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A Physically Active Lifestyle in Old Age – the Role of the Physical and Social Environment

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List of Scientific Articles for the Publication-based Dissertation

I. Article

Herbolsheimer, F., Schaap, L.A., Edwards, M.H., Maggi, S., Otero, A., Timmermans, E.J., Denkinger, M.D., van der Pas, S., Dekker, J., Cooper, C., Dennison, E.M., van Schoor, N.M., Peter, R.; Eposa Study Group (2016). Physical Activity Patterns Among Older Adults With and Without Knee Osteoarthritis in Six European Countries. *Arthritis Care & Research*, 68(2), 228–236. https://doi.org/10.1002/acr.22669

II. Article

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III. Article

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Abstract

Regular physical activity is of utmost importance for the health and quality of life of older adults (F. Sun, Norman, & While, 2013). However, whether and to what extent older adults are physically active is not only the result of individual habits and attitudes, but also shaped by the structural context. The aim of this thesis is to investigate the role of both the physical and the social context for physical activity. Moreover, this thesis was interested in comparing these context effects between adults with osteoarthritis (OA) and older adults without this condition. These insights could be the basis on which effective physical activity promotion activities could be developed, particularly in older adults with OA.

Older adults with OA might have a lower ability to respond to environmental demands because they are restricted in everyday activities (van der Pas et al., 2016). OA is a leading cause of functional limitations among older adults (Dillon, Hirsch, Rasch, & Gu, 2006) and the second greatest cause of disability worldwide (Vos et al., 2012). However, many older adults with OA do not engage in regular physical activity, even though it helps them to overcome symptoms. Moreover, physical activity is recommended as a self-management strategy by the American Colleague of Rheumatology (Hochberg et al., 2012).

Besides a focus on OA, this thesis discusses the influence of social isolation on low physical activity levels. Social isolation has consistently been found to be an important predictor of low physical activity among older adults (Chang, Wray, & Lin, 2014). However, there is little knowledge about the interrelation of physical activity levels in persons with restricted social networks and the location in which physical activity might occur.

In summation, this thesis looks in more detail at the relationship between (low) physical activity levels in older adults and (1) country variations among older adults with OA, (2) physical environmental conditions (e.g., weather conditions) and (3) social environment (e.g., social isolation).

This publication-based dissertation is comprised of three articles, which present results of two different studies. All are part of the ActiFE study (Activity and Function in the Elderly in Ulm) (Denkinger et al., 2010).

The first article of this thesis presents a multi-centric cross-sectional analysis of physical activity data on older adult from six European countries (n=2,942). The study examined whether the same health condition (knee OA) had different effects on physical activity in different European countries. Depending on the country of residence, older adults with knee OA were either equally or much less physically active compared to individuals without the condition. Knee OA had a greater effect on physical activity in southern European countries than northern European countries, which indicated the relevance of environmental factors.

The second article used the same data source with a focus on weather conditions that were retrieved from local weather stations. Similarly, to the first article, this study compared people with OA and older adults without the condition. High temperature and low humidity were associated with more outdoor physical activity. The relationship was stronger in older adults without OA in comparison with individuals with the condition. Older adults without OA might be better able to adapt their behavior to physical environmental circumstances.

Finally, the third article examined the importance of social isolation on physical activity in German participants, without a focus on OA. This study combined objective accelerometer-based physical activity data with data from an outdoor physical activity diary. Social isolation from friends turned out to be strongly associated with lower levels of physical activity. Furthermore, outdoor physical activity was highly correlated with physical activity. Outdoor physical activity was more likely associated with social isolation from friends and neighbors than indoor physical activity.

In conclusion, the results showed that lower physical activity levels were associated with the physical and social environment. These findings document the critical role of the environment in promoting or inhibiting physical activity in older adults.

Zusammenfassung

Regelmäßige körperliche Aktivität wirkt sich positiv auf die Gesundheit und die Lebensqualität im Alter aus (F. Sun et al., 2013). Ob und inwieweit ältere Personen körperlich aktiv sind, ist nicht nur von persönlichen Gewohnheiten und Einstellungen eines jeden Einzelnen abhängig, sondern wird auch durch die Lebensumwelt geprägt. Die vorliegende Arbeit untersuchte nun, inwiefern das physischen und das sozialen Umfeld körperliche Aktivität beeinflusst. Darüber hinaus ging diese Arbeit der Frage nach, ob kontextuelle Einflüsse besonders stark bei Personen mit Osteoarthrose (OA) auf körperliche Aktivität wirken. Der Vergleich von Personen mit OA mit Personen ohne die Erkrankung ermöglichte es, Erkenntnisse zu gewinnen, die als Grundlage für effektive körperliche Aktivitätsförderung herangezogen werden könnten.

Ältere Personen mit OA haben eine geringere Fähigkeiten auf Umweltanforderungen zu reagieren, da OA mit körperlichen Einschränkungen im alltäglichen Leben einhergeht (van der Pas et al., 2016). OA gilt als eine Hauptursache für funktionelle Einschränkungen bei älteren Personen (Dillon et al., 2006) und als zweitgrößte Ursache für körperliche Einschränkungen im Alter weltweit (Vos et al., 2012). Obwohl körperliche Aktivität dabei hilft, die Symptome von OA abzumildern und vom „American College of Rheumatology“ empfohlen wird (Hochberg et al., 2012), sind die meisten ältere Personen mit OA unzureichend körperlich aktiv.

Neben dem Schwerpunkt auf OA, beleuchtet die Arbeit den Zusammenhang zwischen sozialer Isolation und geringer körperlicher Aktivität. Soziale Isolation gilt als ein wichtiger Prädiktor für geringe körperliche Aktivität bei älteren Personen (Chang et al., 2014). Allerdings gibt es wenige Erkenntnisse über das Zusammenwirken von körperlicher Aktivität, eingeschränkten sozialen Netzwerken und dem Ort, an dem ältere Personen besonders aktiv sind.

Zusammenfassend untersucht diese Arbeit das Verhältnis zwischen (niedriger) körperlichr Aktivität bei älteren Personen und (1) länderspezifischen körperlichen Aktivitätsmustern bei Personen mit OA (2) unter Einbeziehung des physischen Umfeldes (z. B. meteorologische Bedingungen) und (3) des sozialen Umfeldes (z.B. soziale Isolation).

Diese publikations-basierte Dissertation umfasst drei Manuskripte, die Ergebnisse aus zwei miteinander zusammenhängenden Studien aufgreift. Alle Studienteilnehmer haben an der ActiFE-Studie (Aktivität und Funktion bei älteren Menschen in Ulm) teilgenommen (Denkinger et al., 2010).

Das erste Manuskript der Dissertation präsentiert eine multizentrische Querschnittsanalyse zu körperlicher Aktivität bei älteren Personen aus sechs europäischen Ländern (n=2,942). Die Studie untersucht, ob die gleiche Erkrankung (Knie OA) unterschiedliche Auswirkungen auf die körperliche Aktivität in den einzelnen europäischen Ländern hat. Je nach untersuchtem Land waren die Personen mit OA im Knie entweder gleich oder weniger aktiv als Personen ohne die Erkrankung. Dabei hatte OA im Knie eine größere Wirkung auf die körperliche Aktivität in den südeuropäischen Ländern im Vergleich zu nordeuropäischen Ländern. Dies weist auf die Relevanz von Umweltfaktoren hin.

Das zweite Manuskript nutzt die gleiche Datengrundlage mit dem Fokus auf meteorologische Bedingungen. Diese Information wurde von Wetterstationen vor Ort abgerufen. Analog zum ersten Manuskript verglich diese Studie Personen mit OA mit älteren Erwachsenen ohne die Erkrankung. Hohe Temperaturen und niedrige Luftfeuchtigkeit hingen mit höherer körperlicher Aktivität im Freien zusammen. Der Zusammenhang war stärker bei älteren Personen ohne OA im Vergleich zu Personen mit der Erkrankung. Eine mögliche Erklärung war, dass ältere Personen ohne OA ihr Verhalten besser an Umgebungsbedingungen anpassen konnten.

Schließlich untersuchte das dritte Manuskript den Zusammenhang zwischen sozialer Isolation und körperliche Aktivität (ohne einen Schwerpunkt auf OA zu legen). Dieses Manuskript kombiniert objektive akzelerometer-basierte Aktivitätsdaten mit einem Tagebuch, in dem außerhäusliche Aktivitäten dokumentiert wurden. Kein oder wenig Kontakt zu Freunden erwies sich als die wichtigste Einflussgröße auf körperliche Aktivität. Darüber hinaus wurde festgestellt, dass außerhäusliche körperliche Aktivität von besonderer Bedeutung war. Sozialer Isolation war eher mit außerhäusliche körperliche Aktivität assoziiert, als mit körperlicher Aktivität, die im oder um das Haus stattfand.

Die Ergebnisse dieser Dissertation deuten darauf hin, dass geringe körperliche Aktivität mit dem physischen und sozialen Umfeld zusammenhängt. Dies dokumentiert die bedeutende Rolle der Umwelt für körperliche Aktivität bei älteren Personen.

1 Physical Activity and Active Aging

The proportion of older adults in Western societies rises continuously as a result of a long-term decline in fertility rates and an enormous increase in life expectancy (Bongaarts, 2009). Over the last decades, the effects of an aging population have been interpreted differently applying varying concepts and prognoses to the health care system, social relationships, family structures, and policies.

A deeply negative image of old age underlies the notion of "age-crisis", which entailed the idea of older adults being burdensome. Since the 1960s, aging research has focused on dependency, frailty, and general misery. This has been formulated in theories like the disengagement theory, which postulated that human aging is comparable with biological loss and leads naturally to a withdrawal from social roles and a gradual weakening and loss of body functions (Touhy & Jett, 2009). Old age was associated with disability, deterioration and inactivity, while research focused on care provision and institutionalization. Societal role expectations of older adults were to remain socially invisible (Wood, 1971).

