The impact of the outdoor physical environment on older adults with osteoarthritis
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2017

document version
Publisher's PDF, also known as Version of record

Link to publication in VU Research Portal

citation for published version (APA)
Timmermans, E. J. (2017). The impact of the outdoor physical environment on older adults with osteoarthritis. [PhD-Thesis - Research and graduation internal, Vrije Universiteit Amsterdam].

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Download date: 13. Apr. 2024
CHAPTER 1

General introduction
OSTEOARTHRITIS

Osteoarthritis (OA) is the most common form of musculoskeletal disorders worldwide and its incidence increases with age. The condition is characterized by focal areas of loss of articular cartilage within synovial joints, which are associated with hypertrophy of bone and thickening of the capsule (Figure 1). The condition is clinically characterized by joint pain, stiffness, tenderness, limitation of movement, crepitus (cracking or popping sound in a joint), occasional effusion (presence of increased intra-articular fluid) and variable degrees of local inflammation [1]. Several risk factors have been identified for the development and progression of OA, including gender, sex hormones, obesity, ethnicity and race, genetics, nutrition, physical activity (PA), muscle strength and weakness, acute injury and repetitive joint loading [2].

The prevalence and incidence of OA increase with age, because the condition is not reversible, but also not fatal [1,2]. Among persons of 65 years and older, estimates of the prevalence of OA vary widely and may depend on OA definition (e.g., self-report OA versus radiographic OA versus clinical OA), study sample (e.g., patient-based versus population-based) and country [3]. Prevalence rates also depend on site of interest. The condition can occur in any joint, but is most common in the knee, hip and the joints of the hand [1]. The prevalence rate of any clinical knee, hip or hand OA among persons of 65 years and older in Europe is 31.7%. The prevalence rates for clinical OA in knee, hand and hip are 20.2%, 17.1% and 6.1% respectively [4]. Increases in life expectancy and concomitant aging of the population, together with rising levels of obesity, are expected to make OA a major health-care concern in the near future [1,5,6].

PERSONAL AND SOCIETAL CONSEQUENCES OF OSTEOARTHRITIS

Osteoarthritis has significant individual consequences as well as societal consequences across most regions of the world [1,5,8,9]. There is evidence that OA is the most common cause of chronic pain in older persons and a major contributor to
functional impairment and loss of independence [1,8,9]. A range of studies showed that older adults with OA are significantly less likely to meet the recommended levels of PA compared to those without OA [10-12]. Furthermore, previous research showed that OA is associated with poor physical performance [13], restricted outdoor mobility and impairments of daily activities [14], frailty [15] and increased (social) participation restrictions [16]. In addition, symptoms of depression, anxiety and fatigue are more prevalent among patients with OA than among the general population [17]. Previous studies also showed that OA is associated with poor self-rated health [18] and poor quality of life (QoL) [19] in older adults.

It has been estimated that OA accounts for the loss of over 17 million disability-adjusted life years worldwide in 2010 [20]. The condition is associated with considerable economic costs, reflecting cumulative costs of decreased work productivity/work absence [21,22], increased health care utilization [23,24] and increased medication use [25]. As an example, the costs associated with OA are estimated to be €2.5 billion per year in the United Kingdom (UK), including three million general practitioner consultations and 115,000 hospital admissions [26]. Considerable economic costs have also been found in other countries [27-34].

**Figure 1:** Representation of a healthy joint (left) and an osteoarthritic joint (right) [7].
A growing body of research suggests that features of the physical environment can facilitate or impede daily functioning of older adults [35-37]. It has been suggested that older adults with OA are especially vulnerable to physical environmental challenges due to functional limitations and symptoms, such as pain and stiffness [38-40]. In order to improve mobility outside the home, physical activity, social participation and QoL in older adults with OA, it is important to understand how outdoor physical environmental factors contribute to aspects of daily functioning in this growing group of older adults.

**ASPECTS OF DAILY FUNCTIONING**

In this thesis, the influence of the outdoor physical environment on specific aspects of daily functioning is examined in older adults with and without OA across Europe. In particular, this thesis focuses on the impact of outdoor physical environmental characteristics on joint pain, PA, use of neighbourhood resources and QoL in these individuals (Figure 2). These specific aspects of daily functioning are described in more detail below.

