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CHAPTER 8

General discussion
INTRODUCTION

This thesis aimed to contribute to the understanding of the impact of the outdoor physical environment on the daily lives of older adults with osteoarthritis (OA) in Europe. The main objective was to examine the associations of outdoor physical environmental characteristics with aspects of daily functioning in older adults with OA. A second aim was 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. In this chapter, the results, as described in this thesis, will be reflected on, the methodological strengths and limitations will be discussed, and suggestions for practical implications and future research will be given.

PERSON-ENVIRONMENT FIT

The studies in this thesis were performed from the perspective of the ecological model of aging from Lawton [1,2]. This model proposes that the level of functioning of older adults is a result of the interaction between the capacities of individuals, or competencies, and the extent of demands from the environment, or environmental press. Derived from the ecological model of aging, the environmental docility hypothesis suggests that the less competent the individual, the greater the impact of environmental factors on that individual [1,2]. Older adults with OA might be especially vulnerable to environmental challenges due to functional limitations and symptoms, such as joint pain and stiffness [3-5]. Based on the environmental docility hypothesis [1,2], perceived and objective characteristics of the outdoor physical environment are expected to have a greater impact on aspects of daily functioning in older adults with OA than in those without OA.
MAIN FINDINGS AND THEIR INTERPRETATION

The main findings of this thesis are summarized below and, if applicable, are interpreted in terms of the environmental docility hypothesis.

Joint pain and self-perceived weather sensitivity

In Chapter 2, the association between joint pain and self-perceived weather sensitivity was examined in older adults with OA. In addition, characteristics of older persons with OA were identified that are most predictive of perceived weather sensitivity. In the study, data from the European Project on OSteoArthritis (EPOSA) were used. It was found that the majority of older adults with OA reported that their joint pain was affected by weather conditions. The results revealed that self-perceived weather sensitivity was associated with more pain in older adults with OA. These findings are consistent with those of Shutty et al. [8], who examined the relationship between weather sensitivity and pain in a more heterogeneous group of pain patients. In all six countries, weather-sensitive older adults with OA reported more pain than their non-weather-sensitive counterparts. In particular, in the Northern European countries (the Netherlands, Sweden, and the United Kingdom (UK)), that are characterized by colder and more humid weather conditions, weather-sensitive older adults with OA reported more pain than non-weather-sensitive older persons with OA. Although most of the weather-sensitive older adults with OA reported damp/rainy and/or cold weather conditions as affecting their pain, the common belief that joint pain in OA becomes worse by living in a cold and damp climate was not supported by our results. Weather-sensitive older adults with OA who were living in a warm and dry climate (Spain) reported higher pain intensity levels than those in a cold and wet (Sweden) or warm and wet climate (Germany, the Netherlands, Italy and the UK). Cultural differences in pain response between countries may be an explanation for this finding. Culturally-based responses to pain are often divided into two categories: stoic and emotive pain responses [9]. It has been suggested that persons from Northern Europe are more likely to have a stoic pain response, whereas persons from Mediterranean countries are more likely to have an emotive pain response [10,11]. Stoic persons
are less likely to express their pain, whereas emotive persons are more likely to verbalize their expression of pain, prefer to have people around and expect others to react to their pain [10,11]. Another explanation for the differences in perceived joint pain across local climate types could be weather (in)stability [6]. Jamison et al. [6] found that chronic pain patients in a colder climate did not report more pain than patients in warmer climates and suggested that the body establishes an equilibrium in relation to the local climate so that changes in weather trigger an increase in pain regardless of the prevailing meteorological conditions.

Our findings showed that sex, anxiety and country are independent predictors of self-perceived weather sensitivity in older adults with OA. Women were more likely to report weather sensitivity than men. A similar finding has been observed in a study by Von Mackensen et al. [12]. It has been suggested that differences in hormonal processes in the adrenal gland may account for the difference in weather sensitivity between men and women [13,14]. More anxious people were more likely to indicate themselves as weather-sensitive persons. It has been suggested that emotional distress increases subjective complaints of pain and that more anxious people with OA may tend to blame their symptoms on something they can understand but cannot control more than less anxious people with OA [15,16]. Older adults with OA from Italy and Spain were more likely to report weather sensitivity compared to those from Sweden. This finding could be explained by differences in weather exposure and socio-cultural factors [9-11,17,18].