In the last decades, however, this picture has shifted. Research has revolved around the idea that decline in old age – beside the natural aging process – is also a consequence of the older adult's social disengagement (van Dyk, 2014). A more positive image of aging is raised in research agendas and theories like "active ageing" theory, aiming to strengthen the understanding of resources in later life (Walker & Maltby, 2012). This re-definition refers to the potentials of the healthy "young-old", who are thought to be capable of softening the burden of handling the forecasted rising number of truly frail and dependent older adults. Terms like successful aging (Rowe & Kahn, 1997), active aging (Walker & Maltby, 2012), productive aging (Kaye, Butler, & Webster, 2003), and optimal aging have replaced negative connotations of aging. Active aging was developed as a policy tool (Lassen, 2015) in which old age is rearticulated in terms of a period of activity and participation rather than one of passivity (Walker, 2002). Older people are encouraged and expected to stay active, flexible and independent through physical, mental and social activities, as well as a longer work life (Brooke, Taylor, McLoughlin, & Di Biase, 2013; European Commission, 2012; World Health Organization, 2002).

Activity theory claims that "it is better to be active than to be inactive; to maintain the pattern characteristic of middle age rather than to move to new patterns of old age" (Havighurst, Neugarten, & Tobin, 1968, p. 161).

In summary, aging is no longer seen as a terminal process of loss that is irreversible and inevitable. Research has turned attention to individuals' assets rather than focusing exclusively on deficits. And it has rejected the assumption that aging is a personal and societal problem. An individual is now understood to have many possibilities open after working life and to be responsible for his or her own fortune. "Both within labor markets and after retirement, there is the potential to facilitate the makin of greater contributions from people in the second half of their lives" (European Commission, 1999, p. 21). Consequently, research has repeatedly shown that morbidities and mortality are – to a certain degree – modifiable (Warburton, Charlesworth, Ivey, Nettlefold, & Bredin, 2010). There is also some evidence that today's population aged 65 and older in advanced industrial countries is less disabled than earlier cohorts (Schoeni, Freedman, & Martin, 2008).

A physically active lifestyle is one important factor that contributes to higher quality of life and longevity (Bize, Johnson, & Plotnikoff, 2007; I.-M. Lee & Paffenbarger, 2000). A growing number of scholars now focus on the relationship between aging and physical activity. Many interdisciplinary studies have been conducted showing the benefits of physical activity, which include reduced chronic diseases, sustained functional capacity, sustained cognitive function (Bauman, Merom, Bull, Buchner, & Singh, 2016), higher quality of life and reduced mortality (Stenholm et al., 2016 and section 2.1). The World Health Organization (2013) estimates that physical inactivity is responsible for 9% of all deaths worldwide. In the 2010 Global Burden of Disease Study, physical inactivity was among the top 10 risk factors for global disease burden accounting for 3.2 million deaths and 2.8% of the total disability adjusted-life years (World Health Organization, 2013).

A position paper from the Health Aging Network has highlighted the challenges of future research in aging and physical activity (Prohaska et al., 2006). Prohaska and colleagues (2006) concluded that more research was needed to address the following research issues: (1) Research is needed regarding **advances in the measurement** of physical activity and health outcomes, which might be achieved by applying age-specific measurement of physical activity and outcome measures perceived as relevant to health. "Some researchers have questioned the validity, reliability, and sensitivity of measures of physical activity across diverse older populations." (Prohaska et al., 2006, p. S271) (2) It has been proposed that a greater focus on physical activity assessment, intervention, and evaluation from a **social ecological framework** is needed. Health promotion and health related interventions to-date are typically downstream at the personal level. These approaches largely ignore the social context that shapes individual behavior. McKinlay (1995) called for new research that addresses physical activity by emphasizing upstream behavioral interventions at the public health level that deal with populations in their environmental context. (3) Research should be extended to other disadvantaged populations, including **frail persons** and older adults with **specific chronic conditions**.

Looking at the claimed research gaps, three important questions arise as the leading questions of my dissertation: Which physical activity patterns can be observed in the lives of older adults using advanced methods in assessing physical activity? How does the physical and social environment facilitate or impede physical activity in old age? Do physical activity levels differ in older adults with OA?

As proposed by Prohaska and colleagues (2006), this thesis applies different perspectives to explain physical activity patterns among older adults. (1) Using an **(objective) accelerometer-assessed** measurement of physical activity, different patterns of physical activity (indoor and outdoor physical activity) are distinguished (article 3). By taking the physical and social environment into account, the thesis focuses on social isolation as one aspect of the social environment (article 3). (2) It compares the physical activity of older adults with the same **chronic** condition – OA – in six European countries with the same age range (article 1). And (3) it estimates the influence of one aspect of the physical environment: weather conditions (article 2).

The three articles are embedded in a broader context, which is arranged as follows: The general background of this thesis (chapter 2) provides theoretical insights regarding physical activity in old age (section 2.1). Following this, the thesis shows the influence of the physical and social environment on physical activity (section 2.2) and discusses the relationship of social influences to health (section 2.3). The sections discussing theoretical background close by identifying research gaps and describing research questions (section 2.5). Next, the design and general methods of the ActiFE study and EPOSA project are described in section 3. In the following sections (sections 4 through 6), three articles are presented, which are the core of this publication-based dissertation. Finally, in the last section (section 7), issues held in common by all three publications are addressed and discussed. Among others, these include the challenge of adequate assessment of physical activity, the interplay between the social and physical environment and individual characteristics, practical implementation of social integration and further future directions for research and practice.

2 Defining the Conceptual Space

"I wanted to be able to do something…with other people…I mean swimming they say is very good exercise…I love swimming but then that is an individual sort of thing and I wanted to do something with another group of people so that you had the social side of it." (Franco et al., 2015, p. 1271).

This exemplary statement from Franco and colleagues' (2015) meta-analysis summarized older people's perspectives on participation in physical activity. The number of participants who value interacting with peers as a main benefit of any kind of physical activity outnumbered those who value other aspects that were reported in conjunction with physical activity. Aside from considerations having to do with interacting with peers, the barriers for not being physical active in old age have been: (1) competing priorities (2) motivation and beliefs (apathy, maintaining habits) (3) no personal benefits of physical activity (i.e., improved physical or mental health), (4) physical limitations like pain or discomfort and (5) environmental barriers (Franco et al., 2015).

Overall, older adults believe in the potential of physical activity but face different barriers including the key barrier, which is a lack of social support. The following section will describe empirical findings regarding the current state of research on regular physical activity in old age. Thereby, I focus on (1) OA as an example of physical limitations by a chronic condition and (2) describe how environmental barriers disable people with OA. Finally, I address (3) the most important factor of the meta-analysis – social relations – by analyzing the effect of social isolation on physical activity.

2.1 Physical Activity in Old Age

One of the first physical activity guidelines was published in 1975 (American College of Sports Medicine, 1975) and physical activity has been repeatedly shown to be positively associated with numerous physiological and psychological benefits. The issue of regular physical activity has become very relevant regarding the general promotion of health in old age (Haskell et al., 2007; M. E. Nelson et al., 2007). However, only about a third of older adults behave according to these physical activity guidelines (F. Sun et al., 2013), with a great variation between such populations in different countries.

Physical activity appears to be an important determinant of health and mortality. A mortality reduction of 40 % was associated with regular time spent doing physical activity (30 minutes 6 days a week), regardless of whether the activity was light or moderate-to-vigorous. Increased physical activity was comparable with smoking cessation in reducing all-cause mortality (Holme & Anderssen, 2015). A current review by Hupin and colleagues (2015) found that physical activity, even at levels below the current recommendation of 150 minutes of moderate-to-vigorous physical activity per week reduced mortality by 22% in older adults. Further increase in physical activity improved these beneficial effects in a linear fashion.

An inactive and sedentary lifestyle is associated with increased incidence of chronic conditions, including diabetes, obesity, cancer, heart disease, depressiveness, and OA (Bassey, 2000). For many of the conditions considered, an active lifestyle reduces the incidences and the consequences of diseases (coping, chances of recovery) (F. W. Booth, Roberts, & Laye, 2012; Stehr & von Lengerke, 2012).

Physical activity is associated not only with lower morbidity and mortality, but also with lower incidences of disability. This is especially an issue in older ages, as physical activity steadily declines and the probability of disability rises. Higher physical activity levels have been shown to be associated with lower incidence of disabilities (Boyle, Buchman, Wilson, Bienias, & Bennett, 2007) that present major limitations in everyday life (Verbrugge & Jette, 1994). After three years, disability incidences for older physically active persons in comparison to sedentary individuals were found to be lower for "activities of daily living" (i.e., bathing, eating, homemaking) and for "instrumental activities of daily living" (i.e., managing money, using the telephone) (Balzi et al., 2010). A meta-analysis provided evidence that being physically active prevents and slows down the process of disablement in aging or diseased populations (Tak, Kuiper, Chorus, & Hopman-Rock, 2013).

From a lifespan perspective, it has been found that the earlier a person establishes a physically active lifestyle, the better. Being physically active throughout adulthood was associated with a smaller decline in physical performance as well as with lower incidences of mobility disability and premature death in comparison with those who had been less active during their adult life (Stenholm et al., 2016). However, starting to be physically active even late in life might postpone diseases (Hamer, Lavoie, & Bacon, 2014). Another longitudinal study followed middle-aged men for 35 years and found that increased physical activity in middle age reduces mortality to the same level as seen among men with constantly high physical activity (Byberg, 2010). After 10 years, the mortality rate of men who had increased their physical activity and men who were at an unchanged high level did not differ. This reduction in mortality is comparable with that associated with smoking cessation.

Up to date, global physical activity prevalences for whole populations are available, but are missing for older adults and for older adults with a chronic condition. Worldwide, we observe a greatly unequal distribution of physical activity across countries. The 2002 Eurobarometer study identified low prevalence of sufficient physical activity (23%) in Sweden and reported one of the highest prevalences of physical activity in Germany (40%) (Sjöström, Oja, Hagströmer, Smith, & Bauman, 2006). Using the same instrument (the International Physical Activity Questionnaire (IPAQ)) in large-scale representative populations, Bauman and colleagues (2009) came to an even greater spread of physical activity prevalences worldwide (Guthold, Ono, Strong, Chatterji, & Morabia, 2008). Prevalence of "high physical activity" varied from 21% in Japan to 63% in New Zealand (Bauman et al., 2009). In order not only to monitor but also to explain these variations, Dumith and colleagues (2011) pooled physical activity self-reports of 51 countries worldwide, which yielded the largest international estimate of physical inactivity so far. According to this, prevalences of physical activity were lowest in wealthier countries (defined by the Human Development Index).