**Joint pain**

Joint pain refers to discomfort, aches and soreness in joints. It is the most prominent symptom of OA in older adults [1,2]. Joint pain in OA is not stable from one day to another. It is often characterized by the alternation of stable periods of varying length, characterized by a low level or absence of pain with periods of flare-up or exacerbation [41].

**Physical activity**

Physical activity is defined as any bodily movement produced by skeletal muscles that requires energy expenditure [42]. According to the PA recommendations of the World Health Organization, older adults should do at least 150 minutes of moderate intensity aerobic PA throughout the week or do at least 75 minutes of vigorous intensity aerobic PA throughout the week or an equivalent combination of
moderate and vigorous intensity activity [42]. Physical activity helps older people with OA to reduce pain and improve functioning [43,44]. Despite the potential health benefits of PA, the majority of people with OA do not engage sufficiently in physical activities [10-12].

Use of neighbourhood resources
A person should ideally be able to perform daily activities in the environment regardless of any impairment [40]. For example, an individual should be able to use neighbourhood resources such as parks, walking areas, public transport and public facilities. Pain and disability caused by OA may give rise to a less than optimal use of the environment [14,45].

Quality of life
Quality of life is the general well-being of an individual. It covers all aspects of life including health status, environment, financial aspects and human rights. Health-
related QoL is a subset of QoL, concerning physical, emotional and social well-being [46-49]. In this thesis, the term QoL is used for health-related QoL. Previous research suggests that OA is associated with poor QoL in older adults [19,50].

THE OUTDOOR PHYSICAL ENVIRONMENT

The physical environment can be broadly described as the material and tangible external conditions in which we live [51]. The outdoor physical environment can be more specifically described in terms of the natural environment (e.g., air, noise, water and climate), the external built environment (e.g., human-made physical structures outside of the home, such as buildings and infrastructures) and the socio-economic and cultural environment (e.g., characteristics of societies and communities) [51].

Outdoor physical environment characteristics can generally be categorized as either subjective or objective attributes [52]. Subjective outdoor physical environment characteristics refer to perceptions of one’s outdoor physical environment in a range of domains (e.g., perceived safety, presence of litter and social cohesion). Objective outdoor physical environment characteristics refer to area-level indicators that can be characterized independent of a resident’s own perception (e.g., weather conditions and presence of, counts of, or distance to specific types of institutions or facilities) [52]. Objective outdoor physical environment characteristics are often collected for official demarcations of areas, including neighbourhoods, zip code areas, census tracts or block groups. The perception of outdoor physical environment characteristics reflects individual appraisals of environmental conditions and does not always correspond with the actual objective conditions [52].

In particular, older people are considered to be vulnerable to their immediate outdoor physical environment [53]. Daily activities tend to become increasingly concentrated within a contracting spatial area as a result of age-related declines in health and mobility disability, making older persons increasingly dependent upon their immediate environment [53,54]. Knowledge on how perceived and objective outdoor physical environment characteristics affect aspects of daily functioning of
older adults with OA could be used to guide environmental and policy interventions that aim to promote well-being in older people with OA.

THE INTERACTION BETWEEN OLDER PERSONS AND THEIR ENVIRONMENT

The World Health Organization’s (WHO) International Classification of Functioning, Disability and Health (ICF) as well as theories from environmental gerontology suggest that environmental factors can facilitate or impede older adults functioning in terms of physical activities and social participation and can contribute to QoL in old age [35-37,55-57].

