LONG-TERM EXPOSURE TO GREENSPACE AND HEALTHY AGEING

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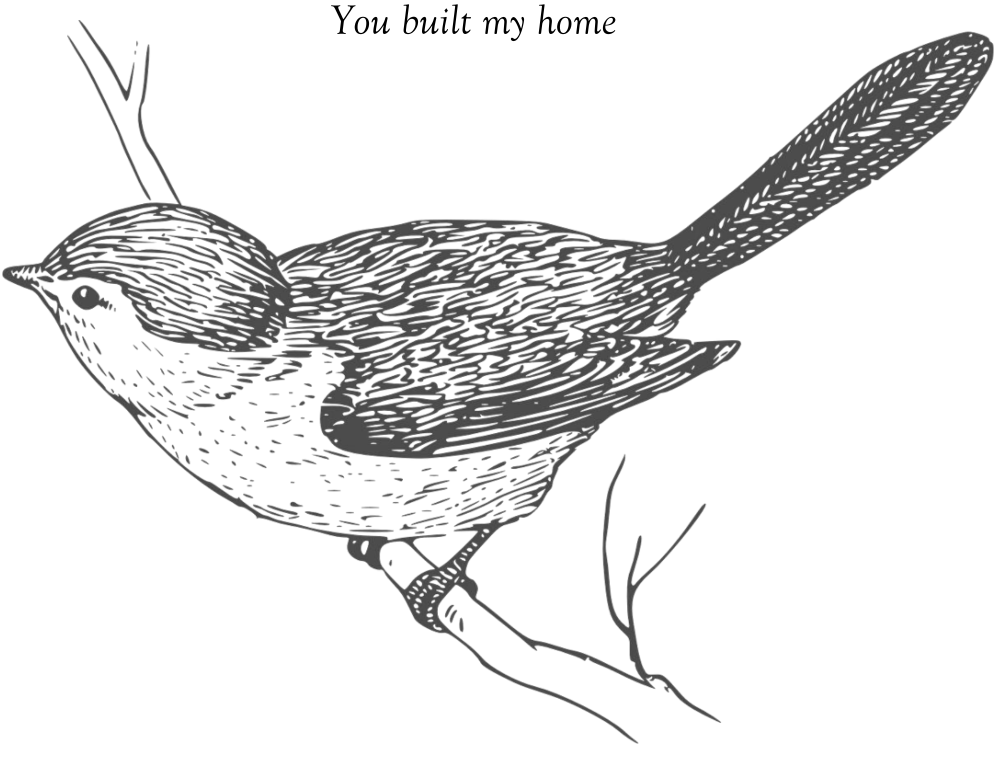
For my dad

You built my home



Acknowledgements

Doing a PhD has been such an adventure. An adventure that has been building up to this last chapter where I finally attempt to slay the dragon (write the thesis) and hopefully get knighted (or well, maybe get another sort of title). However, this has not been the effort of a single person.

First, I want to thank Payam, who gave me the opportunity to work on this great topic. Thank you very much for all your effort and support over these years, especially for your open-door policy, for always being willing to provide help, and for teaching so enthusiastically.

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I also want to give a big hug to my "long-distance" friends, who so patiently forgave me for texting way too little and luckily still offered to spend time with me. Thank you for all fun week(end)-visits, warm company, beautiful conversations, and indispensable encouragement!

Then, my sidekick in this adventure, Mario. I would not have applied for the PhD without you encouraging me with full confidence that it would all turn out alright with us. And throughout the years, you kept reminding me how cool this job is and you

always celebrated all the little and big victories with me. Thank you for being the best person on this planet and, for some mysterious reason, being with me.

At my side since any first adventure have been my mom, my dad, and my big brothers, Bram and Tim. I feel lucky to have you; today or in memory. I'm proud every time I notice I'm a bit like any of you. Thank you for being so amazingly supportive. You have always made me feel free to be far away and confident to do anything; after all, I will be alright anywhere, because I can always come home.

Barcelona, July 5th 2019

Abstract

As the world population is rapidly ageing and experiencing an ongoing urbanization, there is an emerging need for environments that are supportive of healthy ageing. Greenspace exposure may foster healthy ageing by promoting physical activity, mental health, and social support, and reducing exposure to air pollution, heat, and noise.

Therefore, the aim of this thesis was to investigate the longitudinal association of long-term exposure to greenspace with healthy ageing encompassing cognitive, physical, cardiovascular, and metabolic function.

This thesis includes two systematic reviews and four prospective cohort studies. The cohort studies were based on repeated follow-ups of the Whitehall II cohort of middle-aged and older adults from the UK. Our findings suggested that participants who lived in areas with more greenspace had a slower decline in cognitive function and physical functioning, decreased progression of arterial stiffness, and lower risk of metabolic syndrome over the study period.

Concluding, the findings of this thesis suggest that long-term exposure to greenspace could contribute to the promotion of healthy ageing.

Resumen

La población mundial está envejeciendo rápidamente y hay un incremento de la población en áreas urbanas. Por este motivo, existe una necesidad emergente de entornos que beneficien un envejecimiento saludable. La exposición a espacios verdes puede fomentar un envejecimiento saludable, promoviendo la actividad física, la salud mental y el apoyo social y reduciendo la exposición a la contaminación del aire, el calor y el ruido.

Por lo tanto, el objetivo de esta tesis fue investigar la asociación entre la exposición a espacios verdes a largo plazo y el envejecimiento saludable, considerando la función cognitiva, física, cardiovascular y metabólica.

Esta tesis incluye dos revisiones sistemáticas y cuatro estudios longitudinales de cohorte. Los estudios longitudinales se basaron en seguimientos repetidos de la cohorte de Whitehall II de adultos de mediana edad y adultos mayores del Reino Unido. Nuestros resultados sugirieron que los participantes que vivían en áreas con más espacios verdes tenían un deterioro cognitivo más lento, una menor pérdida de la capacidad física, una progresión reducida de la rigidez arterial y un menor riesgo de síndrome metabólico durante el período de estudio.

En conclusión, los resultados de esta tesis sugirieron que la exposición a espacios verdes a largo plazo podría contribuir a la promoción de un envejecimiento saludable.

Preface

This thesis was written at the Barcelona Institute for Global Health (ISGlobal), Barcelona, Spain between May 2016 and July 2019 and was supervised by Dr. Payam Dadvand. It is an accumulative thesis, consisting of six scientific articles of which the PhD candidate was the first author. The thesis complies with the procedures and regulations of the Biomedicine PhD program of the Department of Experimental and Health Sciences of the University Pompeu Fabra, Barcelona, Spain.

The objective of the thesis was to investigate the longitudinal association between long-term exposure to outdoor greenspace and healthy ageing. The present thesis contributes to the evidence of health benefits of long-term exposure to greenspace, which currently lacks longitudinal studies and studies on outcomes of healthy ageing. In two systematic reviews, a coherent and updated overview is provided of the existing available evidence for an association of long-term greenspace exposure with cognition as well as health among older adults. In four original research papers, the longitudinal associations between long-term greenspace exposure and different indictors of healthy ageing were studied in a cohort of middle-aged and older adults from the UK. The outcomes included cognitive decline, loss of physical functioning, progression of arterial stiffness, and risk of metabolic syndrome. For some of these age-related outcomes, the longitudinal associations with greenspace exposure were studied for the first time.

This thesis has relevant implications for public health, because due to the rapid growth in the older population worldwide, the need for age-friendly environments is emerging. Older adults may be more vulnerable to their environment than younger adults. With recent urbanization, an increasing number of older adults live in urban areas where their health may be affected by harmful exposure to air pollution, heat, and noise. The availability of greenspace could counteract these exposures and foster health at older age by increasing physical activity, social support, and mental health and reducing stress and exposure to air pollution, heat, and noise. The findings of this thesis suggest that long-term exposure to greenspace could contribute to healthy ageing.

For this thesis, the PhD candidate conducted systematic reviews, managed the data, performed the exposure assessment for greenspace using remote sensing, conducted statistical analyses, interpreted the findings, and wrote scientific articles for publication. In addition, the PhD candidate has been active in research dissemination, both for the general public (e.g. by writing blogs) as for the scientific public (e.g. by presenting in international conferences).

Furthermore, the PhD candidate has collaborated in the European project ***pro****ductive* ***G****reen* ***I****nfrastructure for post-industrial urban* ***reg****eneration* (proGIreg; funded by the EU Horizon 2020, grant agreement no. 776528) by co-designing and co-writing a protocol for the evaluation of health benefits of newly implemented nature-based solutions.

Abbreviations

ADD	Attention deficit disorder
ADHD	Attention deficit hyperactivity disorder
cf-PWV	Carotid-femoral pulse wave velocity
CI	Confidence interval
CORINE	Coordination and information on the environment
CVD	Cardiovascular disease
DBP	Diastolic blood pressure
DEFRA	Department for environment, food & rural affairs
EVI	Enhanced vegetation index
GPS	Global Positioning System
HDL	High-density lipoprotein
IARC	International agency for research on cancer
IMD	Index of multiple deprivation
IQR	Interquartile range
LSOA	Lower layer super output area
MAP	Mean arterial pressure
MET	Metabolic equivalent
MODIS	Moderate-resolution imaging spectroradiometer
NCD	Non-communicable disease
NDVI	Normalized difference vegetation index
NIR	Near-infrared
OECD	Organization for Economic Co-operation and Development

$PM_{2.5}$	Particulate matter with aerodynamic diameters less than 2.5 µm
PM_{10}	Particulate matter with aerodynamic diameters less than 10 µm
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
SBP	Systolic blood pressure
SD	Standard deviation
SES	Socioeconomic status
SOA	Secondary organic aerosols
UK	United Kingdom
USA	United States of America
VCF	Vegetation continuous fields
VI	Vegetation index
VOC	Volatile organic compounds
WHO	World Health Organization

Content

1. INTRODUCTION

1.1. Greenspace and health

Accumulating evidence demonstrates that greater exposure to greenspace is associated with improved health (Nieuwenhuijsen et al. 2017; Twohig-Bennett and Jones 2018; World Health Organization 2016). The increasing interest in health benefits of greenspace is linked to the ongoing urbanization; for the first time in history, more than half of the world population is living in cities (United Nations 2015b). Cities are sources of innovation and growth and urban residents often enjoy privileges such as better access to healthcare. However, urban living is also associated with relatively high exposure to urban related stressors such as air pollution, noise, and heat and high prevalence of physical inactivity, obesity, stress, and noncommunicable diseases (NCDs) (World Health Organization 2019). Moreover, urban residents often have limited access to greenspace, while increasing the availability of and access to greenspace has been suggested to counteract the aforementioned harmful factors and contribute to healthy urban living (Nieuwenhuijsen et al. 2017).

Greenspace includes any grass, trees, shrubs, or other vegetation that partly or completely cover any open land (Environmental Protection Agency 2018). Throughout this thesis, the term “greenspace” encompasses related terms such as green space, greenness, greenery, natural (outdoor) environments, and specific green spaces such as parks, forests, and community gardens. In addition, although previous studies have demonstrated health benefits of both short- and long-term exposure and of both indoor and outdoor exposure to greenspace, the focus of this thesis is on long-term exposure to outdoor greenspace.