**Joint pain and objective weather conditions**

In Chapter 3, the association of joint pain with objectively measured daily weather conditions, 3-day average weather conditions, and day-to-day changes in weather conditions were examined in older adults with OA. In the study, data from the EPOSA study were used. The results showed that higher daily average humidity levels and higher 3-day average humidity levels were associated with more joint pain in older adults with OA. It was observed that joint pain in these individuals was more strongly affected by daily average humidity in relatively cold weather conditions compared to relatively warm weather conditions. The associations between day-to-day weather changes and joint pain do not confirm causation. There
might be a momentaneous causal effect of weather conditions on joint pain in older adults with OA that is restricted to the same day.

Several suggestions have been made to explain the effects of weather conditions on joint pain in OA [6-8,13,16,20-23]. Humidity and temperature may have an effect on the expansion and contraction of different tissues in the joint, including tendons, muscles, bones and scar tissue, resulting in pain at sites of microtrauma [6,7]. Furthermore, low temperatures may increase the viscosity of synovial fluid, thereby making joints stiffer and perhaps more sensitive to the pain of mechanical stresses [6,7].

In contrast with previous research [22], the results did not show associations between joint pain and day-to-day changes in atmospheric pressure. The inconsistency between our results and those of McAlindon et al. [22] could be explained by differences in study sample. It has been suggested that the effect of atmospheric pressure on joint pain depends on specific joint conditions (e.g., effusions, defect of articular cartilage integrity, and presence of subchondral pseudocysts) [20,22,23]. McAlindon et al. focused on pain-weather associations in patients with knee OA, whereas our study focused on pain-weather associations in older persons with mild and severe OA in the general population. Sample differences imply differences in OA severity that might explain the inconsistencies between our findings and those of McAlindon et al.

Consistent with previous research [22,24], the findings showed that the effects of weather conditions on joint pain are small and likely to be clinically irrelevant. Pham et al. [25] defined a clinically relevant moderate improvement in pain as an absolute change of ≥10 in pain score on a scale of 0 to 100 or an improvement of 20% in pain score. In our study, an increase of 50% in relative humidity was associated with an increase of 0.2 points on a 0-10 pain scale. It is likely that this change in pain is unnoticeable by persons with OA and is not clinically relevant.

Although in Chapter 2 we found that the majority of older adults with OA perceive weather as affecting their pain, the study in Chapter 3 shows significant, but weak and clinically unimportant associations between joint pain and objectively measured weather parameters. It could be possible that the association between joint pain in OA and weather conditions is based on traditional popularity and
several psychological factors, such as selective matching [26]. Selective matching is the tendency to focus on salient coincidences, thereby capitalizing on chance and neglecting contrary evidence. Selective matching may lead people with OA to look for changes in the weather when they experience increased pain and pay little attention to the weather when their pain is stable [26].

**Outdoor physical activity and objective weather conditions**

In Chapter 4, the association between outdoor physical activity (PA) and objectively measured weather conditions was examined in older adults, and it was assessed whether outdoor PA was more strongly affected by objective weather conditions in older adults with OA than in those without the condition. In the study, data from the EPOSA study were used. The findings showed that increased temperature facilitates outdoor PA in older people. Furthermore, this study identified increased relative humidity as a barrier to outdoor PA in older adults. Unexpectedly, outdoor PA and weather conditions were more strongly associated in older adults without OA than in their counterparts with OA. This was particularly true for temperature and relative humidity. The latter condition was observed to affect outdoor walking in particular.

The study in Chapter 4 provides evidence that weather conditions are associated with outdoor PA in older adults. The finding that warmer temperatures were associated with increased PA in older people was in line with previous studies [27-31]. Our finding that outdoor PA in older people decreased with an increase in relative humidity was also in line with previous research [31]. Increased humidity makes it more difficult to cool down in warm weather conditions [32]. Older people may decrease their outdoor PA in humid weather conditions, because of their increased frailty and reduced ability to thermoregulate [33]. Contrary to other studies, our study did not show significant associations of total outdoor PA with precipitation, atmospheric pressure and wind speed [34,35].