2.2 Physical Limitations and Physical Activity

Older adults with arthritis face great restrictions in daily life and in the ability to be physically active. Arthritis (and its most prevalent form, osteoarthritis (OA)) is the most common musculoskeletal condition and is a major cause of disability in older populations around the globe (World Health Organisation, 2003). It is estimated that 40% of the population aged over 65 years is affected by knee or hip symptomatic OA (Neogi & Zhang, 2013). OA is a degenerative disease that affects the structures within the affected joint and is accompanied by stiffness and pain. At this time, there is no treatment that can prevent or cure OA. One major component of OA is pain in the affected joint. Approximately 27% of older adults reported that they suffer from painful joints on most days or every day (Crombie et al. 2004).

For a long time, experts advised people with OA to limit physical activity. The influence of physical activity on the development of OA in weight-bearing joints like the knee was unclear for a long time. Today, research has turned away from advising sedentary behavior. Based on available evidence (Urquhart et al., 2011), older adults should not be afraid of wear-and-tear, but, on the contrary, participate in regular physical activity. There is clinical consent that patients with OA can continue to engage in regular physical activity and exercise as long as the activity does not cause pain (Vignon et al., 2006). A systemic review concluded that physical activity is beneficial, rather than detrimental to joint health (Urquhart et al., 2011).

However, many older adults are still afraid that physical activity will worsen their condition and cause pain (Esser & Bailey, 2011; Woolf & Pfleger, 2003). "Physical deconditioning" and fatigue have been identified as two of eight dimensions (based on concept mapping) that are most burdensome for individuals with OA (Busija, Buchbinder, & Osborne, 2013). Older adults with OA reported being tired, felt a loss of energy, lost fitness, and experienced a deterioration of their general physical condition. This, in turn, leads to obesity and decreased muscle strength arising from decreased physical activity.

A meta-analysis confirmed the hypothesis that avoiding activities leads to muscle weakness and subsequent activity limitations in patients with knee OA (Holla et al., 2014). Pain, pain management and the consequences of persisting pain were found to be major burdens and resulted in reduced activities (Busija et al., 2013; Hsu, Tsai, Lin, & Liu, 2015). Pain medication is the most common strategy used for pain relief. However, pain medication was associated with the use of even more medication to cope with its side effects and led to even more exhaustion (W. Zhang, Nuki, et al., 2010).

The American College of Rheumatology rated physical activity as a first-line non-pharmacological treatment in arthritis management programs for patients with OA (Hochberg et al., 2012; Shih, Hootman, Kruger, & Helmick, 2006). This is in line with a recent review of guidelines and recommendations for the management of OA. The authors of that review found a broad agreement for the beneficial effect of low-intensity exercise for knee and hip OA in 12 of 15 recommendations (A. E. Nelson, Allen, Golightly, Goode, & Jordan, 2014). However, most persons with OA are still inactive. About half of the patients or participants with OA are insufficiently physically active (J. Lee et al., 2013) and only a minority of 12 % meets the official physical activity guideline (Liu et al., 2016). Up to now, contextual factors have been understudied. A different health care system might alter the burden of OA, or specific weather conditions might have a different impact on pain sensitivity and joint pain (Timmermans et al., 2014) as well as on physical activity levels (article 2).

2.3 Person-Environment (P-E) Fit

As they age, older adults may experience a reduction in functional capacities such as walking, hearing, seeing, and cognition. This makes them more vulnerable to a variety of different contextual conditions. Social networks and neighborhood characteristics may change substantially as adults age in in their own home and community. Their social participation and independence may be enhanced or limited as their surrounding contexts are modified.

The problem with a purely individualistic approach, focusing on individual risk factors and individual health behavior is that it might result in a narrow range of recommended interventions, since they would solely focus on individual behavior. In her book "Social Epidemiology", Berkman (2015) concluded that the problem with an exclusively individualistic approach is that even after completely successful interventions, new people would enter the population at-risk. This is because nothing has been done in the community to change the forces that caused the problem in the first place.

Societal factors like social integration and cohesion influence health (Chuang, Chuang, & Yang, 2013). They form – in Émile Durkheim's words – a social reality *sui generis* that is unique to itself and not reducible to the parts of which it is composed, i.e., the single individuals. Émile Durkheim analysed suicides not purely in terms of psychology and individual circumstances but conceptualized suicide rates as a social product (Durkheim, 1963). It seems likely that much of the disease burdens of modern societies reflect social and economic circumstances that vary between societies. It is likely that diseases can in parts be considered to be as much a social product such as suicides can (Jong-wook, 2005).

Wilkinson has shown that cohesive and socially integrated societies tend to experience better health outcomes compared to less integrated societies (Wilkinson, 1996). Neighborhood social cohesion represents one central aspect of the social environment of a neighborhood that has the potential to influence physical activity. Social cohesion refers to two interrelated features of society: (1) the absence of latent social conflict and (2) the presence of strong social bonds that are often measured by levels of trust and norms of reciprocity (Lisa F. Berkman et al., 2015).

In summary, social forces frame and influence a person's actual behavior in a given situation. At the same time, a person might consider features of the environment in different ways (avoiding, adapting, etc.) depending on the individual's abilities or limitations.

Physical activity might therefore be a result of individual strains and contextual factors. In order to illustrate the interaction of individual and environmental factors in relation to physical activity, I summarize the current literature (M. L. Booth, Owen, Bauman, Clavisi, & Leslie, 2000; McKee, Kearney, & Kenny, 2015; McMurdo et al., 2012) and extract major dimensions of it that are discussed in the current dissertation. Figure 1 shows that individual physical activity is shaped by complex interactions between the person and the environment.

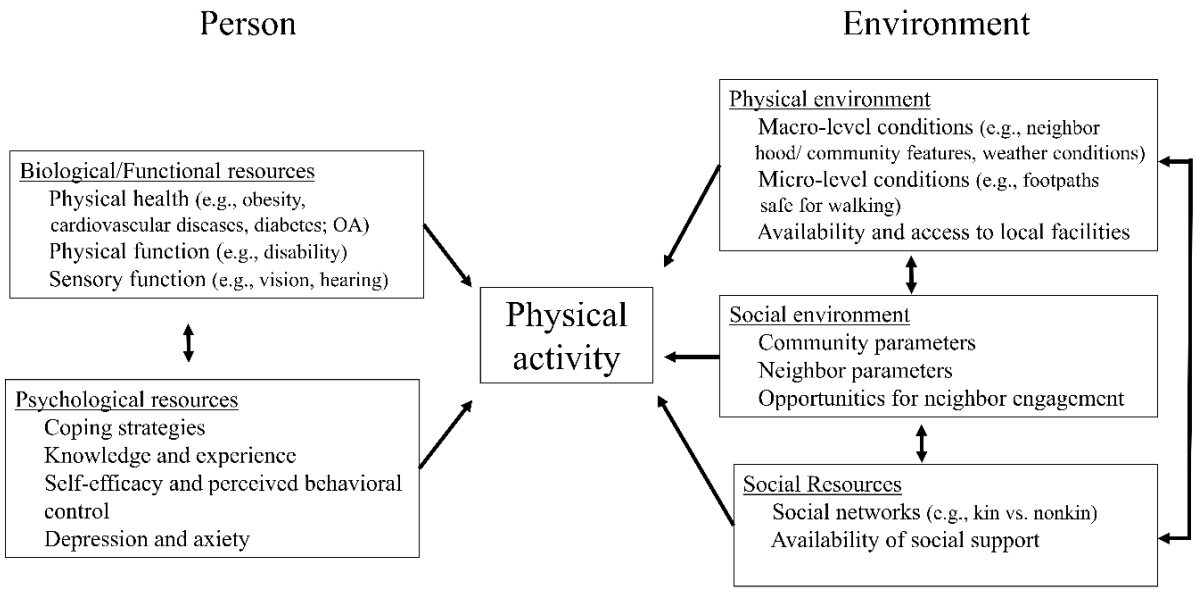


Figure 1. Associations of Physical Activity With Individual and Environmental Factors

One conceptual framework that can be applied to explain physical activity as a result of the environmental context is the Person-Environment (P-E) fit model (Lawton & Nahemow, 1973; Scheidt & Norris-Baker, 2003; Sugiyama, Thompson, & Alves, 2009). Lawton's P–E fit model suggests that human behavior is influenced by the interaction between individual competence (i.e., functional, biological, cognitive, social and behavioral skills and abilities) and the demands (or environmental pressure) of the social and physical environment. By applying this conceptual framework, it can be shown that physical-environmental barriers and a lack of social embeddedness in the environment are not necessarily problems per se. Rather, they cause different magnitudes of P–E fit problems, depending on each person's functional and coping capacity. The unbalance between the individual and the environment might be compensated for either by modifying the environment or altering personal factors (i.e., behavior change).

Lawton (1977) suggested a broad understanding of the term "environment", such that it includes housing, neighborhoods, out-of-home areas, and transportation. A broad understanding of the environment also includes a person's interactions with technology (Wahl, Iwarsson, & Oswald, 2012) and with other people, forming various social networks and relations (Clarke & Nieuwenhuijsen, 2009). Depending on the balance between a person's functional ability and environmental factors, those environmental factors can constrain or encourage physical activity. This framework seems to me particularly appropriate for older adults because great diversity exists within this population in terms of health and functional status, as well as a general decline in the capability to adapt to changing environments. Derived from this model, the environmental docility hypothesis (Lawton, 1986) suggests that the less competent the individual, the greater the impact of environmental factors on that individual. Functional decline mostly results in increased P-E fit problems (Iwarsson, 2005).

2.3.1 Effects of the Physical Environment on Older Adults' Physical Activity

Functional limitations – such as OA – in old age might cause increased difficulties with overcoming barriers inhibiting a physically active lifestyle. Older adults with OA may have lower competence than those without the condition, and may therefore be more vulnerable to environmental demands (Iwarsson & Stahl, 2003). A response to functional loss in later life will require either reduction of demands from the environment or increased the use of resources in that environment. Environmental influences and factors that can help to cope with OA include the climate, accessibility and appropriateness of (health care) services and facilities, socio-economic conditions, pedestrian infrastructure, community life, social network and support, level of urbanism, and exposure to natural settings, among others.

A meta-analysis of European studies conducted in a younger population (18 to 65 years) indicated convincing evidence for the effect of physical environmental factors (walkability, accessibility to shops/services/work, safety from traffic, etc.) on physical activity levels (Van Holle et al., 2012). A review by Moran and colleagues (2014) identified environmental factors (i.e., access to facilities, green open spaces and rest areas) that were especially relevant to older adults' physical activity behavior. These factors tended to emerge more frequently in studies that combined interviews with qualitative methods. However, these findings were limited because they extracted factors based on a comparison of single-country studies and did not explain international physical activity variations.

