920 Australians. Int J Obes. 2014;38:156–9.
76. James P, Kioumourtzoglou M-A, Hart JE, Banay RF, Kloog I, Laden F. Interrelationships between walkability, air pollution, greenness, and body mass index. Epidemiology. 2017;28:780–8.
77. Michael YL, Nagel CL, Gold R, Hillier TA. Does change in the neighborhood environment prevent obesity in older women? Soc Sci Med. 2014;102:129–37.
78. Sarkar C. Residential greenness and adiposity: findings from the UK biobank. Environ Int. 2017;106:1–10.
79. 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.
80. Laatikainen TE, Hasanzadeh K, Kyttä M. Capturing exposure in environmental health research: challenges and opportunities of different activity space models. Int J Health Geogr. 2018;17:29.
81. Orban E, Sutcliffe R, Dragano N, Jockel K-H, Moebus S. Residential surrounding greenness, self-rated health and interrelations with aspects of neighborhood environment and social relations. J Urban Health. 2017;94:158–69.
82. Lara J, Cooper R, Nissan J, Ginty AT, Khaw K-T, Deary IJ, et al. A proposed panel of biomarkers of healthy ageing. BMC Med. 2015;13:222.
83. 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.
84. Maas J, van Dillen SME, Verheij RA, Groenewegen PP. Social contacts as a possible mechanism behind the relation between green space and health. Health Place. 2009;15:586–95.
85. Hong A, Sallis JF, King AC, Conway TL, Saelens B, Cain KL, et al. Linking green space to neighborhood social capital in older adults: the role of perceived safety. Soc Sci Med. 2018;207:38–45.
86. Hartig T, Mitchell R, de Vries S, Frumkin H. Nature and health. Annu Rev Public Health. 2014;35:207–28.
87. de Vries S, van Dillen SME, Groenewegen PP, Spreeuwenberg P. Streetscape greenery and health: stress, social cohesion and physical activity as mediators. Soc Sci Med. 2013;94:26–33.
88. Berman MG, Jonides J, Kaplan S. The cognitive benefits of interacting with nature. Psychol Sci. 2008;19:1207–12.
89. Kaplan R, Kaplan S. The experience of nature: a psychological perspective. New York: Cambridge University Press; 1989.
90. Kaplan S. The restorative benefits of nature: toward an integrative framework. J Environ Psychol. 1995;15:169–82.
91. Fielding RA, Guralnik JM, King AC, et al. Dose of physical activity, physical functioning and disability risk in mobility-limited older adults: results from the LIFE study randomized trial. PLoS One. 2017;12:e0182155.
92. McPhee JS, French DP, Jackson D, Nazroo J, Pendleton N, Degens H. Physical activity in older age: perspectives for healthy ageing and frailty. Biogerontology. 2016;17:567–80.
93. Markevych I, Schoierer J, Hartig T, Chudnovsky A, Hystad P, Dzhambov AM, et al. Exploring pathways linking greenspace to health: theoretical and methodological guidance. Environ Res. 2017;158:301–17.
94. Tzivian L, Dlugaj M, Winkler A, et al. Long-term air pollution and traffic noise exposures and mild cognitive impairment in older Adults: A Cross-Sectional Analysis of the Heinz Nixdorf Recall Study. Environ Health Perspect. 2016. https://doi.org/10.1289/ehp.1509824.
95. Sorensen M, Hvidberg M, Hoffmann B, Andersen ZJ, Nordsborg RB, Lillelund KG, et al. Exposure to road traffic and railway noise and associations with blood pressure and self-reported hypertension: a cohort study. Environ Health. 2011;10:92.