The study in Chapter 4 does not provide supportive evidence for the environmental docility hypothesis [1,2]. Although in Chapter 2 we found that older people with OA often report that their joint pain are influenced by weather conditions, and in Chapter 3 we found significant associations between joint pain in OA and ob-
jective weather conditions, for which the potential mechanisms are well described in the literature [6-8,13,16,20,21], the study in Chapter 4 showed that objectively measured weather parameters do not affect outdoor PA in older adults with OA. In fact, higher temperatures were more strongly associated with more time spent on total outdoor PA in older people without OA than in those with OA. Furthermore, it was found that higher relative humidity levels were more strongly associated with less outdoor walking in older adults without OA than in those with the condition. Thus, in contrast with the environmental docility hypothesis, the impact of weather conditions on outdoor PA is not greater in older adults with OA than in those without the condition. A possible explanation could be that older people without OA might be better able to adapt their daily routines to prevailing weather conditions than their counterparts with OA. In addition, outdoor PA in older adults with OA might be affected by other outdoor physical environmental factors than weather conditions.

Use of neighbourhood resources and neighbourhood environment characteristics

In Chapter 5, the associations of perceptions of neighbourhood cohesion and neighbourhood problems and objectively measured neighbourhood deprivation with the use of neighbourhood resources were examined in older adults with and without lower limb OA (LLOA). Furthermore, it was assessed whether these relationships were stronger in older persons with LLOA than in those without the condition. In the study, data from the Hertfordshire Cohort Study (HCS) were used. The findings showed some supportive evidence for the environmental docility hypothesis [1,2]. The findings showed that, regardless of LLOA, perceived neighbourhood cohesion and objective neighbourhood deprivation were not significantly associated with use of resources by older adults. However, in line with the environmental docility hypothesis [1,2], it was observed that older adults with LLOA perceive more neighbourhood problems than those without LLOA. This suggests that older persons with LLOA might be more vulnerable to environmental demands than those without the condition. The findings further demonstrated that the perception of more neighbourhood problems was marginally significantly associated with more use of public transport in older adults without LLOA, whereas the perception of
more neighbourhood problems was marginally significantly associated with less
use of public transport in older people with LLOA. Thus, in line with the environ-
mental docility hypothesis, the perception of neighbourhood problems seems to
hinder older adults with LLOA to make use of public transport. The perception of
more neighbourhood problems seems not to be a barrier for older adults without
LLOA to make use of public transport. Older adults with LLOA may be less able to
deal with perceived neighbourhood problems and more challenging environments
than those without LLOA and may therefore be more likely to reduce their use of
public transport when they perceive more neighbourhood problems. Older adults
with LLOA may reduce their use of public transport, because they do not want to
travel through their neighbourhood to public transport facilities and be exposed
to their neighbourhood problems. However, the results only show a marginally
significantly negative association between use of public transport and perceived
neighbourhood problems, and do not show any association between perceived
neighbourhood problems and use of other neighbourhood resources.

The perception of more neighbourhood problems seems to hinder older adults
with LLOA to make use of public transport and this may have important negative
consequences for their daily functioning. In a study by Martin et al. [36], com-
munity-dwelling older adults with OA identified public transport as an important
community resource that they use to manage their OA as it facilitates easier access
to public services and health care resources. In addition, previous studies have
shown that public transport is an important resource for older adults to maintain
social relationships, personal independence, and participation in activities [37,38].