1.1.1. Health benefits of greenspace exposure

Over the last decades, an increasing number of studies have observed a beneficial association between greenspace exposure and health. Experimental studies on short-term effects of contact with greenspace have shown positive associations with improved mental health including lower stress levels (Beil and Hanes 2013; Gidlow et al. 2016; Triguero-Mas et al. 2017) and improved mood and self-esteem (Barton et al. 2012; Song et al. 2013), cognitive benefits (Berman et al. 2008, 2012; Bratman et al. 2015), and cardiovascular benefits such as lower heart rate (Brown et al. 2013; Song et al. 2013; Sonntag-Öström et al. 2014), higher heart rate variability (Brown et al. 2013; Lee et al. 2011), and lower blood pressure (Brown et al. 2013; Hartig et al. 2003; Lee et al. 2011; Sonntag-Öström et al. 2014).

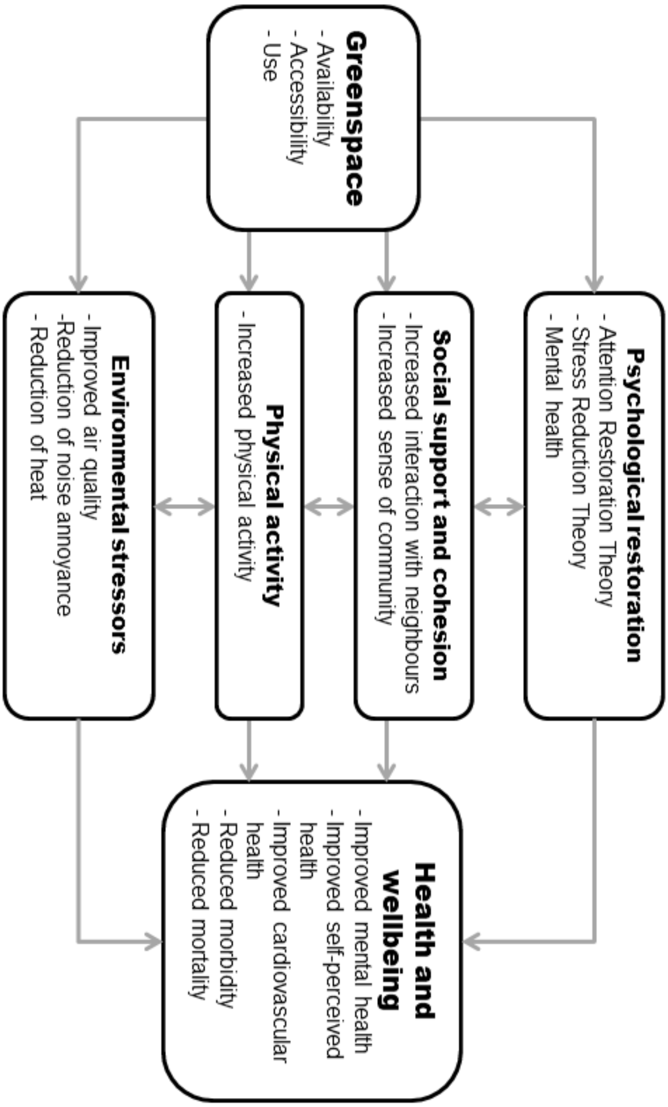
In observational studies, greater long-term exposure to greenspace has been associated with a wide range of health outcomes, including improved mental health, self-perceived general health, and reduced risk of morbidity and mortality (Fong et al. 2018; Gascon et al. 2015, 2016; James et al. 2015; Nieuwenhuijsen et al. 2017; van den Bosch and Ode Sang 2017). The available observational evidence has been evaluated by various systematic reviews including few meta-analyses. These reviews observed the strongest and most consistent evidence for an association between greater greenspace exposure and improved mental health and cardiovascular health and reduced mortality (Fong et al. 2018; Gascon et al. 2015, 2016; James et al. 2015; Nieuwenhuijsen et al. 2017; van den Bosch and Ode Sang 2017). In addition, in a recent systematic review, meta-analyses showed that greater exposure to greenspace was significantly associated with a decreased level of salivary cortisol, heart rate, and diastolic blood pressure, an increased incidence of good self-reported health, and a decreased risk of type II diabetes and cardiovascular and all-cause mortality (Twohig-Bennett and Jones 2018).

However, for most health outcomes, reviews conclude that the evidence is insufficient. The main reasons were the use of heterogeneous methods, limited number of studies regarding certain outcomes, and the lack of prospective studies.

1.1.2. Mechanisms between greenspace and health

The mechanisms that may underlie the association between greenspace exposure and health are yet to be fully understood, but a number of potential pathways have been proposed to be involved, including: (i) psychological restoration, (ii) social support and cohesion, (iii) physical activity, and (iv) mitigation of environmental stressors (Figure 1) (Hartig et al. 2014; Markevych et al. 2017).

Figure 1. Mechanisms between greenspace exposure and health



(i) Psychological restoration

Exposure to greenspace has been postulated to be a resource for psychological restoration by reducing stress and/or restoring attention, as framed by the following two theories:

The *Attention Restoration Theory* is based on the natural fascination that humans have for nature. As viewing nature is suggested to require "effortless attention", contact with nature provides the opportunity to restore directed attention after over-use by numerous attentional tasks, including those necessary for dealing with complex urban environments (Berman et al. 2008; Kaplan and Kaplan 1989; Kaplan 1995).

The *Stress Reduction Theory* suggests that exposure to greenspace improves affective states, evokes positive emotions, and blocks negative emotions and thoughts, which, in turn, could reduce stress (Ulrich et al. 1991). Such an association between greenspace exposure and psychological stress has been found in several studies (de Vries et al. 2013; Pun et al. 2018).

Overall, evidence of the psychological restoration-mechanism was found to be consistent by a recent review (Nieuwenhuijsen et al. 2017). By reducing stress and restoring attention, greenspace exposure could be associated with improved mental health (Gascon et al. 2015) and cognitive function (Marin et al. 2011; Ohly et al. 2016; Pearson and Craig 2014; Stevenson et al. 2018) and reduced risk of cardiovascular disease (CVD) (Fishta and Backe 2015) and metabolic diseases (Tamashiro et al. 2011).

(ii) Social support and social cohesion

The availability of greenspace in a neighbourhood may foster social interactions and promote a sense of community (Jennings and Bamkole 2019). Apart from providing an appealing setting for contact with neighbours, areas with greenspace may invite neighbours to spend more time outdoors and thereby increase visual contact and the probability of interactions. Increased quantity and/or quality of greenspace in the neighbourhood has been associated with less feelings of loneliness, lower risk of lack of social support, and improved social cohesion (Dadvand et al. 2016; de Vries et al. 2013; Maas et al. 2009a; Ward Thompson et al. 2016).

Social relations and social cohesion, in turn, have been demonstrated to improve health and wellbeing (Yang et al. 2016). Studies have observed that greater social support was associated with, among others, lower risk for mortality and CVDs and protection against physical disability and mental health problems (Seeman and Crimmins 2001), including depression (Holzel et al. 2011) and dementia (Kuiper et al. 2015).

(iii) Physical activity

Areas with greenspace may promote physical activity. Many studies have investigated this association, but the reported findings have been inconsistent (Nieuwenhuijsen et al. 2017). One possible explanation of these mixed findings is that most studies focused on the total amount of physical activity or only moderate-to-vigorous physical activities, did not consider where physical activity was performed (i.e. in greenspace or elsewhere), and/or overlooked the quality aspects of the greenspace. Nevertheless, several studies have reported higher levels of physical activity in areas with increased access to greenspace (Almanza et al. 2012; Astell-Burt et al. 2014a; Gong et al. 2014; Richardson et al. 2013).

Overall, physical inactivity is one of the principal risk factors of mortality worldwide (World Health Organization 2018). Increasing physical activity is a public health priority and could contribute to the prevention of NCDs including CVDs, cancer, and diabetes.

(iv) Mitigation of environmental stressors

Greenspace has the potential to reduce exposure to and/or mitigate the negative influence of environmental hazards, especially those hazards experienced by urban populations, including air pollution, noise, and heat (Dadvand et al. 2012; Nieuwenhuijsen et al. 2017; Wu et al. 2015b).

Air pollution
Greenspace may contribute to cleaner air by removing air pollutants by dry deposition and by reducing temperature and hence decelerating smog formation (Janhäll 2015). However, the impact is limited; for instance, the tree canopy of the urban forest in the Greater London Area was estimated to contribute to the air quality by reducing the PM_{10} level by around 1% (Tallis et al. 2011). Similarly, in a study from the USA, the average percentage of air quality improvement in cities during the daytime of the vegetation in-leaf season were estimated less than 1% (Nowak et al. 2006).

Nevertheless, an increased exposure to greenspace has been associated with a reduced exposure to air pollution (Dadvand et al. 2012, 2015b; Hystad et al. 2014), which could be the result of a combination of the improved air quality and the absence of sources of pollution in areas covered by greenspace (Nieuwenhuijsen et al. 2017).

However, in some cases, vegetation may have disadvantages for air quality (Zupancic et al. 2015). Urban trees could contribute to the formation of ozone by the emission of volatile organic compounds (VOC) and the formation of secondary organic aerosols (SOA) through photo-oxidation process. Moreover, depending on the setup of the trees and on the airflow, the concentration of air pollution could be increased; in densely built street canyons, trees may cause a loss of ventilation which leads to an increase in the local air pollution concentrations. In addition, when greenspace reduces the airflow, the ventilation of indoor air may also be reduced, which would cause an increased exposure to indoor air pollution.

Air pollution is one of the environmental factors with the largest contribution to the global burden of disease and is estimated to contribute to 4.2 million deaths per year worldwide (World Health Organization). Specifically, greater exposure to air pollution has been associated with increased risk of NCD-related mortality and morbidity such as impaired cognitive function and dementia (Power et al. 2016), pulmonary health (Kurt et al. 2016), diabetes (Balti et al. 2014), and cardiovascular morbidity and mortality (Koulova and Frishman 2014) including stroke (Scheers et al. 2015).

Noise

Greenspace can be a physical buffer against noise by diffracting, absorbing, or interfering the soundwaves and, hence, reducing exposure to noise (Markevych et al. 2017). In addition, the absence of artificial noise emitting sources also leads to a lower exposure to noise in areas covered by greenspace. Moreover, greenspace can have a psychological effect by reducing noise annoyance, for instance, by blocking the view of the noise source, improving the perceived acoustic quality, and mixing the noise with natural sounds (World Health Organization 2016). Natural sounds may play an important role for the health benefits obtained from nature experience (Franco et al. 2017).

Environmental noise is being regarded as a growing threat to human health; it is estimated that environmental noise contributes to the loss of at least one million disability adjusted life years in high-income western European countries each year (Basner et al. 2014; Fritschi et al. 2011). Increased levels of noise have been associated with higher risk of cognitive impairment, sleep disturbance, and CVD (Basner et al. 2014; Fritschi et al. 2011).