2.3.2 Effects of the Social Environment on Older Adults' Physical Activity

The social environment and other dimensions of the environment such as its physical, organizational, and cultural characteristics are deeply interwoven into reality (e.g., Lawton, 1977, 1982). Social institutions shape the resources available to the individual and hence a person's behavioral and emotional responses to the related aspects of their environment. For example, older adults' attachment to an environment is not only a function of familiarity with their physical surroundings, but also of the social relations available to them, which are created by the interpersonal behavior of others in their particular surroundings. By assessing actual ties between network members, one can empirically test whether community exists and whether that community is defined based on neighborhood, kinship, friendship, institutional affiliation, or other characteristics. A deficiency of these relations – which is social isolation – has continually been reported as harmful to health and has been associated with mortality in epidemiological research since the late 1970s and 1980s (Brummett et al., 2001). However, our understanding of how and why social isolation is risky for health still remains quite limited (House, 2001). Recently, more attention has been paid to the broader context in which physical activity occurs. "Though influences of individual-level factors on physical activity is well-studied, research on social environmental influences is understudied but growing" (McNeill, Kreuter, & Subramanian, 2006, p. 1019). Thus, it is important to understand the contribution of the social-interpersonal environment to older adults' physical activity.

One of the earliest theoretical frameworks that focused on interpersonal relationships was proposed by Kahn and Antonucci (1980). Their "convoy model" takes a life-course perspective and presents a framework for understanding how social networks are formed and developed over time. The convoy model proposes that from childhood to old age people move through life together with other people (Antonucci, Ajrouch, & Birditt, 2014; Antonucci & Akiyama, 1987). This personal social network accompanies a person over time and across different contexts, serving a number of functions (e.g., emotional, and instrumental support). A person's "convoy" is organized in a hierarchical fashion, with family members and friends being among those who are most often asked for assistance. Neighbors

and other people with whom a person interacts on a regular basis follow one level below in their importance.

Using this typology, individuals' social relationship patterns can be classified into different types based on how they arrange their network ties. Although small variations exist across populations, studies indicate both qualitatively and quantitatively that individuals can be consistently classified into four basic network types based on their social relationship characteristics (Fiori, Antonucci, & Cortina, 2006; Li & Zhang, 2015; Litwin, 1998, 2001; Litwin & Shiovitz-Ezra, 2006). Individuals with a diverse network type maintain a broad range of supportive relations with family, friends, and neighbors, and frequently participate in various social activities. In comparison with other network types, these networks generate more resources that can be accessed and potentially mobilized. In other words, such networks are richer in social capital than other types of networks (Lin, 2003). Those with a friend-focused network type have frequent interactions with friends or neighbors, but fewer interactions with family members. In contrast, people with a family-focused network type arrange their social life exclusively around families and have few active relationships with other people. Finally, those with a restricted network type have limited engagement in all kinds of social relations. Older adults with restricted networks have been found to be more physically inactive in comparison with people with the other three network types (Shiovitz-Ezra & Litwin, 2012).

2.4 Social Relations and Health

How do the network structures interact with health behavior? Berkman and colleagues (2010) have proposed a conceptual framework (see Figure 2) for how social networks are linked to health (Berkman, Glass, Brissette, & Seeman, 2000).

In short, social relations are embedded in a wider macro-structural context that is dynamically linked to individual psycho-biological processes. The model points out that the social network structure (mezzo-level) is conditioned by the social and cultural context to which one belongs. Network structures in turn provide and determine social support, social provision and material goods as well as promote social attachment. Behavioral processes are possible pathways besides physiological stress responses, and psychological states (self-esteem, self-efficacy) that link the individual's health to social mechanisms.

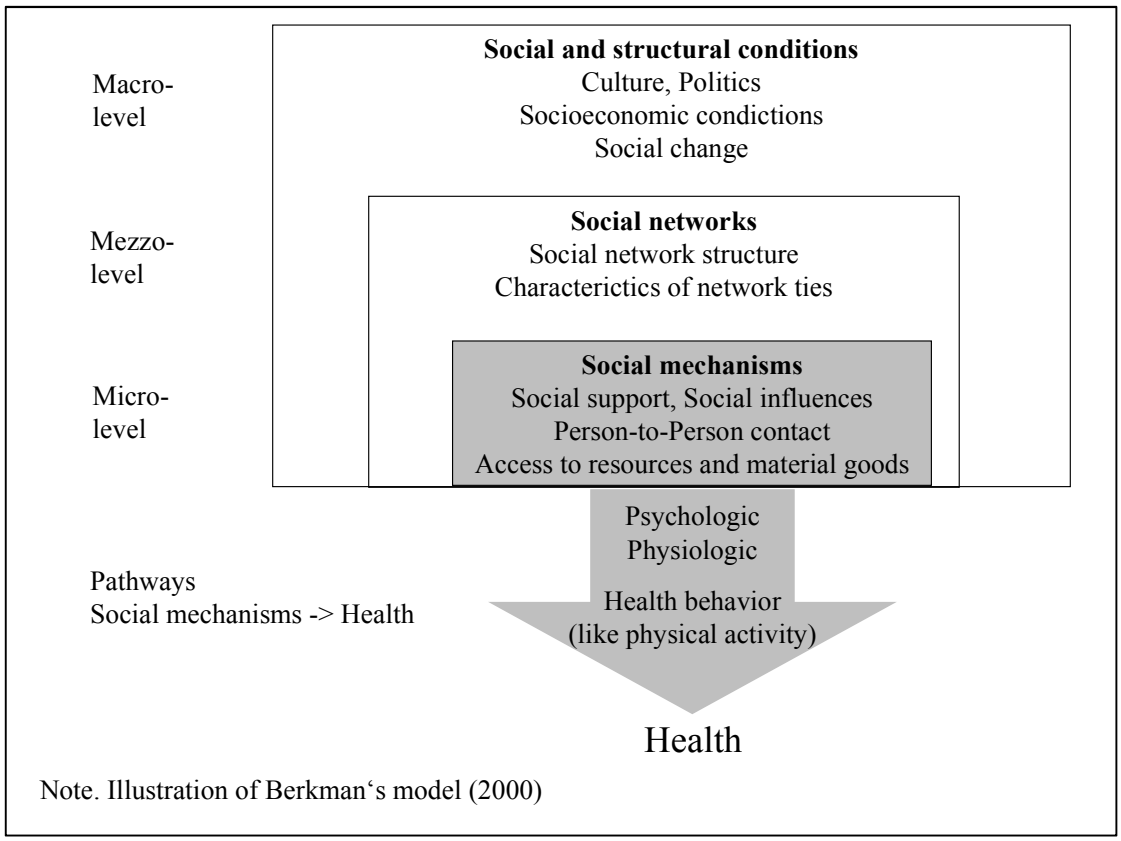


Figure 2. Berkman's Model

My interest in this thesis is focused on the micro level dealing with social isolation. This level includes social support, social influences, social engagement, person-to-person contact and access to resources and material goods.

In a wider understanding of the environmental component of the P-E fit model, the social environment could be operationalized as a component of the environment (Wahl & Oswald, 2010). Social relationships play an important role in the context of health (Newman, 2013) and are interconnected with a person's ability to adapt to an altered environment. People who perceive themselves to be socially supported have consistently been found to be in better physical and mental health than their socially isolated counterparts (Cornwell & Waite, 2009). Accordingly, social isolation can be accordingly described primarily as 1) a response to structural barriers (environment) that deny the individual the ability to participate fully in the benefits of social relations and 2) a result of limited resources to maintain or regenerate social relationships.

This thesis project will not be able to grasp the total complexity of the social environment (see section 2.3.2). It will focus on social isolation and analyze how social isolation is linked to physical activity. Applying the typology of the convoy model, older people embedded in more resourceful network types remained more likely to engage in physical activity in old age (Shiovitz-Ezra & Litwin, 2012).

2.5 Gaps in Previous Research and Research Questions

The literature review in the last sections pointed out some limitations of previous studies. In this section, certain shortcomings of previous research will be identified and research questions for the articles will be derived. The shortcomings of previous research include (1) applying the same assessment instrument for OA and physical activity across countries, (2) examining the role of weather conditions on physical activity in older adults with OA and (3) distinguishing physical activity locations.

2.5.1 Research Gap: Functional Limitations and Physical Activity

There is already a large body of research, analyzing the association between OA and physical activity (see section 2.2). A review involving participants with hip or knee OA found that between 13% (high quality studies) and 41% (low quality studies) of all knee OA participants meet the recommendation of 150 minutes of moderate-to-vigorous physical activity per week, while 58% (low quality studies) of all hip OA participants did so (Wallis, Webster, Levinger, & Taylor, 2013).

Despite this remarkable evidence, single studies are difficult to compare because they have referred to different OA and physical activity operationalization. Although there is a general agreement on the definition of OA (Altman et al., 1986), a variety of standards for diagnosis is still observed (see section 3.2). Prevalences range from 66 to 72%, depending on whether radiographic, self-reported and clinical OA is used which makes any comparison between single studies even more difficult (Parsons et al., 2015).

Furthermore, there is no consensus about the most suitable physical activity instrument. A simple example can be observed comparing two studies that evaluated physical activity in the European Union in similar time periods (Martinez-Gonzalez et al., 2001; Sjöström et al., 2006). These two studies used different instruments: One included only leisure–time physical activity, while the other considered its four domains (leisure, transportation, occupation and household). The most active countries in one study were the least active in the other study. This suggests that even physical activity prevalence estimates in the same country can vary markedly depending on the instrument under consideration (Dumith et al., 2011). That enables one to observe a general trend of lower physical activity among persons with OA, but makes it difficult or impossible to compare the single study sides to account for country-related factors.

Research questions of article 1

1. Are older adults with OA insufficiently physically active?
2. Does the physical activity level in older adults with OA depend on the country of residence?

2.5.2 Research Gap: Meteorological Conditions and Physical Activity

In general, the physical environment (with weather conditions being one factor) plays a crucial role in physical activity levels (Chan & Ryan, 2009; Tucker & Gilliland, 2007; Witham et al., 2014). Higher temperatures and lower humidity have been associated with more physical activity among older adults. However, there is limited literature on the interrelation of weather conditions and physical activity levels in older adults with OA, although older people with OA have reported exacerbated disease symptoms like pain level depending on the current weather. Knowledge about the effects of meteorological conditions on physical activity levels of community-dwelling older adults with OA are rare. Up to now, one intervention study by Feinglass and colleagues (2011), found that very hot and very cold temperatures were associated with physical inactivity in older adults with OA. Another study showed that higher outdoor temperature and younger age were associated with increased physical activity levels in participants with knee OA (Robbins, Jones, Birmingham, & Maly, 2013). However, the results of both studies could only be considered preliminary. Participants volunteered for enrollment in the study and received either an intervention aiming to increase physical activity (Feinglass et al., 2011) or the study was comprised of a rather small sample of 40 persons (Robbins et al., 2013).