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

In Chapter 6, the associations of objectively measured neighbourhood built environ-
ment characteristics with objectively measured PA were examined in Dutch older
people with and without LLOA. This study also assessed whether these associations
were stronger in older adults with LLOA than in those without the condition. In the
study, data from the Longitudinal Aging Study Amsterdam (LASA) were used. The
results showed that, regardless of LLOA, a higher rate of interconnecting streets
within a neighbourhood was marginally significantly associated with more time
spent on low-light PA (e.g., very slow walking) in older adults. It has been suggested that a higher rate of street connections within a neighbourhood provides more travel route options and facilitates direct travelling, which in turn supports being physically active [39]. Furthermore, the results demonstrated that larger distances to specific health care resources (general practice and physiotherapist) and retail resources (supermarket) were more strongly associated with more time spent on PA in older people with LLOA than in those without LLOA. In particular, larger distances to these specific resources were related to more time spent on high-light PA (e.g., slow walking) in older people with LLOA compared to their counterparts without the condition. Consistent with the environmental docility hypothesis [1,2], the impact of distances to specific neighbourhood resources on PA was found to be greater in older adults with LLOA than in those without LLOA. Previous studies show that individuals with LLOA make more use of health care services than those without the condition [40,41]. In addition, it may be a greater effort for older adults with LLOA to travel the distances to these resources and, in comparison to those without LLOA, they may need more time to reach their destinations.

**Quality of life and perceived neighbourhood problems**

In Chapter 7, the association of quality of life (QoL) with perceived neighbourhood problems was examined in older adults with and without OA, and it was assessed whether this relationship was stronger in those with OA. Furthermore, it was examined whether the association between perceived neighbourhood problems and QoL in older adults was mediated by PA. In the study, data from the HCS were used. It was found that the cross-sectional associations between QoL and perceived neighbourhood problems were not significant in the full sample at baseline and at follow-up, and the analyses revealed that these relationships did not differ between older adults with and without OA. However, over time, perceiving more neighbourhood problems was associated with a stronger decrease in QoL in older adults with OA than in those without the condition. The association of QoL with perceived neighbourhood problems was not mediated by the time spent on outdoor PA.
The study in Chapter 7 provides some supportive evidence for the environmental docility hypothesis [1,2]. Due to the experience of more pain and functional limitations, older adults with OA might be more vulnerable to environmental demands and might be less able to overcome neighbourhood problems than those without the condition. The longitudinal results suggest that older adults with OA are less able to deal with perceived neighbourhood problems in comparison to their counterparts without OA and, as a consequence, their QoL decreases more over time. We found no support for a possible explanation that older adults with OA experience more difficulties with regard to spend time on outdoor PA when they perceive more neighbourhood problems, and that this results in poor QoL. It could be that the association of QoL and neighbourhood problems is rather mediated by fear of moving outdoors and unmet PA needs [42], than by the self-reported quantity of outdoor PA.

**EVIDENCE FOR THE ENVIRONMENTAL DOCILITY HYPOTHESIS**

The studies in this thesis provide some supportive evidence for the environmental docility hypothesis [1,2]. The results of the cross-sectional analyses are not fully in accordance with the environmental docility hypothesis. Some cross-sectional analyses demonstrated that environmental factors are more strongly associated with specific aspects of daily functioning in older adults with OA than in those without OA, and some showed the opposite. However, the results of the longitudinal analyses were in line with the environmental docility hypothesis.

In the studies in this thesis, the environmental docility hypothesis is tested by examining the modifying effect of OA-status on the relationship between environmental factors and specific aspects of daily functioning. An appropriate alternative approach is to test the environmental docility hypothesis by only focusing on older adults with OA and to assess whether specific aspects of daily functioning are more strongly influenced by environmental factors in those with more pain and/or functional limitations (e.g., older adults with OA who have higher scores on the pain and/or physical function subscales of the Australian/ Canadian Osteoarthritis
Hand Index [43] and the Western Ontario and McMaster Universities Osteoarthritis Index [44]). Additional analyses of the data from our studies, in which this alternative approach was applied, showed similar results as presented in this thesis. Therefore, this alternative approach does also contribute evidence for the environmental docility hypothesis. However, this alternative approach may have resulted in spurious associations, because of small sample sizes.