Heat

Greenspace could contribute to the mitigation of heat in urban areas by providing shade, evapotranspiration, and, indirectly, by carbon sequestration (Burkart et al. 2015; Gronlund et al. 2015). Greenspace's property of reducing heat is especially of interest in cities due to the urban heat island effect. *Urban heat island* is a term used to describe the rise in ambient temperature in cities compared to sub-urban and rural areas due to the absorption and storage of heat by man-made features present in cities (e.g. high-rise buildings and asphalt) and due to the dense concentration of industry and commercial centres in cities.

Heat in urban areas is of growing concern, especially considering the ongoing changes in the global climate and the anticipated higher frequency and severity of extreme weather conditions including heat waves (Luber and McGeehin 2008; WHO & World Meteorological Organization 2015).

1.1.3. Indicators of long-term greenspace exposure

Epidemiological studies have assessed exposure to greenspace using various indicators. The main indicators can be categorized as (a) greenspace availability, (b) greenspace accessibility, and (c) use of greenspace (World Health Organization 2016).

(a) Availability

Availability of greenspace can be assessed by quantifying the amount of greenspace in a geographical area. In many previous epidemiological studies on the association between greenspace and health, an estimate of the amount of greenspace was obtained using satellite-based indices of vegetation, derived through remote sensing (Ekkel and de Vries 2017; Expert Group on the Urban Environment 2000). Vegetation indices (VIs) are "*spectral* *transformations of two or more bands designed to enhance the contribution of vegetation properties and allow reliable spatial and temporal inter-comparisons of terrestrial photosynthetic activity and canopy structural variations*" (Huete et al. 2002 p. 195). Basically, it provides a standardized measure of all living green vegetation without distinguishing between the greenspace type, size, or access. In addition, studies have used land cover maps to quantify the availability of greenspace. With this method, the type of land cover can be considered.

(b) Accessibility

The accessibility to greenspace can be determined by several aspects, including the proximity, visual access, private/public accessibility, the access points, and the perceived accessibility to greenspace. The perceived accessibility is assessed subjectively by a survey, for instance, using questions on the perceived distance or walking time to reach a greenspace from the home. The objective access to greenspace is often estimated by the proximity to greenspace from the home (or from another location), which is a key indicator of accessibility (World Health Organization 2016). Proximity can be estimated by calculating the linear or path/road network distance from the participant's home to the nearest greenspace edge, entrance, or centroid using land use or land cover maps (Ekkel and de Vries 2017).

(c) Use

Use of greenspace can be measured objectively, for instance, by GPS-tracking of individuals, or subjectively, for instance, by using surveys on self-reported visits or time spent in greenspace. Indicators of use of greenspace add information on how and to what extent greenspace areas are used and could provide further insight in pathways between greenspace availability and accessibility and health (World Health Organization 2016). However, greenspace could have an impact on health without active use of greenspace (e.g. by visual access of greenspace).

In addition to availability, accessibility, and use, studies on greenspace and health could consider specific characteristics of greenspace that could affect the association with health such as safety, aesthetics, maintenance, and amenities (walking paths, lighting, benches/resting places, etc). Furthermore, the size of greenspace areas may be relevant as, depending on the size, a greenspace area may invite for different types of activities. The type of greenspace (e.g. public park, private garden, sports field, or forest) and type of vegetation (e.g. grass or woodland) may also be of influence in the association with health. However, epidemiological studies have not often evaluated these characteristics and, among studies that did evaluate them, the methods to assess these characteristics were heterogeneous and led to results that are difficult to compare.

1.2. Healthy ageing

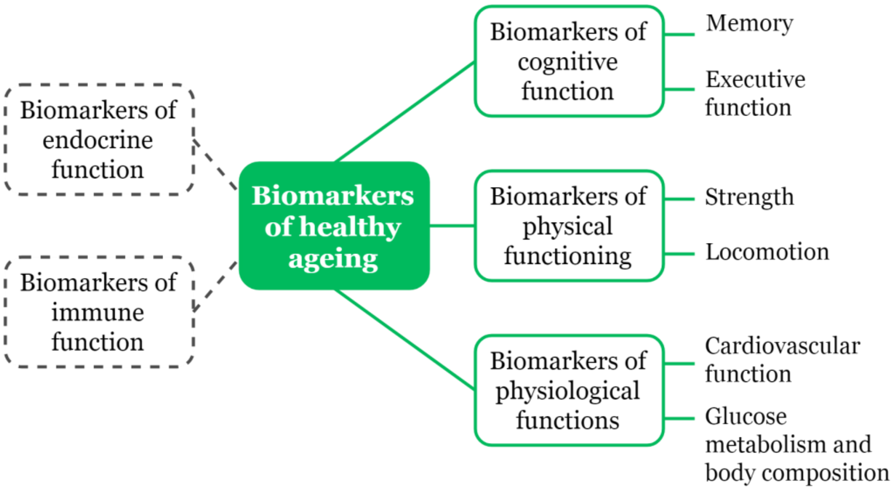
In addition to urbanization, the world population is experiencing another major demographic shift in the form of population ageing. While the average life expectancy worldwide has hit an ultimate high of 71 years, birth rates are falling in most parts of the world (United Nations Department of Economic and Social Affairs 2017). As a result, the age distribution of the world population is shifting; the proportion of adults aged 60 years and over is expected to nearly double from 12% to 22% between 2015 and 2050 (World Health Organization 2015a). However, although life expectancy is increasing, people may not live longer healthily (i.e. with disability and morbidity occurring only at the end of life) but live those "extra years" with disability, low quality of life, and suffering from chronic disease (Leonardi et al. 2014; Schneider and Brody 1983). In general, studies have found that with age, the risk of disability, poor quality of life, chronic disease and co-morbidity increases (Prince et al. 2015).

Healthy ageing is defined as "*the process of developing and maintaining the functional ability that enables wellbeing in older age*" (World Health Organization). *Functional ability* includes a person's mental and physical functions including the ability to walk, think, see, hear, and remember. These functions also affect ability for self-care and to perform tasks of daily life and are influenced by, among others, the presence of diseases, injuries, age-related changes, and the environment.

1.2.1. Biomarkers of healthy ageing

A framework of biomarkers of healthy ageing has been proposed to provide objective indicators that capture five important functions which are affected by biological ageing (Figure 2) (Lara et al. 2015). The present thesis focuses on three of these five functions: (a) cognitive function, (b) physical functioning, and (c) physiological function (Figure 2). A short description and potential methods to measure biomarkers of each of these three functions is given below.

Figure 2. Biomarkers of healthy ageing, adapted from Lara et al. (2015)



(a) Cognitive function

Cognitive function is an important determinant of healthy ageing; it is fundamental to preserve quality of life and the ability to live independently at older age, and has been found to progressively decline with age (Clouston et al. 2013). Cognitive function can be assessed by testing various domains, including executive function, processing speed, and episodic memory. Ideally, to assess cognitive function, a battery of objective tests such as computerized tests or assessments are applied by healthcare professionals to characterize different aspects of cognitive function (Lara et al. 2015).

(b) Physical functioning

Physical functioning, also referred to as physical capability, refers to a person's ability to perform the physical tasks of everyday living (Lara et al. 2015). Physical functioning is considered to be a major component of healthy ageing and has been found to progressively decline with age (Kuh et al. 2014). Limited physical functioning is associated with a lower quality of life and higher risk of disability, depression, and falls and fractures (Tomey and Sowers 2009). Ideally, physical functioning is assessed using objective tests, for instance, tests of walking speed, grip strength, standing balance, and chair rise time (Lara et al. 2015).

(c) Physiological functions

Many physiological functions decline with age, including lung function, body composition, cardiovascular function, and glucose metabolism (Lara et al. 2015). In this thesis, I focused on cardiovascular and metabolic function. With age, cardiovascular and metabolic health deteriorates, which could lead to increased cardiometabolic risk factors (e.g. unhealthy body composition, hypertension, high cholesterol levels, diabetes, and arterial stiffness) and, subsequently, increased risk of chronic disease(s). Cardiometabolic risk factors can be measured objectively in medical examinations, for instance, by measuring blood pressure and fasting blood glucose levels (Lara et al. 2015).

1.2.2. The environment and healthy ageing

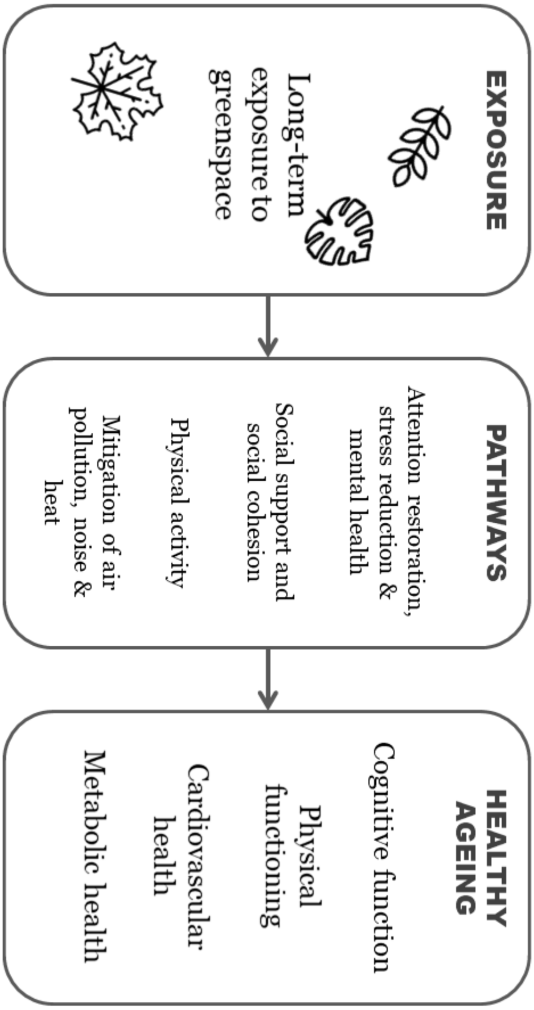
The environment has a profound influence on health at older age (Garin et al. 2014; World Health Organization). There is a constant interaction between a person's *functional ability* (as defined by WHO) and their environment. While a person's environment may change as a result of loss of functional ability (e.g. a person's social life may suffer from a loss of mobility), the environment in turn can influence functional status through the years by either facilitating or impeding the participation in certain activities (Beard et al. 2016; Clarke and Nieuwenhuijsen 2009). Various aspects of the environment, including the built environment, air pollution, and noise, have been associated with cognitive function, physical functioning, and cardiovascular and metabolic health. For instance, walk-friendly infrastructures and access to destinations and services have been found to be positively related with higher levels of physical functioning among older adults (Soma et al. 2017).

1.2.3. Exposure to greenspace and healthy ageing

As part of a supportive environment, exposure to greenspace may foster healthy ageing. Greenspace could be associated with health at older age through various mechanisms, including by enhancing social support, physical activity, and psychological restoration and mitigating urban-related environmental stressors (as described in section 1.1.2. of this thesis). Also among older adults, several studies (that focused on the older population) have observed that increased greenspace exposure was beneficially associated with physical activity (Astell-Burt et al. 2014a; Dalton et al. 2016b; Dewulf et al. 2016; Gong et al. 2014; Shaw et al. 2017; Van Cauwenberg et al. 2017), mental health (Astell-Burt et al. 2013; Pun et al. 2018; Sarkar et al. 2013; Wu et al. 2015b), social support (Hong et al. 2018), and heat-related mortality (Burkart et al. 2015; Gronlund et al. 2015). In turn, through these proposed mechanisms between greenspace and health, namely increased physical activity and social support, improved mental health, reduced stress, and decreased exposure to air pollution, heat, and noise, greenspace exposure could also be associated with improved healthy ageing by benefiting cognitive function, physical functioning, and cardiovascular and metabolic health at older age (Figure 3).