The ICF framework is an internationally recognized classification developed under the auspices of the WHO to operationalize health and health-related domains within the context of personal and environmental factors [35,55]. It is based on the concept that health is influenced by interactions between body functions and structures, activity, social participation, as well as personal and environmental factors [55]. For example, an individual with knee OA may experience joint pain (body functions and structures) that leads to severe difficulty in walking (activity limitation), which may restrict his or her involvement in social activities (social participation). Furthermore, due to difficulty walking, this person is at increased risk of developing secondary health conditions with further implications for restricted functioning and participation. However, an individual who has difficulty walking due to OA may continue to be active in social participation if the person has appropriate coping skills (personal factor) and/or lives in an environment with an extensive, accessible public transport system (environmental factor) [35]. Although the ICF is an appropriate conceptual framework to guide research on the modifying effect of the environment in the relationship between health conditions and functioning [35], it does not give us sufficient direction in explaining how environmental factors influence older adults’ functioning and how these environmental influences differ between groups of older persons.
In environmental gerontology, explanatory theoretical models on the impact of environmental conditions on daily lives of people can be grouped into two broad types, including “person in environment” models and “person-environment fit” models [53,58].

“Person in environment” models assume that all individuals are similarly affected by the environment [53,58]. These models place the individual within an environment, but do not take into account how the person relates to that environment. “Person in environment” models implicitly assume that environmental conditions have a uniform effect on residents. An example is an “advantage of advantaged neighbours” model [59], which posits that, regardless of individual characteristics, people benefit from living in proximity to advantaged neighbours and conversely are harmed by living in proximity to disadvantaged neighbours.

In contrast, “person-environment fit” models are based on the premise that environmental effects vary from person to person as a function of the interaction between environmental conditions and personal attributes and situations [53]. According to these models, the level of functioning can be explained by the fit between individual competence (capacity) and environmental pressure (demand) [53]. In this thesis, it is assumed that “person-environment fit” models explain how environmental factors may affect functioning of individuals. The most prominent “person-environment fit” model in environmental gerontology is Lawton’s ecological model of aging [37,56,57,60]. Thus, the studies described in this thesis have been performed from the perspective of this “person-environment fit” model.

THE ECOLOGICAL MODEL OF AGING

The ecological model of aging suggests that human behaviour is influenced by the interaction between individual competence and the extent of demands from the environment (Figure 3) [54,56,57]. In Figure 3, the “zone of maximum performance potential” is characterized by relatively high environmental press, challenges and stimulation. In this situation, active behaviour and well-being are encouraged. To the right of this zone, there is a marginal zone, where individuals continue to
function, but with some difficulty. For example, falls, stress and other indicators of maladaptive behaviours start to occur here. To the right of this marginal zone is the "zone of negative effect and maladaptive behaviour", where the demands of the environment exceed the individual's ability to meet those demands. In this situation, there is a person-environment misfit, resulting in maladaptive behaviours. In Figure 3, the "zone of maximum comfort" is characterized by relatively weak environmental press and a general relaxation from environmental demands. To the left of that zone is a marginal zone, in which the absence of environmental demands begins to lead to boredom. If there are too few environmental challenges for individuals with higher levels of personal competencies, there is also a person-environment misfit, resulting in maladaptive behaviours. In this case, the environment is so unchallenging that it contributes to functional passivity, disuse and limitation. When the personal and environmental components are matched, adaptation is achieved and individuals feel competent to participate in physical and social activities. It has been suggested that a closer personal-environment fit leads to better well-being [54,56,57].

THE ENVIRONMENTAL DOCILITY HYPOTHESIS

Derived from the ecological model of aging, the environmental docility hypothesis suggests that the behavior of a person is restricted or enhanced by environmental characteristics, depending on the functional capacity of the individual [56,57]. It suggests that the less competent the individual, the greater the impact of environmental factors on that individual. Due to the experience of more joint pain, functional limitations and disability, older adults with OA may have lower competence than those without the condition and may therefore be more vulnerable to environmental demands [38-40]. Based on the environmental docility hypothesis, perceived and objective characteristics of the outdoor physical environment may be more strongly related to aspects of daily functioning in older persons with OA than in those without OA.
Knowledge on the impact of outdoor physical environment on daily functioning of older adults with and without OA could be used to help these persons to deal with their outdoor physical environment and to inform policymakers and city planners about adaptation of the outdoor physical environment to appropriately maximize the personal-environment fit and to improve activity, social participation and QoL of these individuals.