An ecological model is based on the assumption that functioning, health, and well-being are affected by dynamic person-environment interactions. Depending on the historic time and discipline, the model has taken different forms [45]. Lawton and his colleagues applied the ecological model to the field of gerontology [1,2,45]. It might be fruitful to apply elements of other ecological models from other disciplines in our studies to better understand how environmental factors affect aspects of daily functioning in older adults with and without OA. The ecological model of Bronfenbrenner [46-48], that is mainly applied in research on development in childhood and youth, might be an appropriate alternative for Lawton’s ecological model of aging to explain how person-environment interactions affect individual functioning. The ecological model of Bronfenbrenner situates the person explicitly within multiple contexts. It distinguishes four hierarchical levels of ecological systems, with the lower levels embedded in the higher levels (Figure 1). The “microsystem” refers to all social groups and institutions in the individual’s immediate social and physical environment. The “mesosystem” contains all interactions between “microsystems” which are relevant to a person at a certain point of time, and includes the possibility that the influences of “micro-systems” on the individual may be synergistic or antagonistic. Beyond the “mesosystem” is the “exosystem”, which consists of settings that do not contain the individual directly, yet still affect them. The “macrosystem” refers to social and cultural values. In addition to these four hierarchical system levels, Bronfenbrenner introduced the “chronosystem”, which encompasses elements of the life course, calling attention to sociohistorical context, trajectories, transitions, and the importance of timing, place, and cohort.

In comparison to the ecological model of aging from Lawton, the theory of ecological systems from Bronfenbrenner explicitly distinguishes different types of environments, and this may help to better understand the influence of envi-
Environmetal factors on aspects of functioning in older adults with and without OA [49]. In terms of the theory of ecological systems from Bronfenbrenner [46-48], our studies focused on how the outdoor physical environment, as a “microsystem”, affects functioning of older individuals. In our studies, the immediate social environment (e.g., social support from family and peers) as well as its interaction with the outdoor physical environment (“mesosystem”) were not considered. Furthermore, aspects of the home environment were not taken into account in our studies. In addition, the role of the “exosystem” (e.g., social services and local politics) and the “macrosystem” (e.g., social and cultural beliefs on health behaviour) were not

Figure 1: Bronfenbrenner’s ecological systems theory.
considered. Specific aspects of the “chronosystem” also seem to be relevant to consider in our studies, such as the duration of disease and physical activity in childhood [46-48,50]. Although the ecological model of aging from Lawton has considerable overlap with the theory of ecological systems from Bronfenbrenner [49], the inclusion of aspects of the latter model in future studies may help to increase our understanding of environmental influences on aspects of daily functioning in older adults with and without OA.

**PERCEIVED VERSUS OBJECTIVE OUTDOOR PHYSICAL ENVIRONMENT CHARACTERISTICS**

The studies in this thesis contribute to the growing body of evidence that aspects of functioning of older adults are affected by both perceived and objectively measured characteristics of the outdoor physical environment. For example, the results in Chapter 2 show that the majority of older adults with OA perceived cold and humid weather as affecting their pain. The results in Chapter 3 seem to be in line with those in Chapter 2. In Chapter 3, it was observed that joint pain in older adults with OA was more strongly affected by daily average humidity in relatively cold weather conditions compared to relatively warm weather conditions. Subjective and objective assessments of the environment do not always correlate perfectly [51,52] and the influence of perceived and objectively measured characteristics on functioning and health are often not similar [52]. Subjective outdoor physical environment characteristics refer to perceptions of one’s outdoor physical environment in a range of domains. It has been suggested that these assessments are more proximal determinants of behaviour than objective assessments of the environment, of which individuals may even not be aware of [52]. The findings of the study in Chapter 5 seem to be in line with this. In this study, it was found that objectively measured neighbourhood deprivation was not associated with use of neighbourhood resources in older adults with and without OA, whereas perceived neighbourhood problems were marginally significantly associated with use of public transport in these individuals. However, it should be acknowledged that the
objective measure of neighbourhood deprivation did not exactly coincide with the perceived neighbourhood problems that were addressed by the questionnaire.