Although studies on the associations between greenspace and health are accumulating, the older population is currently understudied (Kabisch et al. 2017). In addition, only few studies have investigated the association between long-term exposure to greenspace and indicators of healthy ageing such as cognitive function, physical functioning, and cardiovascular and metabolic health. Moreover, among existing studies, there was a lack of longitudinal studies, while longitudinal data is crucial to provide insight on the potential impact of greenspace on the process of healthy ageing over time.

Figure 3. Potential mechanisms between long-term greenspace exposure and healthy ageing



2. RATIONALE

The 21st century is characterised by two major demographic shifts that present complex challenges for public health worldwide. First, the world is urbanizing. Currently, around 50% of the world population resides in cities and it is predicted that by 2050 almost 66% will live in urban areas (United Nations 2015b). Second, the world population is ageing; the number of older adults, commonly defined as aged 60 years and over, has been projected to double from 962 million in 2017 to approximately 2.1 billion in 2050 (United Nations Department of Economic and Social Affairs 2017). In addition, an increasing number of older adults are living in urban areas. It is estimated that, worldwide, the percentage of older adults increased by 68% in urban areas compared to 25% in rural areas between 2000 and 2015 (United Nations 2015a). Therefore, there is a need for strategies to promote healthy ageing in urban areas, where lifestyle factors such as stress and physical inactivity and greater exposure to air pollution, heat, and noise may affect older adults' health.

Increasing the availability of and access to greenspace has been suggested as an important measure to promote healthy urban living (Nieuwenhuijsen et al. 2017). Over the last decades, accumulating evidence has demonstrated beneficial associations between exposure to greenspace and health. However, much of the evidence is based on cross-sectional studies and there is still a lack of longitudinal studies on associations between long-term greenspace exposure and health assessed over time (Fong et al. 2018; Gascon et al. 2015, 2016; James et al. 2015; Nieuwenhuijsen et al. 2017; van den Bosch and Ode Sang 2017). Furthermore, greenspace exposure could promote healthy ageing by increasing physical activity, improving social cohesion and mental health, and reducing exposure to air pollution, heat, and noise. However, studies on the association between exposure to greenspace and health at older age are limited, especially studies considering outcomes of healthy ageing such as cognitive function and physical functioning.

Therefore, there is a need of longitudinal studies on the effects of long-term exposure to greenspace on health at older age, including cognitive function, physical functioning, and cardiovascular and metabolic health.

3. OBJECTIVES

The overarching aim of the present thesis was to investigate the association of long-term exposure to outdoor greenspace with healthy ageing. Towards this aim, the association between residential greenspace exposure and main indicators of healthy ageing, including cognitive function, physical functioning, and cardiovascular and metabolic health, was evaluated by analysing longitudinal data obtained from middle-aged and older adults.

There were six specific objectives:

1. To systematically evaluate the current available body of observational evidence on the association between long-term exposure to greenspace and cognition over the life span. *(Paper I)*
2. To investigate the association between long-term greenspace exposure and cognitive decline. (*Paper II)*
3. To investigate the association between long-term greenspace exposure and physical functioning. (*Paper III)*
4. To investigate the association between long-term exposure to residential surrounding greenspace and arterial stiffness and its progression over time. (*Paper IV)*
5. To investigate the association between long-term exposure to greenspace and the risk of metabolic syndrome. *(Paper V)*
6. To systematically review the existing evidence on the association between long-term exposure to outdoor greenspace and health at older age. *(Paper VI)*

Each objective resulted in a scientific paper. All scientific papers are presented in the results section of the present thesis, in the order as presented above. Objective 6 is presented as the last paper of the thesis to provide an up-to-date overview of the existing evidence on the association between greenspace exposure and health at older age, including evidence obtained in papers II and III (i.e. the papers that were published at the time of the systematic review).

4. METHODS

4.1. Systematic reviews

For research objectives 1 and 6, I performed systematic reviews based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al. 2009). Briefly, two databases (PubMed and Scopus) were searched for relevant articles using a systematic search strategy with a comprehensive keyword list. Articles were selected to be included in the systematic review by using strict selection criteria that were determined *a priori*. To summarize the available evidence, the main characteristics of each article were extracted and presented in tables. In addition, the evidence was evaluated based on the quality of the studies (assessed using established criteria), quantity of the studies, and the consistency of the findings.

4.2. Longitudinal cohort studies

For research objectives 2, 3, 4, and 5, I conducted longitudinal cohort studies using data from the prospective cohort of the Whitehall II study, a well-established, ongoing cohort from the UK. As part of this, I geocoded the residential postcode of the participants, assessed the participants' exposure to greenspace over the study period, complied a database by merging data on exposures, outcomes, and covariates, performed the statistical analyses, and interpreted the results.

4.2.1. Description of the Whitehall II cohort

The initial objective of the Whitehall II study was to investigate the longitudinal associations between social and occupational factors and health and disease. In a later stage, this objective was expanded to studying the influence of dietary, lifestyle, biological, and psychosocial risk factors on health and health-related quality of life (Marmot and Brunner 2005).

The recruitment of participants of the Whitehall II cohort started in 1985. The participants were identified from British civil servant registries. All civil servants between age 35 and 55 from 20 government departments in London were invited to participate in the study, leading to a sample size of 10,308 study participants (3413 women and 6895 men). Although all participants were civil servants, their socioeconomic status varied widely with occupation grades ranging from clerical and office support grades to senior administrative grades, leading to widely varying salaries (e.g. <£8,000 a year to >£80,000 a year) (Marmot and Brunner 2005).

The Whitehall II study has several important strengths. First, the collection of longitudinal data allowed us to study the change in health over time. The participants were invited for follow-ups of questionnaires and medical examinations every five years and the response rates were high for each follow-up (>70%, see Table 1) (University College London 2016). As such, this cohort benefits from a rich database encompassing repeated records on a wide range of indicators of lifestyle, socioeconomic position, and mental and physical health, including objective indicators of health assessed in medical examinations.

The analyses in the present thesis were based on data collected from the fifth follow-up (1997-1999) onwards. In 1997-1999, measurements of certain indicators related to healthy ageing (e.g. cognitive function) were introduced. In addition, the fifth follow-up was the first follow-up in which the study population included only middle-aged and older adults (age between 44 and 69 years old), which provides an appropriate cohort to study healthy ageing.

At the start of the present thesis (2016), we were allowed access to data of the Whitehall II cohort up to the follow-up of 2007-2009. Therefore, our first study on cognitive function (*paper II*) included data up to 2007-2009. However, in a later stage of the PhD, data of the follow-up of 2012-2013 became available, which were then requested and used in the analyses of the following studies (*paper III, IV, and V*).

4.2.2. Residential locations of participants

We assessed exposure to greenspace for each participant at the residential location. We did not have access to information on other locations where the participants might have been exposed to greenspace. Nevertheless, in general, the older population is more bound to their residential environment than younger populations (Yen et al. 2009), thus greenspace surrounding the home was likely to be a main source of greenspace exposure.

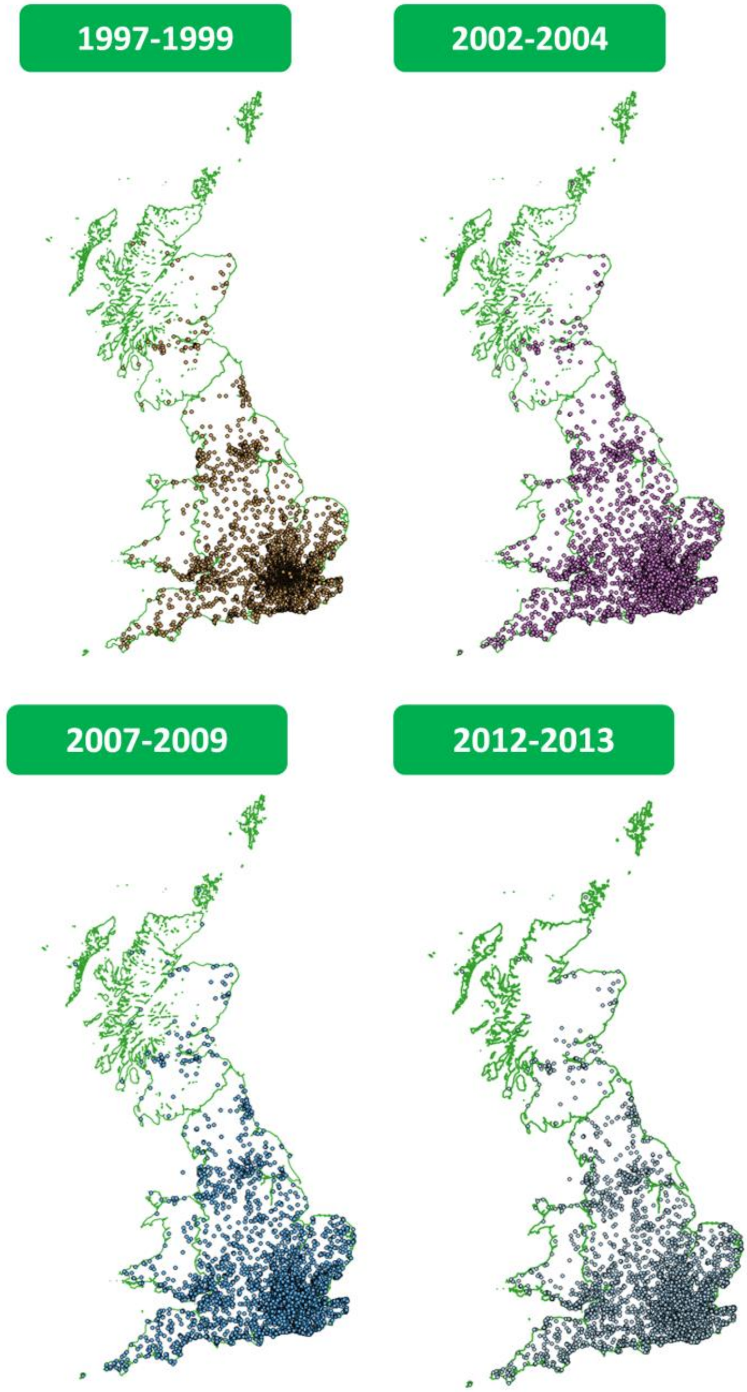
Table 1. Data collection phases (University College London 2016)

Follow-up	Years	Type	N	Response rate[(a)]	Response rate[(b)]
1	1985-88	Questionnaire & Clinic	10,308	ref.	Ref.
2	1989-90	Questionnaire	8,132	79.3%	79.3%
3	1991-94	Questionnaire & Clinic	8,815	86.6%	86.6%
4	1995-96	Questionnaire	8,628	85.3%	92.4%
5	1997-99	Questionnaire & Clinic	7,870	78.7%	86.3%
6	2001	Questionnaire	7,355	74.4%	82.5%
7	2002-04	Questionnaire & Clinic	6,967	71.6%	82.2%
8	2006	Questionnaire	7,173	75.2%	87.2%
9	2007-09	Questionnaire & Clinic	6,761	72.3%	84.5%
11	2012-13	Questionnaire & Clinic	6,318	70.9%	84.1%

(a) participants alive
(b) participants eligible (alive and not withdrawn from the study)

To indicate the residential location of the participant, we geocoded the centroid of the postcode of each participant at each follow-up. We did not have access to the full address due to data protection restrictions. Nevertheless, a postcode in the UK contains an average of 15 addresses (Dalton et al. 2016b), providing a reliable estimation of the residential location. We did not geocode postcodes of participants living outside of the UK, because the postcode systems might not be comparable with the system of the UK and because of the low participation rates among participants who had moved outside of the UK.