**OUTDOOR PHYSICAL ENVIRONMENT CHARACTERISTICS**

In this thesis, the associations of several perceived and objective components of the outdoor physical environment with aspects of daily functioning are examined in older adults with and without OA across Europe. Below, these outdoor physical
Joint pain and self-perceived weather sensitivity

The impairment of well-being and/or incidence of symptoms or exacerbations of diseases related to weather is termed weather sensitivity [61]. Individuals with OA often report that their pain levels are affected by weather conditions [62]. Prior studies on the relationship between self-perceived weather sensitivity and joint pain have been conducted in the United States of America (USA) and Australia and focused on chronic pain patients and rheumatology patients [63,64]. Research on the association between joint pain and self-perceived weather sensitivity in older persons with OA is lacking. For the development of appropriate pain coping strategies, it is important to know whether self-perceived weather sensitivity is associated with more pain in older adults with OA and whether there are specific characteristics of these persons that are predictive of self-perceived weather sensitivity.

Joint pain and objective weather conditions

Various psychological and physiological mechanisms have been suggested to explain the effects of specific weather parameters, such as temperature, precipitation, atmospheric pressure, humidity and wind speed, on joint pain in OA [63-67]. For example, it has been suggested that because tendons, muscles, bones and scar tissues are of varied densities, differential expansions and contractions due to changes in humidity and temperature may result in pain at sites of microtrauma [63,64]. In addition, alterations in temperature and atmospheric pressure may increase stiffness in the joints and may trigger subtle movements that can heighten a nociceptive response [63,66]. Changes in atmospheric pressure may also cause a transient disequilibrium in body pressure that may sensitize nerve endings [64,66]. Furthermore, weather may affect mood, resulting in an alteration of pain perception [63,64,66,67].
Previous research addressing the relationship between meteorological conditions [66,68], such as temperature [69-75], precipitation [62,69-72,75], atmospheric pressure [65,69-76], humidity [69,71-74,76,77] and wind speed [62,69,72], and joint pain in OA shows conflicting findings. The inconsistencies in results between studies could be caused by differences in data collection and techniques of statistical analyses [69]. Notably, several methodological limitations are presented among current research [66,68]. Particular problems include disclosure of the study hypothesis to participants and small sample size. As a consequence, previous studies lacked statistical power and the results are likely biased. Furthermore, many studies did not specify the osteoarthritic joints and focused on static 24-hour average conditions, instead of changes in weather. Individuals with OA often report that their joint pain becomes worse during weather changes [66,68]. However, most studies focused on effects of weather conditions in the short term instead of ambient weather conditions (average weather conditions in the days prior to a pain report) and weather changes immediately preceding each pain report. Furthermore, most studies were performed at single geographical sites, resulting in limited geographic and meteorological variability.

To help individuals with OA, physicians and therapists to better understand and manage fluctuations in pain, it is important to obtain more knowledge about the relationship between joint pain and weather conditions.

Outdoor physical activity and objective weather conditions
As a range of studies have shown, weather is an important determinant of PA in older adults [78-81]. Only few studies have focused on the association of PA with weather conditions in older people with OA [82,83], even though older people with OA often report that their disease symptoms are exacerbated by the weather [62,64]. Previous studies on the relationship between PA and weather conditions in older adults with OA did not make a distinction between indoor and outdoor PA and did not focus on specific activities [82,83]. More insight into the relationship between PA and weather conditions in older people with OA in the general population is particularly valuable for determining during what meteorological conditions PA interventions should be modified to maintain a sufficient compliance
Knowledge on the relationship between specific outdoor physical activities and weather conditions, could be used in the prevention of mobility limitations and management of pain, which are both very relevant in older adults and to an even greater extent to older people suffering from OA.

**Use of neighbourhood resources and neighbourhood environment characteristics**

Several perceived and objective characteristics of the neighbourhood environment have been identified as facilitators and/or barriers for the use of neighbourhood resources by older adults. For example, previous research showed that older adults perceiving higher levels of neighbourhood cohesion, fewer neighbourhood problems, and living in objectively less deprived neighbourhoods made more use of neighbourhood resources.

Only a few studies have examined environmental influences on the use of neighbourhood resources by older adults with OA. In a qualitative study using focus groups of older adults with OA on the use of community resources for OA self-management, environmental characteristics, such as sidewalk conditions, both facilitated and hindered use of community resources. Furthermore, two previous studies showed that environmental attributes, such as presence of parks and walking areas and public transport, facilitate outdoor mobility of older adults with functional limitations due to knee OA.