The EPOSA project enables us to observe physical activity levels in the general population, including older adults with OA, in combination with meteorological information from local weather stations. Furthermore, the physical activity questionnaire allowed us to distinguish between several outdoor activities: walking, cycling, and gardening.

Research questions of article 2

1) Which weather condition has the greatest effect on older adults' physical activity?

2) Do persons with OA respond differently to certain weather conditions compared to participants without the condition?

2.5.3 Research Gap: Social Resources and Physical Activity

There is already a large body of research about the association of social isolation and social disconnectedness with poor health and mortality among older adults (Cornwell & Waite, 2009; Deindl, Brandt, & Hank, 2016; House, 2001). Theoretical models like the Berkman model (see section 2.4) and empirical evidence support the link between poor social network compositions and low levels of physical activity (Litwin, 2003; Shiovitz-Ezra & Litwin, 2012). The greater the network density, the higher the physical activity levels (Legh-Jones & Moore, 2012). These studies either assessed individual ties by using a social network position generator or differentiated – by applying a cluster analysis – up to five different network types, with friend-focused networks being more beneficial to physical activity than family-focused networks (Legh-Jones & Moore, 2012).

A recent study of 36 older adults showed that most sedentary time occurred when time was spent alone or in one's own home (Leask, Harvey, Skelton, & Chastin, 2015). This raised the question of whether social isolation is connected in an important way to the location of physical activity in the general older population. In order to answer this question, the article combined objective accelerometer data with diary recordings. This makes the article novel because all of the aforementioned studies assessed self-reported physical activity measures that are prone to socially desirable response and did not take into account the location of physical activity. Differences between accelerometers and self-reported physical activity have also been associated with sociodemographic characteristics (Winckers et al., 2015), which in turn could be linked to certain network types. This raises the following questions addressed in the third article:

Research questions of article 3

1. Are socially isolated older adults less physically active?
2. What is the contribution of indoor and outdoor physical activity to the overall physical activity level?
3. Is social isolation from family differently associated with physical activity in comparison with social isolation from friends?

3 General Methods of the ActiFE Study and the EPOSA Project

The "**Acti**vity and **F**unction in the **E**lderly in Ulm" study (ActiFE) is a longitudinal cohort study that aims to assess physical activity using different methods (accelerometer, questionnaire, and a diary) and analyses its associations with different health-related parameters in a community based older population (Denkinger et al., 2010). After two years from the first assessment, the European Project on OsteoArthritis (EPOSA) data collection started with a randomly selected subsample of ActiFE. Participants were interviewed in six European countries (Germany, the Netherlands, Italy, Spain, Sweden, and the UK).

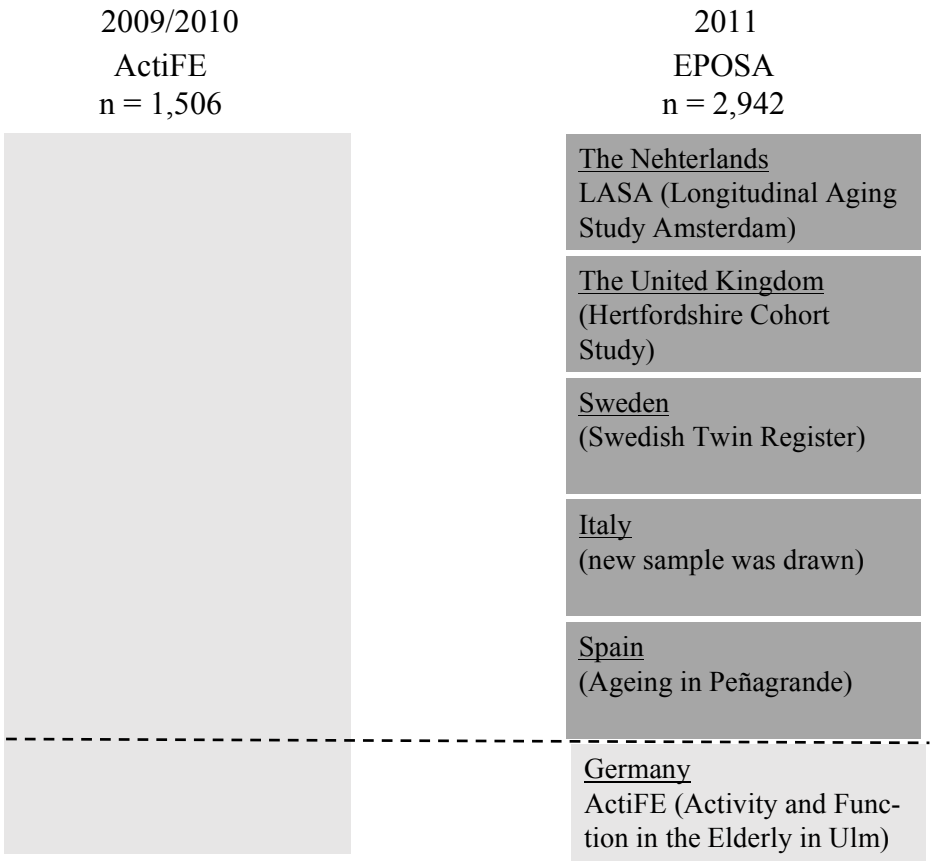


Figure 3. Visualization of the Study Design

A subsample of 407 people from the initial ActiFE study population participated and were re-interviewed after 1 year (van der Pas et al., 2013). The EPOSA study can be considered as a side-study with the aim to study the social burdens of osteoarthritis (OA) in an international comparison. The study aimed to explore "the personal and societal burden and its determinants of OA in the aging European population" (van der Pas et al., 2013, p. 2). Figure 3 provides an overview of the designs and topics of the two studies. Two articles are based on the EPOSA interviews (articles 1 and 2) and one article (article 3) shows results from the ActiFE study.

The ActiFE study recruited participants from the greater area of Ulm, Germany. The study was carried out by the Institute of Epidemiology and Medical Biometry and was scientifically supported and conducted by the Bethesda Geriatric Clinic, Ulm. The German cohort of the EPOSA study was organized accordingly.

3.1 Main Questionnaire Instruments

Established instruments served as basis for the development of the ActiFE and EPOSA questionnaire. Great emphasis was placed on the selection of assessments that are comparable with previous questionnaires from each study cohort across all six countries in the development process of the EPOSA study. Social participation, social networks, physical activity, functional limitations, physical function, depression, body function, and well-being were some of the central measurement instruments of the EPOSA study (van der Pas et al., 2013). Two measurements will be described in deatil – OA and physical activity – since they are central topics in this dissertation.

3.2 Osteoarthritis Assessment

The core of the EPOSA study consisted of the clinical OA examination, which followed the guidelines set by the American College of Rheumatology for knee OA (Altman et al., 1986; Jiang et al., 2012; W. Zhang, Doherty, et al., 2010). A lack of uniformity in identifying cases of OA in epidemiological studies made it difficult to draw reliable conclusions about temporal and geographic trends in OA morbidity (Busija et al., 2010). There are only a few studies that present prevalence estimates for OA, namely the National Health and Nutrition Examination Survey (Davis, Ettinger, & Neuhaus, 1990), the Framingham Osteoarthritis Study (Felson et al., 1987), The Johnston County Osteoarthritis Project (Jordan et al., 1997), OsteoArthritis Initiative (Nevit, Felson, & Lester, 2006) and the Beijing Osteoarthritis Study (Y. Zhang et al., 2001). Among these, the EPOSA study is the first of its kind, making it possible to compare country specific prevalence rates and factors that are associated with OA by applying the same OA definition across all countries.

Generally, OA can be assessed with three different methods: (1) self-reports, (2) clinical/symptomatic OA and (3) radiographic measures such as the Kellgren and Lawrence scale (K-L). Radiographic measures have been used as the field's standard for assessing of OA and are still the most widely used criteria. However, many people with radiographic OA may be free of symptoms and many of those with symptomatic OA may have normal radiographs (Spector & Hochberg, 1994; Szoeke et al., 2008). This observation has led clinical and public health authorities to incorporate some measurement of joint symptoms (mainly pain) into the definition of OA, since the presence of symptoms is important for everyday living. Symptomatic OA prevalence estimates are now lower since they are now based on radiographs in combination with pain, aching or stiffness in the joint (Neogi & Zhang, 2013). A systematic review has reported that radiographic case definitions of OA present the highest prevalence rates of OA in each joint (hand, knee and hip) compared to self-reports or clinical OA definitions (Pereira et al., 2011). Comparable results have also been reported for a subsample of the EPOSA study, namely the Hertfordshire cohort study. Again, radiographic OA outscored the other two assessment methods with a modest agreement between each other (Parsons et al., 2015).

The first and the second article used the clinical OA definition, because symptomatic OA might affect everyday living most and might have the greatest impact on physical activity. In brief, the diagnosis of knee OA was based both on self-reports and clinical examination. For instance, a person was classified as having clinical knee OA if he or she reported pain in the knee using the "Western Ontario and McMaster University Osteoarthritis Index" (Bellamy, Buchanan, Goldsmith, Campbell, & Stitt, 1988) pain scale. Furthermore, three of the following criteria had to be met: being 50 years or older, having morning stiffness lasting longer than 30 minutes, having crepitus on active motion in at least one side, having bony tenderness, having bony enlargement or having no palpable warmth of synovium in both knees

3.3 Physical Activity Assessment

Physical activity was the main variable in all articles of the dissertation. It is a multidimensional construct that no single method can capture in all its subcomponents (Warren et al., 2010). Physical activity has been defined as "any bodily movement produced by skeletal muscles that result in caloric expenditure" (Caspersen, Powell, & Christenson, 1985, p. 128). Four dimensions are of major interest when describing physical activity: (1) frequency, (2) duration, (3) intensity and (4) type.