Figure 4. Geographical distribution of the study population per follow-up (based on the postcode centroids)



The geographical locations of the postcode centroids of the study participants are represented in Figure 4. While all participants of the Whitehall II cohort were employed by civil servant departments in London at recruitment to the cohort (1985-1988), by the follow-up of 1997-1999, many participants had moved away from London (Figure 4).

4.2.3. Exposure assessment for the Whitehall II cohort

The assessment of greenspace exposure for the Whitehall II cohort was based on data sources that were available and comparable for the entire UK and covered the study period from the fifth follow-up (1997-1999) to the eleventh follow-up (2012-2013). I obtained estimates of both residential availability and accessibility to greenspace.

(i) Availability

The availability of greenspace was quantified by estimates of greenspace surrounding the residential location of each participant at each follow-up using satellite-based vegetation indices. Residential surrounding greenspace has been the most-used greenspace indicator in epidemiological studies (Ekkel and de Vries 2017; World Health Organization 2016). We applied vegetation indices derived from satellite images with a spatial resolution of 250 m × 250 m from the Moderate-resolution Imaging Spectroradiometer (MODIS). MODIS was used instead of satellite images with a higher spatial resolution due to the very large geographical area of our study region encompassing England, Scotland, and Wales, that would make processing of higher resolution satellite image data extremely computationally heavy. Moreover, as only postcodes were available (i.e. instead of the exact home geolocation of the study participants), the residential location was based on the geolocation of the centroid of the postcode. Therefore, satellite images of higher resolution would not improve the precision of exposure estimates.

The MODIS vegetation indices are "*designed to provide consistent, spatial, and temporal comparisons of global vegetation conditions*" (Huete et al. 2002). I obtained the following three indices:

(a) *Normalized Difference Vegetation Index* (NDVI) is an index based on land surface reflectance of visible (red) and near-infrared parts of the spectrum (Weier and Herring 2000). It ranges between −1 and 1 with higher values indicating more greenness (i.e. photosynthetically active vegetation).
(b) *Enhanced Vegetation Index* (EVI) is a vegetation index similar to NDVI, but more responsive to canopy structural variations (i.e. it functions better in densely vegetated parts) and it minimizes soil background influences (Didan 2015).
(c) *Vegetation Continuous Fields* (VCF) estimates the percent of ground covered by woody vegetation (i.e. tree cover) with a height of five or more meters (Hansen et al. 2003).

MODIS images of NDVI and EVI were obtained over periods of 16 days. For each follow-up, I looked for images from a maximum vegetation period of the year (i.e. May-June in our study region, representing a "summer estimate") with minimum cloud cover. In addition, to take into account seasonality variability in NDVI and EVI, I also downloaded MODIS images obtained in December (i.e. a period of minimum vegetation in our study region, obtaining a "winter estimate") of the relevant years to each follow-up. MODIS images of VCF were provided as annual values, thus for VCF, I only downloaded one annual image for each follow-up of a relevant year to each follow-up.

To estimate the residential surrounding greenspace, I abstracted the average NDVI, EVI, and VCF across circular buffers of 500 and 1000 m surrounding the postcode centroid of the address at each follow-up. The 500 m distance represented the direct environment outside of the home. The use of a buffer smaller than 500 m was not possible due to the use of the postcode centroid to geocode the residential location of the participants. The larger buffer of 1000 m was chosen to represent the walking distance that adults generally cover to go to places near the home (Stockton et al. 2016). In addition, buffers of 500 and 1000 m have been used in numerous greenspace studies [including studies on middle-aged and older adults, e.g. (Astell-Burt et al. 2013; Pun et al. 2018; Sarkar et al. 2013, 2018b; Villeneuve et al. 2018a)]. In addition, I abstracted the average NDVI, EVI, and VCF across an administrative area using the Lower layer Super Output Areas (LSOAs) corresponding to the residential postcode of each participant at each follow-up. LSOAs are created by grouping postcodes considering social demographics, proximity, and natural barriers.

(ii) Accessibility

I collected an indicator of accessibility to greenspace by estimating the residential proximity to greenspace. Especially for older adults, who are at higher risk of limited mobility than younger populations, the proximity to greenspace could be an important determinant of use of greenspace. We applied the COoRdination and INformation on the Environmental (CORINE) land use map (2006) to assess the distance of participants' residential location (i.e. postcode centroid) to the nearest greenspace, blue spaces, and natural environments (i.e. either green or blue spaces, whichever was nearest) at each follow-up.

4.2.4. Outcome assessment

In this thesis, I focused on objective markers of healthy ageing including cognitive function, physical functioning, arterial stiffness, and metabolic syndrome. All these variables were measured repeatedly over time and hence provided information about the ageing process.

Cognitive function was assessed by a battery of cognitive tests in the medical examinations including four cognitive tests that assessed three domains of cognitive function (reasoning, verbal fluency, and short-term memory) in the follow-ups of 1997-1999, 2002-2004, and 2007-2009 (*Paper II*).

Physical functioning was assessed by measures of lower and upper body function. Lower body function was evaluated by *walking speed*, assessed in 2002-2004, 2007-2009, and 2012-2013. Upper body function was assessed by *grip strength* at the follow-ups of 2007-2009 and 2012-2013 (*Paper III*).

Arterial stiffness was assessed in the medical examinations by measuring the *carotid-femoral pulse wave velocity* (cf-PWV) in the follow-ups of 2007-2009 and 2012-2013. Pulse wave velocity is a marker of the intrinsic elasticity of the arterial wall and is regarded as one of the best measures of arterial stiffness (Millasseau et al. 2005) (*Paper IV*).

Metabolic syndrome was assessed using data obtained in medical examinations of the follow-ups of 1997-1999, 2002-2004, 2007-2009, and 2012-2013, including measurements of waist circumference, serum triglyceride levels, HDL cholesterol levels, systolic blood pressure, diastolic blood pressure, and medication use (*Paper V*).

4.2.5. Statistical analyses

For each paper, appropriate statistical methods were chosen to analyse the association between greenspace exposure and the outcome. For *Paper II-IV*, I used linear mixed effect models with person random effect and for *Paper V*, I used Cox proportional hazards regression models. All analyses were adjusted for the relevant confounders as described in the papers (presented in the results section of this thesis).

5. RESULTS

1. *Paper I*
   Long-term green space exposure and cognition across the life course: A systematic review.
2. *Paper II*
   Residential surrounding greenness and cognitive decline: A 10-year follow-up of the Whitehall II cohort.
3. *Paper III*
   Green and blue spaces and physical functioning in older adults: Longitudinal analyses of the Whitehall II study
4. *Paper IV*
   Long-term greenspace exposure and progression of arterial stiffness: The Whitehall II cohort study
5. *Paper V*
   Long-term exposure to greenspace and metabolic syndrome: A Whitehall II study
6. *Paper VI*
   Long-term exposure to residential greenspace and healthy ageing: A systematic review

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* References of all papers are presented in the bibliography section of this thesis.

1. Paper I

Carmen de Keijzer[a,b,c], Mireia Gascon[a,b,c], Mark J. Nieuwenhuijsen[a,b,c], Payam Dadvand[a,b,c]. **Long-term green space exposure and cognition across the life course: A systematic review.** *Current Environmental Health Reports. 2016; 3(4): 468-477: doi: 10.1007/s40572-016-0116-x.*[*]

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2. Paper II

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3. Paper III

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Green and blue spaces and physical functioning in older adults: Longitudinal analyses of the Whitehall II study.
Environment International 2019. 122; 346-356: https://doi.org/10.1016 /j.envint. 2018.11.046 [*]

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4. Paper IV

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5. Paper V

Carmen de Keijzer [a,b,c], Xavier Basagaña [a,b,c], Cathryn Tonne [a,b,c], Antònia Valentín [a,b,c], Jordi Alonso [b,c,d], Josep M Antò [a,b,c], Mark J Nieuwenhuijsen [a,b,c], Mika Kivimäki [e], Archana Singh-Manoux [e,f], Jordi Sunyer [a,b,c], Payam Dadvand [a,b,c]. **Long-term exposure to greenspace and metabolic syndrome: A Whitehall II study.** Environ Pollut. 2019 Dec;255(Pt 2):113231. DOI: 10.1016/j.envpol.2019.113231

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6. Paper VI

Carmen de Keijzer[a,b,c], Mariska Bauwelink[d,e], Payam Dadvand[a,b,c].
Long-term exposure to residential greenspace and healthy ageing: A systematic review. *Curr Environ Heal reports. 2020 Mar 24;7(1):65–88. DOI: 10.1007/s40572-020-00264-7*

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6. DISCUSSION

The objective of the present thesis was to investigate the association between long-term exposure to outdoor greenspace and healthy ageing. The main results of this thesis come from four original research papers that provided evidence on the association of long-term exposure to greenspace with cognitive decline (*Paper II*), physical functioning (*Paper III*), progression of arterial stiffness (*Paper IV*), and the risk of metabolic syndrome (*Paper V*). In addition, this thesis includes two systematic reviews, providing an evaluation of the existing evidence on the association between long-term greenspace exposure and cognitive function over the life span (*paper I*) and health at older age (*paper VI*). Each of these six papers (all presented in the results section of this thesis) includes a discussion section. In the current discussion section of the complete thesis, the main points of the discussion sections of each paper are summarized and complimented by a comprehensive discussion and interpretation of this thesis.

6.1. Main findings

6.1.1. Findings of the systematic reviews (Paper I and VI)

In the systematic review on the evidence on the association between greenspace exposure and cognitive function over the life course (*Paper I*), we identified 13 studies on the topic (including four studies on older adults), providing inadequate but suggestive evidence for a positive association between long-term greenspace exposure and cognition function.

In the systematic review on the evidence of the association between long-term greenspace exposure and healthy ageing (*Paper VI*), we identified 59 studies including outcomes of mental health, cognitive function, physical capability, morbidity, cardiometabolic risk factors, and perceived wellbeing at older age (*Paper VI*). The evidence for an association of long-term greenspace exposure with the aforementioned outcomes was found to be limited or inadequate, but suggestive of a beneficial association.

6.1.2. Findings of Whitehall II studies (Papers II-V)

In *papers II-IV*, greater long-term exposure to greenspace was associated with a reduction in cognitive decline, loss of physical functioning, and progression of arterial stiffness.