**COMPARISONS ACROSS COUNTRIES**

In our studies on the influence of weather conditions on joint pain (Chapters 2 and 3) and outdoor PA (Chapter 4), we used data from all six population-based cohort studies in the EPOSA project. This enabled us to make cross-country comparisons of the influence of weather conditions on these aspects of functioning in older adults with and without OA. For example, in Chapter 2, it was observed that perceived weather sensitivity has a greater influence on joint pain in the Northern European countries (the Netherlands, Sweden, and the United Kingdom). The influence of objectively measured weather parameters on joint pain did not differ across countries (this finding was not reported in Chapter 3). As presented in Chapter 4, higher levels of relative humidity were associated only with increased outdoor PA in Spain. In comparison to the participants in the other countries, Spanish participants were, on average, exposed to low humidity levels. Although the association between outdoor PA and relative humidity was not significant in Spain, more humid conditions may facilitate outdoor PA in this country. Furthermore, it was found that, in particular, higher levels of relative humidity were associated with less time spent on outdoor PA in Italian and Dutch older adults. To our knowledge, there is no explanation for the stronger negative associations between outdoor PA and relative humidity in Italy and the Netherlands.

In our studies on the influence of neighbourhood characteristics on use of resources (Chapter 5), PA (Chapter 6), and QoL (Chapter 7), we did not use data from multiple cohort studies. In these studies, the environmental determinants (Chapters 5, 6, and 7) and/or outcome measures (Chapter 6) were only available in one specific cohort study. Cross-country comparisons regarding associations between neighbourhood (built) environmental characteristics and aspects of functioning in older adults with and without OA remain a challenge for future studies.
UNIQUENESS OF RESULTS FOR OLDER ADULTS WITH OSTEOARTHRITIS

In this thesis, the influence of OA on the relationships between outdoor physical environmental factors and self-reported outdoor PA (Chapter 4), use of neighbourhood resources (Chapter 5), objectively measured PA (Chapter 6), and QoL (Chapter 7) in older adults was examined. These associations, as presented in this thesis, are not necessarily unique and specific for older adults with OA. Previous research has focused on similar associations in older adults with other chronic health conditions than OA, but did not stratify the associations for specific chronic disease groups, such as chronic obstructive pulmonary disease, diabetes and/or heart disease [4]. A characteristic that makes OA unique compared to other chronic diseases, is the fluctuating course of the disease. The condition is often characterized by the alternation of stable periods of varying length, characterized by a low level of absence of pain with flare-up or exacerbation [53]. This may make the current results unique and specific to OA, and not to other chronic health conditions. However, future research is needed to confirm this assumption.

METHODOLOGICAL CONSIDERATIONS

Some methodological strengths and limitations should be taken into account in the interpretation of the results that are described in this thesis. The most important issues are described in this section.

Population-based cohort studies
This thesis is based on data from the EPOSA study [54]. Furthermore, additional data from the HCS [55] and the LASA [56], both participating in the EPOSA study, have been used separately in this thesis. The EPOSA study is a population-based study including pre-harmonized data from six ongoing cohort studies across six European countries on older persons. 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 [54]. A particular strength of the EPOSA study is the standardized clinical assessment of OA across countries. In addition, in all six cohort studies, extensive information was collected on several domains of functioning in older adults, by using the same instruments and procedures. Therefore, we were able to test and include important confounding variables in our models. The inclusion of two-week pain calendars on three occasions during the EPOSA project allowed us to examine the relationship between joint pain and weather conditions in a large geographically dispersed group of older adults with OA over a considerable time-period, generating greater opportunity for weather exposure variability than in local short-term studies.

Although we had a rich data-set on various domains of functioning in older adults, we may have lacked information on important potential confounders and modifiers in our studies. For example, in our studies, we did not consider whether the relationships between the outdoor physical environment and aspects of functioning are affected by aspects of the social environment, such as social support from family and peers. Furthermore, we did not consider residential self-selection in our study on the relationship between objectively measured PA and characteristics of the neighbourhood built environment. Residential self-selection is the phenomenon that people choose where to live based on their needs and preferences [57]. For example, it could be that people are more physically active because the neighbourhood built environment invites them to do so, but it could also be that people who like to be physically active tend to choose residential neighbourhoods conducive to exercising that preference. In addition, we had no data available on disease duration in our studies. It could be that the participants with OA already have this joint disease for many years and that they are well adapted to this situation. As a consequence, the impact of environmental factors on aspects of daily functioning in these individuals may be unidentifiable and appear similar to the impact in older adults without OA.