Physical activity is sensitive to long-term, environmental and short-term influences, since day-to-day variation and seasonal variability were observed (Sartini et al., 2015). Physical activity takes place in different domains. Usually they are defined as the household or domestic domain, the occupational domain, the transportation domain and the leisure time domain (Warren et al., 2010). Everyday physical activity – the variable of primary interest in the ActiFE study and the EPOSA project – was intended to capture all daily movements (Bellew, Bauman, Martin, Bull, & Matsudo, 2011).

Basically, data about physical activity can be classified according to two general assessment methods: self-reports and objective measurements. Self-reports are comprised of questionnaires, diaries, logs and recalls, whereas objective measurements cover motion sensors like accelerometers and pedometers, heart rate monitoring, doubly labeled water and direct observations. These assessment methods vary in terms of reliability, the effort required for application, validity and responsiveness, financial costs, variables measured, and the extent of standardization. Warren and colleagues (2010) reported that the lower the cost, the lower the accuracy of an assessment method.

Self-reported physical activity is the most common, cheapest and most feasible method, especially in large-scale studies. Various approaches for assessing self-reported physical activity are available. Several measures have been proposed, from Visual Analog Scales to single-item and multi-item questionnaires, with longer versions showing a better construct validity. A further advantage of self-reports is that questionnaires can distinguish between different types and domains of physical activity, which most objective measures cannot. However, there are numerous limitations related to self-reported methods. Physical activity questionnaires that have been designed and validated in younger populations, might be inappropriate for the older adults (Washburn, 2000). Social desirability and recalling biases might lead to over-reporting physical activity, which could especially be an issue in an older population since recalling behavior is a complex cognitive task (Adams et al., 2005; Baranowski, 1988; Sallis & Saelens, 2000). Biased estimations are potentially encountered in terms of frequency, duration and intensity of the behavior, as the reliability and validity of questionnaires are improvable (Helmerhorst, Brage, Warren, Besson, & Ekelund, 2012).

The quality of objective measures largely depends on the technique used (Warren et al., 2010). Pedometers are simple and cheap devices. However, they only measure the number of steps taken. A review by Tudor-Locke and colleagues (2002) considered pedometers to provide a valid measurement of physical activity that was moderately correlated with other measures of energy expenditure.

Nevertheless, pedometers do not assess physical activity that does not involve steps. Accelerometers are more cost-intensive, but offer more possibilities because they assess acceleration (mostly) in three dimensions and can also objectively measure the intensity level of activities. Another advantage is that accelerometers assess low intensity physical activity in everyday life (e.g., going to the toilet at night) which is difficult to assess in questionnaires. Nevertheless, most accelerometers do not capture water-based activities or upper body movements and underestimate the energy expenditure of moving up-hill or carrying heavy loads (Warren et al., 2010). Overall, all objective measures of physical activity are not affected by self-report biases or social desirability. However, they cannot distinguish well between different types of physical activity and do not assess the domains in which physical activity occurs. Furthermore, compliance is often lower in comparison with self-report measures since their application is more complex.

Self-reported and objectively assessed physical activity correlated in most studies to a moderate degree. For example, a review reported a median correlation between pedometer and self-reported physical activity of r = .3 and correlations between accelerometer and questionnaires mostly ranged from r = .3 to r = .5 (e.g., Dyrstad, Hansen, Holme, & Anderssen, 2014; Segura-Jimenez et al., 2014). Large epidemiological studies, such as the ongoing National Health and Nutrition Examination Survey, and a literature review documented self-reported physical activity to be over-reported when compared to accelerometer-assessed physical activity (Prince et al., 2008; Schuna, Johnson, & Tudor-Locke, 2013). Combining self-reported and objective measures seems to be promising for assessing physical activity, since it balances out the different advantages and disadvantages of each. The choice of the most appropriate method depends on the researcher's intention regarding what is to be measured, the purpose of the measurement, and a compromise between accuracy level and feasibility (Terwee, Bouwmeester, van Elsland, de Vet, & Dekker, 2011; Warren et al., 2010).

The ActiFE study assessed physical activity using a combination of methods: (1) self-reported physical activity was assessed using the LASA Physical Activity Questionnaire (LAPAQ). The LAPAQ examines the frequency and duration of different activities in the past two weeks. On the basis of these reports, the total time spent on physical activity can be calculated. The LAPAQ appeared to be a valid and reliable instrument for assessing physical activity in older people. It correlated well with a 7-day diary ($r = .68$, $p < .001$), and correlated moderately with the pedometer ($r = .56$, $p < .001$) (Stel et al., 2004). (2) A 7-day outdoor physical activity diary was applied and given to the participants. Among other things, this diary included a specific question about times leaving and returning home and the purpose of the outdoor activity undertaken. (3) These self-reports were combined with an accelerometer device, the activPAL^{TM} (PAL Technologies Ltd. Glasgow, UK). The device was attached to the right thigh and recorded physical activity up to a period of seven continuous days. The accelerometer and the outdoor physical activity diary provided contemporaneous measurements in order to allow these two measurements to be merged.

4 Physical Activity Among Older Adults With and Without OA (Article 1)

Herbolsheimer, F., Schaap, L. A., Edwards, M. H., Maggi, S., Otero, A., Timmermans, E. J., … Peter, R.; Eposa Study Group 2016

There is limited knowledge about the effect of environmental factors on the association between OA and physical activity in older adults. When researchers compare individual risk factors for this chronic condition, they mostly assume (explicitly or implicitly) that risk factors work exactly alike in different countries. Yet, the observation of significant global variation in physical activity in older adults (see section 2.1) gives rise to the question of whether the country matters. This implies that the physical and social environment facilitates or restricts physical activity in older adults with OA.

This article was based on cross-sectional data from the European Project on Osteoarthritis (EPOSA). A total of 2,551 participants from 6 European countries (Germany, Italy, The Netherlands, Spain, Sweden, and the UK) were included in the analyses. In accordance with the literature, participants with knee OA were less likely to follow physical activity recommendations and had poorer overall physical activity profiles than those without the condition (mean 62.9 vs. 81.5 minutes/day). Depending on the country of residence, the article showed that knee OA is associated differently with physical activity. Older adults with knee OA did not show different physical activity levels (compared to those without OA) in the Netherlands, while great differences were found in Germany, Spain and the UK.

These results raised a second question: Which physical activity (walking, cycling, gardening, sports) do people with knee OA omit? There was almost no difference for gardening and doing sports. The article pointed to less walking activity time (odds ratio 1.31) as a major source of overall lower physical activity levels among people with knee OA. Another interesting result was that in the Netherlands those with knee OA actually tend to cycle more than those without knee OA.

The Netherlands has expanded and developed its cycling infrastructure during the last decades. These results suggest that physical activity might be promoted by supportive physical environments.

5 The Influence of Weather Conditions on Outdoor Physical Activity (Article 2)

Timmermans, E. J, van der Pas, S., …, Herbolsheimer, F., Sánchez-Martinez, M., Siviero, P., Queipo, R., Schaap, L.A., Deeg, D. J., 2016

Up to now, researchers have collected evidence that physical activity levels are sensitive to weather changes (Chan & Ryan, 2009; Tucker & Gilliland, 2007; Witham et al., 2014). However, the impact of weather conditions could however work quite differently for persons with OA, since they often report that their disease symptoms are exacerbated by weather conditions (Dorleijn et al., 2014; Timmermans et al., 2014). Accordingly, this article examines the association between outdoor physical activity and weather conditions in older adults from six European countries and assesses whether outdoor physical activity and weather conditions are more strongly associated in older persons with OA than in those without the condition.

Again, data from the EPOSA project were applied. In this analysis, 2,439 participants aged 65-85 years were included. Weather information was gathered from local weather stations. According to the first article, participants with OA spent fewer minutes in physical activity than participants without OA. Higher temperature (B=1.52; $p < .001$) and lower relative humidity (B=-0.77; $p < .001$) were associated with more physical activity among older adults. Distinguishing participants with and without OA revealed that higher temperatures were associated more strongly with outdoor physical activity in participants without OA than in those with OA. With rising temperatures, older adults without OA spent more time walking outdoors than those with OA.

Older adults with OA are less affected by weather changes. This may result from overall lower physical activity levels in this group, since they might experience greater effort required to react to weather changes. Furthermore, low outdoor physical activity levels might also be affected by other environmental aspects such as the social and built environmental factors that were not considered (van der Pas et al., 2016). Overall, information about weather conditions and physical activity provides help designing interventions to overcome barriers posed by inclement weather that result in low levels of physical activity.

6 Social Isolation and Indoor and Outdoor Physical Activity (Article 3)

Herbolsheimer, F, Mosler, S & Peter, R.; and the ActiFE Ulm Study Group 2016

The third paper extended the perspective from the physical environment of older adults to aspects of their social environment. A lack of social relations, i.e., social isolation, has repeatedly been associated with poor health behaviors like reduced physical activity (section 2.3.2). A potential explanation of the mechanism active here has been proposed by Lisa Berkman's model (see section 2.4). However, it is still unclear which sources of social isolation are responsible for explaining daily physical activity patterns.

Data from the German ActiFE study (n=1,506) were used because they offer the possibility to analyze physical activity more precisely by using accelerometer data in combination with self-reported diary documentations. This enabled us to distinguish between (objective) indoor and outdoor physical activity.

Eighteen percent of all participants were considered socially isolated and on average engaged in 56 minutes less physical activity per week. This corresponds to 7 percent of daily physical activity. By differentiating the source of isolation, it was established that friends and neighbors seemed to play a crucial role in maintaining a physically active lifestyle, whereas social isolation from family played a negligible role. Isolation from friends and neighbors had the greatest effect on physical activity that occurred outside the house. Overall, the location of physical activity had a strong influence on the social isolation measures as well as on the overall statistical fit of the models. The outdoor model was acceptable (R^2 = .228), whereas all predictors in the indoor model only showed weak associations with indoor physical activity (R^2= .096). Indoor physical activity seemed to be a constant behavioral pattern that is less prone to change than outdoor physical activity. The diary allowed tracking the purpose of each outdoor activity. Compared to people who were not isolated, socially isolated older adults engaged in less outdoor physical activity that involved meeting people or visiting cultural events.

These findings suggest the need for a nuanced assessment of the non-kin network and a differentiated view of physical activity to understand how social isolation affects the everyday physical activity. Future research needs to highlight the benefits of outdoor physical activity in contrast to overall physical activity measures. Further directions for future research will be discussed in section 7.4.