In *paper II*, increased residential surrounding greenspace (as assessed by summer estimates of NDVI and EVI across a 500 or 1000 m buffer around the residential location) was associated with a slower decline in global cognitive function. Cognitive function was evaluated by repeated cognitive tests assessing three domains of cognition (reasoning, fluency, and short-term memory). These results were similar when using NDVI or EVI and when using the 500 or 1000 m buffer.

In *paper III*, Whitehall II participants living in neighbourhoods with more availability of greenspace (as assessed by NDVI or EVI across a 500 or 1000 m buffer around the residential location) were found to have a slower decline in walking speed, an important indicator of lower body function. The associations with the decline in walking speed were similar when using estimates of NDVI and EVI from a summer month or averaged over a summer and winter month and when using estimates across the 500 m buffer, 1000 m buffer, or LSOA. However, no associations were observed between NDVI or EVI and the decline in grip strength, a marker of upper body function. Increased accessibility to greenspace (as assessed by proximity to green or blue space) was associated with both a slower decline in walking speed and a slower decline in grip strength.

In *paper IV*, greater exposure to greenspace (NDVI, EVI, or VCF in a 500 or 1000 m buffer around the residential location) was associated with a decreased progression in arterial stiffness, as assessed by two repeated measurements of carotid-femoral pulse wave velocity (cf-PWV). The findings were similar when using greenspace estimates across the 500 m buffer, 1000 m buffer, and LSOA and when using the summer or the average of the summer and winter estimates of EVI and NDVI.

To facilitate the comparison of these results, I estimated the average decline in cognition and physical functioning and the average progression of arterial stiffness over the study period using a model including averages for all covariates. Subsequently, I could compare the difference in the decline/progression that was associated with one interquartile range (IQR) increase in NDVI in the 500 m buffer with this average decline/progression. Table 2 presents the percentage of difference in the decline/progression associated with one-IQR increase in NDVI for each outcome.

Table 2. Percentage of difference in cognitive decline, physical functioning, or arterial stiffening associated with one-IQR increase in NDVI in a 500 m buffer around the residential location

Outcome	**Average decline/ progression over study period**	**Difference associated with IQR increase in NDVI**	**% of difference**
Cognitive function (z-scores)			
Global cognition	-0.437	0.020	4.6%
Reasoning	-0.322	0.022	6.8%
Fluency	-0.384	0.021	5.5%
Short-term memory	-0.332	-0.003	NS*
Physical functioning (z-scores)			
Lower body function (walking speed)	-0.266	0.02	7.5%
Upper body function (grip strength)	-0.252	-0.01	NS
Arterial stiffness (cf-PWV)			
cf-PWV (m/s)	0.59	-0.05	8.5%

**NS=Not significant*

In addition to the estimate of the association of greenspace exposure with the decline/progression in cognitive function, physical functioning, and arterial stiffness, we obtained an estimate of the cross-sectional baseline association with each outcome (*Papers II-IV*). Baseline estimates reflected the cross-sectional association between greenspace at the first follow-up and the outcome at that follow-up. In general, we observed that the baseline associations were weaker than the associations with the trajectories. One possible explanation is that the greenspace exposure at baseline does not take into account accumulated historical exposure, for instance, because of previous changes in the residence or changes in land cover. This historical exposure may have affected the health outcome at baseline. For instance, recent studies have shown that greenspace exposure in childhood may affect health in adulthood (Preuss et al. 2019).

In *paper V*, the findings suggested that greater exposure to residential surrounding greenspace (as assessed by NDVI and VCF across 500 or 1000 m buffers around the residential location) was associated with a lower risk of metabolic syndrome over a 15-year period. Metabolic syndrome is a cluster of conditions that are prominent risk factors for NCDs, including high fasting glucose level, large waist circumference, dyslipidaemia, low HDL cholesterol level, and hypertension. As NCDs contribute to a major burden of disease in the older population, the prevention of metabolic syndrome is a relevant intervention to promote healthy ageing. Increases in VCF, an estimate of tree cover, were consistently associated with a decreased risk of metabolic syndrome. One-IQR increase in VCF in the 500 m buffer was associated with a 14% (95% CI: 5%, 22%) lower risk of metabolic syndrome. The associations were similar when using VCF estimates across the 500 m buffer, 1000 m buffer, and LSOA. For NDVI, the associations were less consistent. One-IQR increase in the summer-winter estimate of NDVI in the 500 m buffer was associated with a 13% (95% confidence interval (CI): 1%, 23%) lower risk of metabolic syndrome. However, increases in NDVI were only associated with lower risk of metabolic syndrome when using NDVI estimates averaged over summer and winter; no significant association was observed with metabolic syndrome when using summer estimates of NDVI.

6.1.3. Underlying mechanisms

Several mechanisms may underly the observed associations between long-term greenspace exposure and healthy ageing.

First, physical activity may be a relevant mediator in the association between greenspace and health at older age, as a number of previous studies have observed higher levels of physical activity in areas with more greenspace (Gong et al. 2014). Older adults often do not reach the recommended levels of physical activities. One potential cause is, for instance, that older adults may experience more barriers in the environment. Providing greenspace could encourage older adults to be active, which provides health benefits even if it is only light physical activity (World Health Organization 2016).

Second, social relations and social cohesion in the neighbourhood are an important determinant of older adults' health and well-being (Elliott et al. 2014; Steptoe et al. 2013). Previous studies observed improved social cohesion and social support (Dadvand et al. 2016; de Vries et al. 2013; Maas et al. 2009a) and an improved sense of community belonging among residents living in neighbourhoods with more greenspace (Rugel et al. 2019). Hence, by strengthening social relations, greenspace exposure could benefit health.

Third, long-term greenspace exposure has been found to benefit mental health (Gascon et al. 2015), including reduced levels of stress (Pun et al. 2018; Ward Thompson et al. 2016). Also among older adults, most of the studies on long-term greenspace exposure and mental health and psychological stress at older age have showed a beneficial association (*Paper VI*). Mental health is an important determinant of quality of life at older age and has been associated with risk of chronic disease (Chen et al. 2017).

Fourth, as described in section 1.1.2(iv), exposure to air pollution, noise, and heat may be reduced in areas with more greenspace. Reduction of exposure to these environmental stressors can also be a relevant mechanism for health benefits of greenspace at older age, as older adults may be especially vulnerable for harmful environmental exposures. Numerous previous studies have found that outdoor air pollution was negatively associated with health in older adults (Simoni et al. 2015). Moreover, noise could also have a significant impact on health at older age, including by increasing the risk of cognitive impairment (Dzhambov et al. 2018b; Tzivian et al. 2016). Furthermore, heat during heat waves and extreme heat events is an emerging health threat, especially for older adults. Several studies found that greenspace mitigated heat-related mortality in older adults (Benmarhnia et al. 2017; Burkart et al. 2015; Gronlund et al. 2015).

In our systematic review (*Paper VI*), we identified several articles that performed mediation analyses. Among the 57 studies included in our systematic review (excluding the articles of this thesis, i.e. *paper II and III*), mediation analyses were included in 13 studies (Astell-Burt et al. 2014b, 2014d; Banay et al. 2019; Clarke et al. 2012; Dalton et al. 2016b, 2016a; Jia et al. 2018; Mowen et al. 2007; Orban et al. 2017; Pun et al. 2018; Sarkar 2017; Villeneuve et al. 2018a; Yu et al. 2018). Most of these studies investigated mediation by physical activity (11 studies) and various indicators of social support (5 studies). In addition, potential mediators that were tested were perception of neighbourhood; park visitation; time spent outdoors; individual health conditions; mental health; and dog walking.

In *Papers II, III*, and *V*, I investigated potential underlying mechanisms by performing mediation analyses to evaluate whether certain mediators could partially explain the associations between greenspace and the outcomes of healthy ageing. The mediation analyses were based on four steps of Baron and Kenny (1986) as used in other studies of health benefits of green spaces (Dadvand et al. 2016; Zijlema et al. 2017). Below, a summary of the findings of the mediation analyses is provided for each paper.

In *Paper II*, the association between long-term greenspace exposure and cognitive decline was not mediated by physical activity, air pollution, or social network. Physical activity was assessed by a questionnaire on the frequency and duration of participation in physical activities, providing estimates of moderate and vigorous physical activities separately. For air pollution, I obtained annual levels of particulate matter with an aerodynamic diameter up to 10 μm [PM_{10}] with a spatial resolution of 1 km × 1 km from the Department for Environment Food & Rural Affairs (Defra 2016). For social network, the response to a questionnaire on the number of family and friends in a person's network and the frequency of contact, and participation in social or religious activities was scaled into an index score. No mediation of the association between NDVI and the decline in global cognition over the study period was observed by these variables.

In *Paper III*, the results indicated some suggestions that mental health and social functioning mediated the association of greenspace with the decline in physical functioning over the study period. Mental health and social functioning were assessed by sub-scores of the SF-36 questionnaire (Ware et al. 1993). However, moderate-to-vigorous physical activity (assessed as described before), gardening (assessed by a question on the frequency of gardening in last year), and air pollution (obtained from annual levels of particulate matter with an aerodynamic diameter up to 2.5 μm [$PM_{2.5}$] with a spatial resolution of 1 km × 1 km from the (Defra 2016)) were not found to mediate the association with physical functioning.

In *Paper V*, the association between greenspace and metabolic syndrome may have been mediated by moderate-to-vigorous physical activity (assessed as described before) and air pollution (annual levels of PM_{10} assessed as described before).

6.1.4. Effect modification

Previous studies found that the association between greenspace and health may be modified by sex and SES, although the findings have not been consistent. In *Papers II-V*, we performed stratified analyses to test for effect modification by sex and SES. In most studies, we observed potential effect modification by sex; in general, stronger associations were found between greenspace and the change in the age-related health outcome over time among women compared to men (*Paper II, IV, V*). However, we did not observe clear trends for effect modification by education (as indicator of individual level SES). Regarding area level SES, there were some indications of stronger associations between greenspace exposure and the trajectory of the health outcome in areas with higher income deprivation (*paper II-V*), although not always consistent (i.e. in some cases, such a trend was observed for one of the greenspace indicators but not for another).

6.2. Contribution to current evidence

This thesis contributes to the evidence base on health benefits of greenspace by providing two systematic reviews of the available evidence on such benefits as well as by conducting four original prospective cohort studies. The findings of this thesis fill an important gap in the evidence regarding the association between long-term greenspace exposure with the ageing process in the older population, especially regarding longitudinal associations with age-related outcomes. We add four longitudinal studies that evaluated the association of long-term exposure to greenspace with objective indicators of healthy ageing, which were assessed repeatedly over time.

In our systematic review of the evidence on the association between greenspace and health in the older population (*paper VI*), we identified 59 studies on this topic (including two studies of this thesis, i.e. *paper II and III*). Most of these studies were published recently; 34 studies included in the review (58% of the total) were published during the PhD period of this thesis (i.e. 2016 to 2019). However, despite this recent growing number of studies of health benefits of greenspace among older adults, we observed a shortage of studies on the association with age-related health outcomes. Few studies focused on cognitive decline or physical functioning and we did not identify any study that evaluated the association with arterial stiffness. In addition, no study evaluated the association of greenspace exposure with metabolic syndrome, although several focused on individual components of metabolic syndrome (e.g. obesity, diabetes, or hypertension).