**Study design**

In this thesis, mainly cross-sectional analyses were performed. By using cross-sectional analyses, we were able to examine whether outdoor physical environmental
factors are associated with aspects of daily functioning in older adults with and without OA. However, a limitation of cross-sectional studies is that it is impossible to determine a causal relationship.

It thus remains unclear whether changes in characteristics of the outdoor physical environment actually contribute to changes in PA in older adults with OA. Longitudinal designs are more suitable to address this issue.

**Statistical power issues and time-gaps**

In several studies (Chapters 5, 6 and 7), the sample size was fairly small, which resulted in low statistical power. In addition, in some studies (Chapters 5 and 7), there was a considerable time gap between the assessment of environmental determinants (perceived neighbourhood cohesion and perceived neighbourhood problems) and outcome measures. Although it could be assumed with reasonable certainty that the environmental determinants remained stable over this time period, the time gaps between assessments and the small sample sizes in these studies made it difficult to gauge the true size of associations.

In most studies in this thesis (Chapters 4, 5, 6, and 7), subgroup analyses are described. In order to save statistical power, subgroup analyses were only applied when the interaction term reached significance. Multiple testing increases the risk of false positive findings [58]. Therefore, we used a stricter level of significance in our studies.

In Chapter 4, outdoor PA in minutes per day was based on the frequency and duration of PA in the previous two weeks and did not provide detailed information about PA on specific days. The average weather parameters were objectively measured for each day in this study. It would have been better to also assess outdoor PA on a day-to-day basis. For example, by using physical activity diaries or accelerometers.

**Linkage of objectively measured neighbourhood data**

In Chapter 6, Geographic Information Systems (GIS) software, ArcGIS 10.1 (ESRI Inc, Redlands, CA, USA), was used to allocate the centroid of 6-digits post code areas of participants residential addresses to a neighbourhood, as defined by
Statistics Netherlands and The Netherlands’ Cadastre, Land Registry, and Mapping Agency. This approach does not take into account that participants can live at the administrative border of a neighbourhood and actually make use of resources in the adjacent neighbourhood. In Chapter 6, the mean road distance in kilometres of all occupied addresses in a neighbourhood to a specific resource was used as a proxy for the distance from the participants’ home to that specific resource. It would be more accurate to geocode the exact addresses of all participants (e.g., by using the Dutch Basic Administration of Addresses and Buildings (BAG)) and to measure the road distances in kilometres between each specific address and the most approximate resources that are actually used by the participants. In addition, it would be more accurate to consider one-way traffic, prohibitions, foot paths and bicycle lanes in this measurement. This approach could result in stronger associations.

**PRACTICAL IMPLICATIONS**

The knowledge obtained on the relationship between pain and weather conditions (Chapter 2 and 3) could be used to help older adults with OA, clinical practitioners and therapists, to better understand and control pain fluctuations in OA. The identification of weather sensitivity in older adults with OA and offering pain coping strategies may help to reduce pain in this group. Pain coping skills training aims to teach cognitive and behavioral techniques which enable patients to reduce the impact of pain on functioning. Common techniques include relaxation, attention diversion, activity pacing, and reducing pain-related cognitions and emotions [59-61]. Although the study in Chapter 3 shows significant, but weak and clinically unimportant associations between joint pain and weather parameters, it is important to pay attention to the effects of weather conditions on joint pain in older adults with OA, because OA is the most common form of musculoskeletal disorders worldwide [62] and this large group of older adults might be impaired in their daily functioning because of weather effects on their joint pain. Based on the results in
Chapter 4, weather conditions should be taken into consideration when designing PA interventions and interpreting the results of PA studies in older adults.