Prior studies on the association of use of resources with perceived as well as objective neighbourhood characteristics have been mainly conducted in the USA. To support PA, social participation and QoL in older adults with OA, it is also important to obtain more knowledge on this relationship in a European context.

**Physical activity and the objective neighbourhood built environment**

Limited research has been conducted on the association between PA and objectively measured characteristics of the neighbourhood built environment in older adults with disabilities, such as those with OA. To date, most studies on the association between PA and the neighbourhood built environment are conducted in the USA and Australia and less is known about this relationship in Western European countries. Associations between PA and neighbourhood built
environment characteristics in the USA and Australia may differ from those in Western European countries, because of differences in lifestyle and environmental factors. Furthermore, most studies are based on self-reported PA and perceived assessment of the built environment [94].

For older people with OA, the built environment might be especially relevant as their pain and functional limitations might cause difficulties in overcoming environmental barriers towards PA [38-40], such as objectively larger distances to facilities [95] and a lower rate of interconnecting streets within a neighbourhood [96].

A comprehensive understanding of the outdoor physical environmental determinants of PA among older adults with OA is essential for the identification of appropriate points of intervention to promote active lifestyles and their associated benefits. Therefore, it is important to obtain more insight in the relationships between objectively measured characteristics of the neighbourhood built environment and physical activity in older adults with OA.

**Quality of life and perceived neighbourhood problems**
The importance of the neighbourhood environment for QoL has been recognized [56,57,97,98], but the association between specific features of the neighbourhood environment and QoL in older community-dwelling adults with OA has not been studied extensively. A study by Levasseur et al. [99] showed that fewer barriers in the outdoor physical environment predicted better QoL in older adults with physical disabilities. Rantakokko et al. [97] showed that perceived barriers in the outdoor environment, such as traffic and poor street conditions, reduce QoL in older community-dwelling people. It was found that older persons who had more chronic diseases and slower walking speed reported more barriers in their outdoor environment and had lower QoL than those who were healthier [97]. To promote PA and improve QoL of individuals with OA, it is important to obtain more knowledge on the relationships between perceived neighbourhood problems, outdoor PA and QoL in this specific group.
CHAPTER 1

OBJECTIVES

This thesis aims to contribute to the understanding of the impact of the outdoor physical environment on older adults with OA in Europe. The main objective is to examine whether characteristics of the outdoor physical environment are associated with aspects of daily functioning of older adults with OA. A second aim is to examine whether environmental factors have a greater impact on aspects of daily functioning in older adults with OA than in those without the condition.

COHORT STUDIES USED IN THIS THESIS

This thesis is based on data from the European Project on OsteoArthritis (EPOSA) [4]. Furthermore, additional data from the Hertfordshire Cohort Study (HCS) [100] and the Longitudinal Aging Study Amsterdam (LASA) [101], both participating in the EPOSA study, have been used separately in this thesis. These cohort studies are described in more detail below.

European Project on OsteoArthritis

The EPOSA project studies the personal and societal burden and its determinants of OA in the ageing European population [4]. The EPOSA project is a collaborative study including pre-harmonized data from six ongoing cohort studies on older community-dwelling persons aged 65 to 85 years. The six cohort studies are from six European countries and include: the Activity and Function in the Elderly in Ulm study (Germany) [102], the Longitudinal Aging Study Amsterdam (LASA) (the Netherlands) [101], the Peñagrande study (Spain) [103], the Swedish Twin Register (Sweden) [104] and the Hertfordshire Cohort Study (HCS) (UK) [100]. In Italy, a new sample was drawn with recruitment procedures and age/sex distributions similar to those in the other studies [4]. The study cohort is representative of older adults living in the community. The EPOSA project provides the opportunity to study both persons with mild and severe OA, and those seeking care and not seeking care [4].
The study design and data collection of the EPOSA study are described in detail elsewhere [4]. In summary, the EPOSA data collection was considered as a side-study in all participating cohort studies (except in Italy). Data collection took place twice with 12 to 18 months between the baseline and the follow-up measurement. At baseline and at follow-up, a total of 2,942 and 2,455 persons, respectively, participated in the EPOSA project. All participants were interviewed by a trained researcher at home or in a clinical center, using a standardized questionnaire and a clinical exam. The baseline and follow-up interview lasted about one and a half hours. In all six countries, the same measurement instruments were used and data were collected on a variety of domains. During the interviews, data were collected on demographics, health characteristics, lifestyle characteristics, social characteristics, psychological characteristics, well-being, health care utilisation and the physical environment. During the clinical exam, data were collected on anthropometry, muscle strength and physical performance. At baseline, OA was assessed in the knee, hip and the hand by using the clinical classification criteria of the American College of Rheumatology [105]. At the end of the baseline interview, after six months and after the follow-up measurement, data on joint pain were collected by using pain calendars. A flow chart of the EPOSA study is presented in Figure 4.