Moreover, as observed in our systematic review (*paper VI*), longitudinal studies on greenspace exposure and health at older age are still scarce. A longitudinal design allows to study the progression of health over time. This is essential for studying healthy ageing, which is defined as a *progress* over time. In addition, many processes of biological ageing have been found to begin in adulthood. For instance, cognitive decline is already evident in mid-adulthood (Singh-Manoux et al. 2012). The studies of this thesis were based on longitudinal data of the prospective Whitehall II cohort, a well-established, large cohort including middle-aged and older adults. The maximum follow-up of the studies in this thesis (*papers II-V*) was 15 years, over which medical examinations and the exposure assessment was repeated a maximum of four times. For the exposure assessment, we obtained updated residential locations and updated satellite-based indicators of greenspace at each follow-up, thus taking into account changes in address and changes in land cover. These longitudinal data allowed us to evaluate the association between long-term greenspace exposure and the trajectories of the age-related outcomes.

Furthermore, most evidence of benefits of greenspace exposure for health at older age is based on studies using single indicators of greenspace (*paper VI*). In contrast, our exposure assessment was based on three different vegetation indices (NDVI, EVI, and VCF) that were estimated across two circular buffers (of 500 and 1000 m) and one administrative area (i.e. Lower layer Super Output Area). In addition, we obtained the proximity to large natural environments, separately for green and blue spaces. Therefore, we were able to assess the association with different indicators of greenspace.

6.3. Future research

6.3.1. Replication of findings

The present thesis provides evidence for a beneficial association between long-term greenspace exposure and healthy ageing. However, some of the outcomes were evaluated for the first time, thus our findings should be replicated in similar longitudinal studies using population-based cohorts. In addition, the associations between greenspace and health may be affected by the context, culture, and climate, thus it is important to repeat the studies in different countries and populations.

6.3.2. Study design

Future prospective cohort studies are important to investigate the association between greenspace and health at older age. Regarding healthy ageing, studies should consider follow-ups from middle-adulthood, when processes of biological ageing are already evident. In addition, a life-course approach could contribute to gain further insight on how exposure over the life course may influence health at older age. However, longitudinal studies on older adults should take extra care regarding differential loss to follow-up; findings may be affected if participants with poor healthy ageing outcomes are more likely to be lost to follow-up (as they are at higher risk of loss of mobility, disease, and mortality).

Furthermore, there is a need for natural experiments which present opportunities to study the impact of implementations of new greenspace (e.g. a newly build park) and provide strong inferences about causality (Benton et al. 2018). Properly conducted natural experiments can rule out the risk of self-selection; in observational studies, self-selection could bias the results if, for instance, healthier participants choose to live in greener neighbourhoods than less healthy participants. In addition to studying the impact of newly implemented greenspace, the impact of a change in greenspace exposure due to, for instance, changing residence would also present an interesting research opportunity (Nieuwenhuijsen et al. 2017).

Further to observational studies, interventional studies are possible, because, in contrast with other environmental factors such as air pollution or noise, greenspace exposure is beneficial to health. Randomized controlled trials are considered to be the study design that provide the strongest evidence for a causal relation, compared to observational studies (Concato et al. 2000).

Furthermore, qualitative studies could also provide important contributions, for instance, regarding mechanisms between greenspace and healthy ageing and the preferences and perceived barriers of the living environment that may influence the use of greenspace (Finlay et al. 2015).

6.3.3. Other outcomes

In this thesis, we evaluated the association between greenspace exposure and cognitive decline, physical functioning, arterial stiffness, and metabolic syndrome. However, a number of indicators of healthy ageing have not been considered yet, while, through the proposed mechanisms (Figure 1), associations of greenspace with these outcomes can be hypothesised. For instance, long-term greenspace exposure could benefit the immune system; visiting forests has been associated with a beneficial immune response in previous studies, mainly from Japan (World Health Organization 2016). Studies on age-related immune function and inflammatory factors are scarce, but several immune function indicators are proposed as biomarkers of healthy ageing, including markers of systematic inflammation (Lara et al. 2015). Another example could be lung function. Lung function, categorized by, for instance, lung capacity, declines with age (Lara et al. 2015). To my knowledge, the association with lung function at older age has not yet been evaluated.

Moreover, other end points that should be considered in the association with long-term greenspace exposure are diagnosis of clinical conditions such as Alzheimer, stroke, and cancers, which are conditions with important impacts on quality of life at older age. As observed in our systematic review (*Paper VI*), while some studies exist on the association with morbidity at older age, many of these conditions remain unexplored.

Furthermore, some studies have observed associations between greenspace exposure and adverse health outcomes that could also be relevant for older adults. Certain harmful environmental exposures may be higher in areas with more greenspace, for instance, pesticides and herbicides, allergenic pollens, and, in some situations, the concentration of air pollution (World Health Organization 2016). Moreover, in greenspace areas with low walkability, older adults may be at higher risk of falls. Studies on adverse health effects of greenspace exposure are still scarce, especially among older adults. In our systematic review (*paper VI*), only one study was identified, which observed a higher risk of skin cancer in areas with more greenspace (Astell-Burt et al. 2014d).

6.3.4. Exposure assessment

For the Whitehall II cohort, the exposure assessment was limited to the use of open access, secondary data sources that covered the entire UK and provided us with standardized estimates of overall availability of greenspace and access to large natural environments. However, using different methods to assess the availability or access to greenspace or assessing other aspects of greenspace exposure may result in different findings.

(i) Availability

Apart from NDVI, EVI, and VCF, other satellite-based indices of greenspace could contribute to characterize residential surrounding greenspace. For instance, the Modified Soil-Adjusted Vegetation index (MSAVI) was created with the aim to improve NDVI (which has some limitations in areas with a high degree of exposed soil surface) by minimizing the soil background influences, resulting in a greater vegetation sensitivity (Qi et al. 1994).

Moreover, other data sources could be used to assess residential surrounding greenspace. For instance, aerial photos can provide high-resolution information. Additionally, LIDAR (Light Detection and Ranging) is a remote sensing technique that can be used to map natural environments and measure vegetation across wide areas (National Ecological Observatory Network). Furthermore, few studies have used street view measures to assess the availability of greenspace. For instance, a recent study used both the NDVI and a Google street view measure; though no association with physical activity was found with NDVI, the street view measure of greenness was positively associated with physical activity (Villeneuve et al. 2018b).

Lastly, land cover maps are important sources of information, because they allow to distinguish between types of land cover. Future studies should investigate whether the type of greenspace area (e.g. public park, orchard, private garden, agricultural area, sports field, etc.) is relevant in the association between greenspace and health at older age, because different greenspace areas may promote different use; e.g. a sports field invites for physical activity, while a small neighbourhood park may invite for social contact between neighbours. Therefore, the greenspace type is likely to affect the mechanisms between greenspace and health.

(ii) Accessibility

Regarding accessibility, in this thesis, I only used CORINE to estimate the distance from home to a large blue or green space (*Paper III*). However, future studies should use high resolution data that allows to assess the access to small greenspace areas, which could be associated with health through different mechanisms.

Moreover, while Euclidian distance is informative of, for instance, visual access to greenspace, the network distance contributes information which may be especially important regarding other mechanisms such as physical activity. In addition, subjective measures may compliment these objective measures. Questionnaires could provide information on, for instance, the perceived distance to a greenspace area or the perceived walking time to reach a greenspace area.

(iii) Use

Future studies should include measurements of the use of greenspace areas. For instance, participants could be tracked by GPS or smart phones, which provides the additional opportunity to couple the geographical location with physical activity data. Other potential measured could be found in citizen science and by complimenting objective measurements with questionnaire data on frequency and duration of greenspace visits.

(iv) Quality

Future studies are needed to provide information on the characteristics of greenspace that are driving the beneficial associations with health. Apart from the overall availability and proximity of greenspace, the quality and maintenance of greenspace are likely to be prominent determinants of usage by older adults (Aspinall et al. 2010; Sugiyama and Ward Thompson 2008). The quality of greenspace may be related with size, safety, aesthetics, and maintenance of greenspace and the provision of amenities, sport facilities, and walking and cycling paths, among other features, in greenspace areas. These factors are also essential to advice policy makers on the priorities for the new implementation, maintenance, and improvements of greenspace. Additionally, the accessibility (e.g. points of access, paths to enter the space, etc.) of the greenspace areas should also be considered, as it is an important facilitator of use.

(v) Timing & place

Furthermore, the influence of the timing of greenspace exposure remains largely unexplored. To give relevant recommendations about individual greenspace exposure, we need to answer questions of when, how often, and how long exposure is needed to provide health benefits. In a recent study, nature exposure of 20 to 30 minutes was found to be most efficient for benefits of stress, as assessed by cortisol response (Hunter et al. 2019). However, other durations may be effective for other health outcomes. The interaction between when and where may also be relevant. For instance, it is unclear if frequent, short visits to a neighbourhood park are as beneficial as infrequent day-trips to large natural parks (Nieuwenhuijsen et al. 2017).

In addition, exposure to greenspace is often assessed at the residence, but greenspace at other places (for instance, along the commuting route) may also be a relevant source of exposure (Nieuwenhuijsen et al. 2017).

6.3.5. Mechanisms

While several mechanisms between greenspace exposure and health have been proposed, studies investigating the magnitude of the contribution of each mechanism to the association are still scarce.

Regarding physical activity, future studies should consider the intensity of physical activity when evaluating mediation of the association between greenspace and health at older age. Moreover, studies should consider the place of physical activity (i.e. focusing on outdoor physical activity). In our systematic review (*paper VI*), we identified six studies that included walking (i.e. a light, outdoor physical activity) as outcome. Five out of these six (83%) studies found a positive association between greenspace and walking levels. In contrast, among the 12 studies that included a measure of total physical activity, six (50%) reported a beneficial association.

Furthermore, future studies should focus on social cohesion and assess the frequency and type of contact with neighbours as a mediator of the association between greenspace and health at older age. Among the seven studies included in our systematic review (*Paper VI*) that investigated mediation by social relationships, none assessed social cohesion in the neighbourhood; the mediators were all indicators of personal social life (e.g. social relations, feelings of loneliness, etc).

In addition, numerous studies observed beneficial associations between long-term exposure to greenspace on mental health and levels of stress in older adults (*Paper VI*). However, only few studies have investigated if by benefiting mental health, greenspace exposure could have a subsequent impact on other aspects of health at older age.

Moreover, in our systematic review (*Paper VI*), we did not identify any study that evaluated mediation of the association between greenspace and health at older age by air pollution, noise, or heat (except our own studies, *Paper II and III*).

Furthermore, there are more potential mechanisms than those highlighted in this thesis. For instance, exposure to greenspace may support the immune system. Greenspace can increase microbial biodiversity in the environment and the health benefits of greenspace may be (partially) stimulated by microbial input from the environment to drive immunoregulation (Rook 2013). However, this is still a little studied pathway and should be considered by future studies.