7 General Discussion

The thesis is comprised of three peer-reviewed articles that bring together individual and environmental factors that explain low levels of physical activity in old age. Two thirds of all older adults in Germany do not follow the World Health Organization's recommendation of at least 150 minutes of moderate-intensity aerobic physical activity per week (Lampert, Mensink, & Müters, 2012; M. E. Nelson et al., 2007). Sociological and (social) epidemiological research has the important function of (1) determining factors associated with (low) levels of physical activity in old age and (2) explaining the circumstances that constitute barriers and facilitators for an active lifestyle in old age. This dissertation aims to add knowledge to both research topics. To address these topics, national and international cross-sectional data were analyzed elaborating on environmental factors that previous research found to be associated with physical activity among older adults. The theoretical background was provided by the Person - Environmental fit model in order to examine how (social and physical) environmental factors influence the behavior of individuals, while taking into consideration a person's ability to adapt to or change the environment.

The general discussion of this thesis addresses broad issues active in all its articles, such as the interplay between the physical environment and physical activity, the social context and physical activity, and adequate assessment of physical activity. After providing a short summary of all articles (section 7.1), the results will be integrated into the broader context of research on social and environmental influences on physical activity (section 7.2). Section 7.3 will describe general strengths and limitations of the ActiFE study and EPOSA project and section 7.4 will give an outlook on future research directions – like preparing country-specific recommendations considering norms, social

structures and possibilities to be physically active. The thesis closes with a discussion of practical implications for public health authorities (section 7.5) before finishing with closing remarks (section 7.6).

7.1 Summary of Studies

All of the articles belonging to this thesis integrate data from participants in the ActiFE study and the EPOSA project, the latter of which represents a subsample of the initial ActiFE population of adults aged 65 and older. Article 1 provides an in-depth analysis of physical activity patterns across countries, comparing older adults with and without osteoarthritis (OA) in order to extract country-specific differences. Article 2 explains the contribution of meteorological factors on physical activity in older adults with OA in comparison with individuals without that condition. Article 3 examines the social environment and its association with physical activity in the ActiFE study.

7.2 Integration of Study Results into the Broader Context

A progressive decline in physical activity with increasing age may be the most consistent finding in epidemiological research about physical activity (K. Sun et al., 2014). Beside age related changes, researchers have identified other factors that are associated with physical activity variations among older adults. This dissertation project showed associations between lower physical activity and the socioeconomic status (education: all articles), functional resources (disability, multimorbidity and OA: article 1), psychological resources (depressiveness: article 3), social resources (social isolation from friends and neighbors: article 3), and meteorological conditions (maximum temperature: article 2). Applying the Person-Environment fit framework, functional resources and psychological resources can be described as the person's perspective, whereas social/interpersonal resources and meteorological conditions can be described as the environmental perspective.

When analyzing physical activity in old age, our understanding of personal resources becomes increasingly important, as the likelihood of suffering from one or more chronic conditions, disabilities or functional limitations rise. When assessing barriers that older adults hold responsible for lower physical activity or factors that keep them away from a physically active lifestyle, 87% named at least one barrier to participating in exercise (O'Neill & Reid, 1991). The most common reasons given by older adults for not participating in physical activity was ill-health, pain and injury (M. L. Booth et al., 2000; Schutzer & Graves, 2004). However, limitations in everyday physical activity might depend on the interaction of the person with the environment. Physical and social environments that are age-friendly can make the difference between a physically active and an inactive lifestyle.

First, I will go into detail about an individual characteristic that is important for explaining everyday physical activity levels: frailty. Lipsitz and Goldberger (1992) observed the tendency to less complex patterns (such as heart rate variability) during aging and disease and formulated the "loss of complexity hypothesis" (LOC). LOC has been hypothesized to be an indicator of the transition from normal aging to frailty (Sleimen-Malkoun, Temprado, & Hong, 2014). In the course of the ActiFE study and EPOSA project, I contributed to several articles that considered various aspects of the frailty syndrome in conjunction with OA (Edwards et al., 2014; Timmermans et al., 2014, 2015, van der Pas et al., 2013, 2016; van Schoor et al., 2016). OA represents a central limitation in functional resources and serves as a key aspect of this dissertation.

The EPOSA group showed that there is a higher probability of being frail or prefrail among persons with OA (Castell et al., 2015), and this increased with the number of affected joints. Three of the five criteria of frailty defined by Fried and colleagues (2001) (i.e. physical weakness, slowness and physical activity) depict a more or less physiological measure of "fitness", which can be distinguished into physical performance (Guralnik, Ferrucci, Simonsick, Salive, & Wallace, 1995) and physical activity. Both of these aspects were analyzed in the EPOSA project. Restrictions in physical performance were observed in older adults with OA in the hip, hand or knee (Edwards et al., 2014) and so were lower levels of physical activity (article 1). People with knee OA were less physically active and had a lower probability of meeting recommended physical activity levels in comparison with older

adults without the condition. In addition, article 1 shows that individual characteristics, such as higher BMI and increased comorbidities were associated with lower physical activity in older adults with knee OA. A recent review that identified characteristics associated with the relation of physical activity and hip or knee OA had similar results (Stubbs, Hurley, & Smith, 2015). Apart from individual characteristics, the review showed that for both, a better social functioning and physical environment (higher outdoor temperature) were positively associated with physical activity.

This leads directly to the question: How do characteristics of physical and social environments explain variation in everyday physical activity among older adults? In the first article, differences in physical activity levels between participants from different countries remained, even after adjusting for individual factors. Macintyre, Maciver and Sooman (1993) asked "Should we be focusing on places or people?". This raised the question of whether the environment has an independent effect on health and health behavior, such as physical activity. When it comes to facilitators for a physically active lifestyle in the near future, most older adults named environmental context ("Facilities closer to my home") and social factors ("presence of people to assist me if I need it", "my friends joining me") (O'Neill & Reid, 1991). Similar results have been reported by a literature review of physical activity among the oldest group (80 years or older) (Baert, Gorus, Mets, Geerts, & Bautmans, 2011). These two aspects (social and physical environments) mirror the two foci of this thesis.

The focus of the dissertation was to picture a lack of social resources in terms of social isolation. Low physical activity has been associated with poor social networks (Crombie et al., 2004; Stathi et al., 2012), lack of company (Baert et al., 2011; M. L. Booth et al., 2000), living alone (Victor, Scambler, Bond, & Bowling, 2000) and loneliness (Hawkley, Thisted, & Cacioppo, 2009; McKee et al., 2015). Article 3 showed that social isolation was associated with lower physical activity. Little or no contact with friends and neighbors was far more important than limited contact with family. The different benefits of these two social resources have also been shown in other studies, which compared the effects of the family-focused network type and the friend-focused network type. Using different network types (friend-centered, family-centered, restricted, diverse, congregant), older adults with friend-centered types engaged in more physical activity than those with family-centered types (Shiovitz-Ezra & Litwin,

2012). The friend-focused network type was also more beneficial to both physical (Li & Zhang, 2015; Litwin, 1998) and psychological well-being (Fiori, Smith, & Antonucci, 2007).

The importance of friendship ties late in life rests in the fact that they are entered into voluntarily and are maintained if they continue to provide benefits (Litwin, 2007). Social isolation is frequently associated with negative outcomes (Iliffe et al., 2007), and it might impact daily life differently depending on the source of isolation. Social isolation from the family might affect one's life when care needs arise, which, in turn, may be associated with multimorbidity and poor health. In contrast, perceived isolation from friends might affect different aspects of one's life like informal social activities, well-being and health-promoting behaviors like physical activity.

One additional interesting aspect is provided in article 3 by distinguishing between indoor and outdoor physical activity and its predictors in old age. All of the well-known predictors of physical activity (i.e. age, education, BMI, and multimorbidities) (Koeneman, Verheijden, Chinapaw, & Hopman-Rock, 2011) fit the outdoor physical activity model very well but were almost unrelated to indoor physical activity. Indoor physical activity might be a rather constant behavior pattern (i.e., cleaning the house or moving around the building) that is even independent of increasing age or health problems. A person's adaptation to adverse circumstances might first affect outdoor rather than indoor physical activity. It is obvious that outdoor social contacts are restricted first, and these are more likely neighbors and friends.

In the course of the EPOSA project, the research group identified weather conditions as a central physical environmental aspect that affects persons with OA. In the literature, meteorological conditions have already been identified to be associated with physical activity in older adults with joint pain or with OA (Stubbs et al., 2015). In both, weather conditions resulted in lower physical activity levels among older adults. Findings suggested that older adults were more active in summer than winter and that physical activity levels are positively associated with higher outdoor temperature, longer day-length and duration of bright sunshine (Aoyagi & Shephard, 2010; Klenk et al., 2012; McMurdo et al., 2012; Sumukadas, Witham, Struthers, & McMurdo, 2009; Yasunaga et al., 2008). Consequently, article 2

examined whether the association between weather conditions and physical activity is different when comparing older adults with and without OA. Persons with OA might be more prone to cutting back on physical activity due to adverse weather conditions because they feel pain and are more sensitive to weather conditions (Timmermans et al., 2014). Several meteorological conditions such as temperature, precipitation, atmospheric pressure and wind speed have been reported to affect persons with OA (Dorleijn et al., 2014; Laborde, Dando, & Powers, 1986; Wilder, Hall, & Barrett, 2003). The humidity has been shown to affect joint pain, even more strongly in cold weather (Timmermans et al., 2015). Article 2 shows that warmer temperature was associated with higher physical activity levels in a way more pronounced in persons without OA and much less pronounced in older adults without the condition. This was contrary to the expectations. Less competent older adults (i.e., those with lower functional, biological, cognitive, social and behavioral skills) should not have been able to buffer adverse weather effects and should have benefited less from positive weather conditions.

The results of article 2 suggest that differences in physical activity that were identified in article 1 have to be sought elsewhere. One possible factor might be the built-environment. Older adults who reported environmental barriers in their neighborhood had a greater risk of difficulties with walking, whereas the availability of parks and green areas within walking distance decreased the risk of difficulties with walking (Eronen, von Bonsdorff, Rantakokko, & Rantanen, 2014) and promoted leisure-time physical activity (Ribeiro, Mitchell, Carvalho, & de Pina, 2013). The EPOSA study found a significant difference in the availability of neighborhood resources in different European countries and in rural vs urban regions. In this way, we found a quite heterogeneous picture. Older persons with lower limb OA were less likely to use parks and walking areas and more frequently use places to sit and rest, if they were available (van der Pas et al., 2016).