**Figure 4:** Flow chart of the European Project on OSteoArthritis. Numbers indicate the subjects participating in the baseline and follow-up interview.
Hertfordshire Cohort Study
The principal objective of the Hertfordshire Cohort Study (HCS) is to study interactions between the genome, the intrauterine and early postnatal environment, and adult diet and lifestyle in the aetiology of chronic disorders in later life [100]. The study aims to place these interactions within a life-course model for disease pathogenesis and to characterize the psychological mechanisms underlying the pathways to chronic disorders. The HCS comprises 3,225 individuals born in Hertfordshire, UK, between 1931-1939 and who still lived in the county between 1998 and 2004. The HCS is county wide and was conducted in phases according to Hertfordshire county divisions. In total, 3,225 participants agreed to a home interview with a trained research nurse and 2,997 individuals attended a clinic for detailed physiological investigations. In 2008, 2,689 surviving participants were invited to take part in a postal survey and were asked about their perceptions of neighbourhood cohesion and neighbourhood problems. In total, 1,417 individuals returned a completed questionnaire [106]. The HCS database includes detailed information on study participants’ socio-demographic, lifestyle and clinical characteristics. The HCS participants are generally comparable with those in the nationally representative Health Survey for England [100].

Longitudinal Aging Study Amsterdam
The Longitudinal Aging Study Amsterdam (LASA) is an ongoing cohort study in the Netherlands on determinants, trajectories and consequences of physical, cognitive, emotional and social functioning in older persons [101]. For the LASA, a random sample of older men and women (55-85 years), stratified for age and sex, was drawn from the population registries of eleven municipalities in three geographic areas of the Netherlands, thereby representing variation in religious background and urbanicity. Data collection started in 1992/1993, with 3,107 respondents participating. Approximately every three years, data were collected in a main face-to-face interview, a medical face-to-face interview and a self-administered questionnaire [101]. Additional respondents from later birth cohorts were recruited from the same sampling frame in 2002/2003 and 2012/2013.
In Chapters 2, 3 and 4, data from the EPOSA study were used. In Chapters 5 and 7, data from the HCS were used. Chapter 6 is based on data from the LASA.

OUTLINE OF THIS THESIS

Figure 5 shows a schematic overview of the studies that are presented in this thesis. In Chapter 2, the association between joint pain and self-perceived weather sensitivity in older adults with OA is described. In addition, predictors of self-perceived weather sensitivity in older people with OA are described in this chapter. Chapter 3 focuses on the associations of joint pain with objective weather conditions in older adults with OA. Chapter 4 describes the relationships between objective weather parameters and self-reported outdoor PA in older adults with and without OA. In Chapter 5, the associations of perceived neighbourhood cohesion, perceived neighbourhood problems and objective neighbourhood deprivation with the use of neighbourhood resources in older adults with and without lower limb OA (LLOA).
are described. Chapter 6 describes the associations of objectively measured PA with objectively measured characteristics of the neighbourhood built environment in older people with and without LLOA. Chapter 7 reports on the associations between perceived neighbourhood problems, PA and QoL in individuals with and without OA. In Chapter 8, the main findings are summarized and are discussed in relation to the results of previous studies. Methodological considerations, practical implications and directions for future research are also addressed.
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