The results of Chapter 5, 6 and 7 show potentially important relationships between perceived and objective characteristics of the neighbourhood environment and various aspects of daily functioning in older adults with and without OA. Knowledge on the impact of the neighbourhood environment on daily functioning of older adults with and without OA could be used to help these persons to deal with their environment and to inform policymakers and city planners about adaptation of the outdoor physical environment to appropriately improve PA, social functioning and QoL in these individuals. In particular, the results, as described in this thesis, imply that it is important that policymakers and city planners do not only focus on objective neighbourhood characteristics, but are also in close contact with the residents of a neighbourhood to monitor and address their perceived neighbourhood problems. The reduction of perceived neighbourhood problems in older adults with OA may result in higher levels of QoL and may increase the use of public transport, which is important for social participation and living independently.

SUGGESTIONS FOR FUTURE RESEARCH

A number of issues have arisen from the studies in this thesis, which could be elaborated on in future research. Suggestions for future research are described in this section.

Improvements on our studies

The studies in this thesis show potentially important associations between specific aspects of daily functioning and perceived and objective characteristics of the outdoor physical environment in older adults with and without OA. Replication of our studies is needed to confirm the results of this thesis. Future research should include a larger sample size, and should avoid considerable time gaps between the assessments of determinants and outcome measures. Furthermore, future
research should consider important confounding and modifying factors in the relationship between the outdoor physical environment and aspects of daily functioning in older adults with and without OA. Based on the theory of ecological systems from Bronfenbrenner [46-48], support from social network and disease duration seem to be important aspects to consider in future studies. In addition, residential self-selection should be taken into account.

More research is needed to further examine how other outdoor physical environmental factors, such as hilly terrain, accessibility of buildings and poor pavement conditions, are associated with functioning and well-being in older adults with and without OA. Qualitative studies could be used to indicate which specific environmental factors facilitate or impede physical activity in older persons with OA. Longitudinal, prospective studies are needed to examine causal relationships between outdoor physical environmental factors and aspects of daily functioning in older adults with and without OA.

**Actual exposure to weather conditions**

Future research on the relationship between joint pain and weather conditions in older adults with OA should take the differences between indoor and outdoor climate into account and should also consider exposure time to both environments. Future research should also focus on the hour-to-hour weather changes, because this could be of more importance to pain than day-to-day changes.

Future research should also focus on the hour-to-hour influence of weather on outdoor PA in older adults. Recent studies linked weather and PA measured on a daily basis [27-31], but a person can still be active in hours of a day in which the weather is better. Studies using weather and PA measured on an hour-to-hour basis eliminate this potential bias [35].

**Use of Global Positioning System devices**

Global Positioning System (GPS) is a satellite based global navigation system that provides a precise location at any time on the Earth’s surface [63,64]. In future studies, GPS tracking devices could be used to objectively examine the geographical location of participants and to assess their exact activity space [63-65]. From
GPS data, the precise exposure to environmental factors can be measured [63-65]. For example, it can be derived whether participants are engaged in indoor or outdoor activities and whether these activities take place at home, within the neighbourhood or outside the neighbourhood. Furthermore, GPS data provide more detailed information about specific travel modes and travelled distances [66,67]. For example, by combining GPS data with GIS, it is possible to indicate whether a participant walked 1 km in a park, cycled 4 km to a supermarket, or travelled 8 km to a general practitioner by car. The use of GPS tracking devices, in combination with GIS, would be a very valuable and promising addition to our studies, because they provide detailed information that place activities into a context, and this helps to obtain a better understanding of how the outdoor physical environment affects aspects of daily functioning in older adults.

**CONCLUSIONS**

To conclude this thesis, our studies contribute to the growing body of evidence that aspects of functioning of older adults are affected by characteristics of the outdoor physical environment. The findings suggest that some specific perceived and objectively measured characteristics of the outdoor physical environment facilitate or impede aspects of daily functioning in older adults with and without OA. Some supportive evidence has been observed for the environmental docility hypothesis, that suggests that the impact of environmental factors are greater on functioning and well-being in older adults with OA than in their counterparts without the condition. The current results suggest that there are potentially important environmental factors that can be addressed to improve functioning and well-being in the growing group of older adults with OA. More research is needed to confirm the results in this thesis and to further examine how other outdoor physical environmental factors are associated with functioning and well-being in older adults with and without OA. The use of longitudinal study designs and GPS tracking devices, in combination with GIS, seems to be valuable and promising additions to future studies in this field of research.
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