Currently, mediation analyses have often been limited by the assessment of the mediators, which were often general indicators of, for instance, total physical activity and social relations. These indicators often do not take into account the place (i.e. they do not provide information on whether physical activity or social contact actually took place in a greenspace area). In addition, the methods used to assess mediation have been heterogeneous. In our studies, we used the criteria of mediation of Baron and Kenny (1986) and only evaluated single mediation. However, several recent studies argue other approaches when having multiple mediators (VanderWeele and Vansteelandt 2014), including, for instance, parallel mediation. Furthermore, there are various methods to quantify mediation and provide estimates of the contribution of a mechanism (Preacher and Kelley 2011). There is a need to standardize these methods to make results more comparable

6.3.6. Effect modifiers

Considering the diversity of older adults' health, functional status, attitudes, and lifestyle, many factors may modify the impact of greenspace on their health (Finlay et al. 2015). Therefore, studies should consider the interaction between environmental, socioeconomic, and individual factors that could work together to foster healthy ageing.

In the studies of this thesis (*Paper II-V*), effect modification by sex and individual and area level socioeconomic status was investigated. However, effect modification by other factors such as ethnicity and urbanity could not be investigated because of the low number of Whitehall II participants that were non-white or lived in rural areas. In addition to these potential effect modifiers, future studies should consider the influence of climate, region, type of vegetation, and the quality of greenspace on the association between greenspace exposure and health.

6.4. Implications for public health and policy

The promotion of healthy ageing is a public health priority considering the rapid growth of the older population worldwide. The findings of this thesis suggest that providing access to public greenspace could be supportive of healthy ageing, in particular, by reducing cognitive decline, loss of physical functioning, arterial stiffening, and the risk of metabolic syndrome. Subsequently, this suggests that greenspace could provide important contributions to the improvement of health, wellbeing, and quality of life of the older population. This is of special interest as the ongoing urbanization has resulted in an increasing number of older adults living in urban areas, where access to greenspace is often low.

The studies in the current thesis present evidence for associations with outcomes of functioning rather than the presence of disease(s). Assessments of functioning are considered important predictors of health and quality of life at older age (World Health Organization). Each of the outcomes selected in *papers II-V* have an important role in healthy ageing. In addition, improvements in these outcomes may contribute to reduced risk of disability and disease.

The maintenance of cognitive function is a fundamental aspect of healthy ageing; poor cognitive function has been regarded as one of the most disabling conditions at older age. Although cognitive function progressively declines with age, a stimulating environment could slow down cognitive ageing (Cassarino and Setti 2015). Findings of this thesis suggest that increased availability of greenspace was associated with decelerated cognitive decline, and thus could be contribute to such a health-promoting environment and hence foster health, quality of life, and overall functioning at older age.

Physical functioning is an important determinant of the capability of participation in physical and daily routine activities (Rooth et al. 2016 p. 382) and thus has a major impact on daily life. In the present thesis, we observed that more residential surrounding greenspace and living nearer natural environments was associated with a slower decline in physical functioning which was assessed by walking speed, an indicator of lower body function, and grip strength, an indicator of upper body function. Poor physical functioning has been associated with reduced mental wellbeing and higher risk of CVD, dementia, and mortality (Cooper et al. 2010, 2011, 2014).

Arterial stiffness is a marker of the ageing of the cardiovascular system. We observed that participants living in neighbourhoods with more greenspace had a slower progression in arterial stiffness than those living in neighbourhoods with less greenspace. In turn, the reduction of arterial stiffness may reduce the risk of new cardiovascular events and mortality. Increasing the availability of greenspace may hence reduce the major burden of disease of CVD in older adults.

Metabolic syndrome is a cluster of some of the most dangerous risk factors for CVD. Greater exposure to greenspace, especially increased tree cover, was associated with a lower risk of metabolic syndrome. These findings suggest that, subsequently, greenspace could contribute to a reduced risk of diabetes, heart attack, and stroke.

Therefore, greenspace may contribute to building supportive and enabling environments that benefit not only cognitive and physical function, arterial stiffness, and cardiovascular and metabolic health, but go further to support healthy ageing by reducing the major burden of chronic disease and co-morbidity at older age (Prince et al. 2015). In addition, greenspace benefits may extend beyond individual health, as healthy older adults are a resource for their family, their community, and their economy (World Health Organization 2015b).

Moreover, the implementation of greenspace in cities has important co-benefits, including environmental and economic, providing a solid ground for public investment. However, special care is needed regarding green gentrification (Cole et al. 2019); because people are willing to pay more to live in greener neighbourhoods, greener neighbourhoods tend to have higher housing prices. Though increasing greenspace in cities could improve the urban environment and benefit public health, specific regulations should be in place to protect the residents of neighbourhoods from any financial or social repercussions.

7. CONCLUSIONS

The present thesis contributes to the limited evidence on the longitudinal association between long-term exposure to outdoor greenspace and healthy ageing. In two systematic reviews, insufficient but suggestive evidence was found for a positive association between long-term greenspace exposure and cognition over the life course (*Paper I*) and health at older age (*Paper VI*). However, the findings indicated a need for longitudinal studies on the benefits of long-term greenspace exposure on cognitive function and health at older age.

In four longitudinal studies of the Whitehall II cohort, I investigated the association with four indicators of healthy ageing, including cognitive function, physical functioning, and cardiovascular and metabolic health. The findings of these longitudinal studies suggested that participants who had a greater residential exposure to greenspace had a slower decline in cognitive (*Paper II*) and physical functioning (*Paper III*), a reduced progression of arterial stiffness (*Paper IV*), and lower risk of metabolic syndrome (*Paper V*) than participants who had less greenspace exposure.

The findings of this thesis suggest that long-term greenspace exposure could contribute to more favourable trajectories in age-related health outcomes, by maintaining cognitive and physical functioning and reducing arterial stiffness and risk of metabolic syndrome. This is of particular interest considering the rapid growth of the older population and the increasing number of older adults living in urban areas. If confirmed by future studies, increasing the availability of and access to greenspace could be a relevant intervention to compliment public health strategies for healthy ageing.

Future studies should investigate optimal greenspace interventions for an effect on health, regarding quantity and quality of greenspace and frequency and duration of exposure. Therefore, future research is needed, including studies that use different study designs such as natural experiments and randomized controlled trials, studies that investigate the characteristics of greenspace that contribute to the association with health, and studies that further investigate the underling mechanisms of the association between greenspace exposure and health.

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Zupancic T, Westmacott C, Bulthuis M. 2015. The impact of green space on heat and air pollution in urban communities: A meta-narrative systematic review.

APPENDIX

A. Other (co-)authored papers

De Keijzer C, Agis D, Ambrós A, Arévalo G, Baldasano JM, Bande S, Barrera-Gómez J, Benach J, Cirach M, Dadvand P, Ghigof S, Martinez-Solanas E, Nieuwenhuijsen MJ, Cadum E, Basagaña X. **The association of air pollution and green space with mortality and life expectancy in Spain: A small-area study.** *Environment International. 2017; 99*

Dadvand P, Tischer C, Estarlich M, Llop S, Dalmau-Bueno A, López-Vicente M, Valentín A, de Keijzer C, Fernández-Somoano A, Lertxundi N, Rodriguez-Dehli C, Gascon M, Guxens M, Zugna D, Basagaña X, Nieuwenhuijsen MJ, Ibarluzea J, Ballester F, Sunyer J. **Lifelong Residential Exposure to Green Space and Attention: A Population-based Prospective Study.** *Environ Health Perspect. 2017; 125(9)*

B. Presentations at international conferences

Green infrastructure (3-6 April 2017, Orvieto, Italy)
Oral presentation: *"A systematic review of the evidence on the association between green spaces and cognition"*
Poster presentation: "*Greenness and mortality and life expectancy in Spain: A small-area study"*

ISEE Young (19-20 March 2018, Freising, Germany)
Oral presentation: *"Green space exposure is associated with slower cognitive decline in older adults: a 10-year follow-up of the Whitehall II cohort"*

Planetary Health Annual Meeting (29-31 May 2018, Edinburgh, Scotland)
Poster presentation: *"Residential surrounding greenness is associated with slower cognitive decline in the ageing Whitehall II cohort"* (presented by Dr. Cathryn Tonne)

ISEE Joint Annual Meeting (26-30 August 2018, Ottawa, Canada)
Oral presentation: *"Green spaces and cognitive decline over 10 years of follow-up of the Whitehall II cohort"* (presented by Dr. Cathryn Tonne)

Urban Transitions (25-27 November 2018, Sitges, Spain)
Oral presentation: *"Exposure to green and blue spaces and the decline in physical functioning in older adults of the Whitehall II cohort"*

ISEE (25-28 August 2019, Utrecht, The Netherlands)
Oral presentation: *"Residential surrounding greenspace and arterial stiffening: A Whitehall II longitudinal study"*

C. Other activities

Media attention

The published *Papers II and III* received international media attention, resulting in online published news articles and radio interviews. Below a handful of examples of headlines.


EL INDEPENDIENTE Suscríbete Mi perfil Buscar Menú

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Los mayores que viven en barrios más verdes muestran un deterioro cognitivo más lento

Publicado el 11/07/2018 | Actualizado el 12/07/18 - 00: 44

EL INDEPENDIENTE


U.S. EDITION Thu, Jul 12, 2018 Newsweek SIGN IN SUBSCRIBE

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HEALTH

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BY KASHMIRA GANDER ON 7/11/18 AT 6:00 PM

ORBYT

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PROFESIÓN ESPECIALIDADES ECONOMÍA TECNOLOGÍA POLÍTICA NORMATIVA SALUD ESPECIALES DMÉDICO JOVEN

Estudio del Isglobal en 'Environment International'

Vivir en zonas verdes contribuye a una mejor capacidad funcional en edades avanzadas

La cantidad de zonas verdes en torno al domicilio y la proximidad a espacios naturales se asocian con un deterioro más lento de la velocidad al caminar en mayores y, por tanto, con un mejor capacidad funcional, según un estudio del Isglobal, que se publica en 'Environment International'.

Qwerty @qwerty_radio · 22 jan.

Sabemos cuál es el remedio de la eterna juventud, y lo tienes más cerca de lo que piensas 🌴🌳🌲 @ISGLOBALorg @CarmenDeKeijzer @oscar_gomez #podcast #podcastdeldía #Ciencia #radio #podcastING qwertyradio.es/urbanismo-enve...

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Blogs

"Happy International Day of Forests! Scientific Evidence Shows that Nature Benefits our Health"
https://www.isglobal.org/en/healthisglobal/-/custom-blog-portlet/-feliz-dia-internacional-de-los-bosques-la-ciencia-muestra-que-la-naturaleza-beneficia-nuestra-salud

"Green spaces and Healthy Ageing"
https://www.isglobal.org/en/healthisglobal/-/custom-blog-portlet/green-spaces-and-healthy-ageing/6113078/0

DKV

Technical revision of the document "*Baños de bosque, una propuesta de salud*" (Forest bathing, a proposal for health) of the Instituto DKV de la Vida Saludable.

Development of a short survey assessing nature exposure and information regarding the health benefits of nature exposure and recommendations to increase nature exposure for the app *QuieroCuidarme* of DKV Seguros.

ProGIreg

Collaboration in the European project ***pro****ductive* ***G****reen* ***I****nfrastructure for post-industrial urban* ***reg****eneration* (proGIreg) by co-designing and co-writing a protocol for the evaluation of health benefits of newly implemented nature-based solutions.