In conclusion, the physical environment was differently accessed by people with OA in comparison with older adults without OA, and it presents a potential barrier or a potential facilitator to physical activity adherence. Environments with available and convenient resources used for physical activity, such as sidewalks, parks, recreation centers, and fitness facilities, make it easier for people to be physically active.

Physical activity does not occur in a vacuum, but results from an interaction of personal characteristics and actual physical and social environments. The two foci – the social and the physical environments – of this thesis do not have to be regarded separately. In addition to methodological factors, the dynamic and possibly reciprocal association between social relationships and health adds complexity to this line of inquiry. Neither individuals' social relationships nor their health is static over the course of their lives. Both factors evolve with age in certain ways, and such changes can complicate their association. However, many studies examine only a snapshot of this association and thus lack thorough understanding of its complex dynamics (Fiori et al., 2006, 2007; Litwin, 1998). Furthermore, most research focuses on the one-way effect from social relationship to health, while the possible influence of health on social relationship patterns has largely been overlooked. Ignoring this possible reverse causality may impair the validity of the estimated causal effects of social relationships on health because the effects of social relationships on health may explain only part of the observed association between these two factors.

7.3 Limitations and Strengths of this Dissertation

Each publication included in this dissertation has its own limitations and strengths, which are addressed in the respective discussions of the articles. In this general discussion, issues will be discussed that target all of these studies.

Although the EPOSA project and the ActiFE study are comprised of representative population based surveys, one limitation might be that participation rates tend to be higher in healthy, younger and higher educated older adults. This selectivity raises concern about potential biases and about the

generality of the results. In all three articles, we either adjusted for potential socio-demographic biases or weighted the results according to official socio-demographics.

A further limitation is that only short questionnaires could be implemented that covered exclusively some aspects of the central foci of my dissertation. The ActiFE study and the EPOSA project took place through large international or multidisciplinary cooperation that required limiting research instruments to those most essential. In order to reach an agreement among the six already established cohorts in the EPOSA study on measurement instruments, only one aspect of social networks was investigated. Accordingly, the social isolation and the physical environment scales only capture some aspects.

A major challenge within all studies was to adequately assess physical activity. In two out of three articles, a self-reported multi-item scale was used to measure physical activity. Physical activity questionnaires are prone to reporting biases mainly because of social desirability, cognitive limitations in recalling behavior and biased estimates of duration and frequency (Warren et al., 2010). There is some indication that self-report measures do not reliably reflect cardiovascular fitness and may not predict health outcomes as clearly as objectively measured cardiovascular fitness. With this limitation in mind, a physical activity questionnaire was utilized that has been proven to be a reliable and valid instrument for the assessment of physical activity (Stel et al., 2004).

One further problem was the right-skewness of the physical activity questionnaire data or the clumping at the zero of single physical activity domains. This is a typical problem for the assessment of physical activity and time-use-data (Slymen, Ayala, Arredondo, & Elder, 2006). In order to cope with this problem, we calculated tertiles of physical activity for each single domain in the first article.

Another difficulty in measuring physical activity is its different subcategories, e.g. exercise, leisure-time physical activity, and household activity. When combining all different components of the physical activity questionnaire, very high amounts of physical activity emerged and the total physical activity scores were found to be unrealistic if they exceeded three standard deviations. Consequently, a person's physical activity level dramatically varied depending on the applied measures.

Aside from the limitations of the ActiFE study and the EPOSA project, the results are highly relevant and novel in the related research fields. As described in section 2.1, comparative studies in the field of OA and physical activity are rare and the use of objective physical activity measures are novel. Since (mainly) epidemiological research has shown the beneficial effects of physical activity in old age, social epidemiology and sociology must now investigate topics like physical activity and social cohesion, social participation and physical activity and physical activity behavioral patterns in different social groups.

A further strength of this research is that all articles are based on representative samples. EPOSA is the first multi-country study that aimed to contribute knowledge about the social burdens of OA. Single-country studies can provide only county-specific associations. That means that differences between physical activity levels in single countries can only be observed but not statistically tested. Consequently, article 1 was the first that also estimated the extent to which OA explained differences in physical activity between countries and patterns that might be responsible for these differences.

Despite the noted difficulties in adequately assessing physical activity, the ActiFE study is distinguished from other studies because it used a mixed-method approach. This dissertation provides results from a combination of standardized questionnaires, activity diaries and accelerometers (article 3). The mixture of methods provided the opportunity to compare subjectively and objectively measured physical activity and enabled us to distinguish between objectively assessed outdoor and indoor physical activity.

7.4 Future Directions in Research

Many research questions remain open with regard to the attempt to determine factors that predict (low) levels of physical activity in older adults. In general, future research should: (1) use longer follow-up periods for investigating the influence of social and physical environments on physical activity, (2) use country-specific analyses that account for different patterns and mechanisms, (3) analyze the change of influential individual and social factors in a longitudinal perspective (4) expand the focus from

describing functional limitations and its determinants to facilitating factors and coping strategies that enable older adults with OA to be physically active, and (5) examine the interplay between sociological variables, medical issues and socio-demographic factors.

The Importance of Social Relations

This thesis addressed social isolation and its association with outdoor physical activity levels (article 3). Social isolation represents only a small part of the conceptual framework of Lisa F. Berkman and colleagues (2000) that I described in section 2.4. Social networks, as the "web of social relationships" that surround an individual and the characteristics belonging to those relationships (Fischer, 1982), are more multifaceted than we have applied in our analyses. The density, boundedness, and homogeneity of networks are only some of the additional interesting aspects that future research needs to address in a more sophisticated network approach. Through this, the objective constellation of a network and patterns of interactions should be applied in order to explain physical activity levels.

Derived from the Berkman model, health-behavior needs to take higher levels of abstraction into account. Social structure requires conditions on the neighborhood-level (social cohesion) and the country-level (norms and values). Future research needs to consider a multi-level analysis using not only individual-level factors to explain physical activity, but also using factors pertaining to social and physical environments at the neighborhood- and country-levels to explain individual differences in physical activity outcomes.

However, it will continue to be a challenging task to separate the effects on different levels because research has revealed contradictory results. Low physical activity in older adults with few social networks were found to be compensated for by high levels of neighborhood cohesion in one study (Mohnen, Volker, Flap, Subramanian, & Groenewegen, 2015). Neighborhood social capital was associated with physical activity, while physical activity significantly and strongly reduced the direct effect of neighborhood social capital on self-rated health (multilevel mediation) (Mohnen, Volker, Flap, & Groenewegen, 2012). However, neighborhood cohesion had no effect on the individual physical activity in another study (Gao, Fu, Li, & Jia, 2015).

At the country-level, article 3 showed variation in the physical activity levels of older adults. There are only a few studies comparing social structures and country-specific physical activity patterns. Up to now, the information that exists that depicting the international variation of physical activity prevalences is mainly descriptive (Bauman et al., 2009; Sjöström et al., 2006). Dumith and colleagues (2011) found a positive relationship between the human development index and physical inactivity (ρ = 0.27). That means that less developed countries showed the lowest prevalence of physical inactivity. Another outstanding study is the International Physical Activity and the Environment Network study (Kerr et al., 2013), which collected data about physical environmental characteristics among adults with a mean age of 43 across 11 countries and used objectively measured physical activity to explain the importance of different physical environment attributes for physical activity (Cerin et al., 2014). A similar approach of collaboration and pooling resources needs to be undertaken. By international cooperation and pooling of available data, social aspects of the environment (neighborhood and country differences) could be used to explain older adults' physical activity levels. Important parameters might be the stability of social connections, trust, social inequality, and the collective efficacy of neighborhoods.

Neither an individual's social relationships nor their health is static over the course of their life. Both factors evolve with age and influence each other. According to the convoy model (Kahn & Antonucci, 1980), which was also described in section 2.3.2, there are systematic variations across individuals that are shaped by their personal characteristics and situational factors that change over time. Different network types might evolve from selectivity in old age. The emotional selectivity theory proposes that older adults tend to shift their preferences to emotionally meaningful relations as they become more aware of the time left in life (Carstensen, Fung, & Charles, 2003). Additionally, changes in physical activity and social network structures might result from the same cause, which is increasing multimorbidity and functional limitation. Future research needs to apply longer observation periods in order to decompose possible mechanisms that overlap or occur contemporaneously.

Physical Activity and Osteoarthritis

In order to understand OA in all its complexity, a qualitative study by Busija, Buchbinder and Osborne (2013) has drawn a conceptual map with major clusters of statements from persons with OA. The EPOSA project and my thesis have contributed to understanding relationships within the cluster "restrictions and limitations of activity". The map, however, also points to the questions that remained unexplained. It is unknown how pain management, physical activity promotion, and coping with frustrations are mutually affected by each other. Worries about the causes of the disease, worries about the adverse effects of physical activity, the adoption of social relations and pain management are central aspects that need to be addressed – in combination – in the future. If these aspects are insufficiently addressed, shifts toward fewer social contacts, less physical activity and more pain could easily occur.

Additionally, the authors collected both the patient's and the professional's perspective. It would be essential to know how well patients agree with the subjective assessments given by professionals. Using a similar concept map, another study showed that patients rated some limitations differently than professionals did (Klokker et al., 2015).

The Granular Society

The idea of the so called "granular society" (Kucklick, 2014) describes the way that nature, the body and all other objects now can be viewed in a higher resolution by technical means. Computer scientists usually use the term "granularity" when they refer to the degree of resolution: the more finely-grained the more granular.

This idea can be nicely transferred to different fields of research that have used quite simplistic ways of understanding reality in the past. Now objects of research can be detected and monitored at much more precise levels of "granularity". In the 20th century, physical activity research started asking participants if they perceive themselves as being highly physically active or not physically active at all. Modern accelerometer devices are far more accurate by providing information about the participant's physical activity 10 times a second. Accelerometer-based devices have experienced tremendous

advances and growth. However, the new devices bring the need for new analytic strategies, including a shift from count based estimation of physical activity to estimation based on features and behavioral patterns extracted from raw acceleration signals (Troiano, McClain, Brychta, & Chen, 2014). Future directions of social network research will also profit from social platforms and social interactions (via e-mail or other means) as one way to detect social dynamics in relationships. Analyzing the dynamics and complexity of this fine-grained information about social networks will shift the current perspective.

7.5 Practical Implications

Article 3 demonstrated that social isolation and outdoor physical activity levels were significantly associated, which makes physical activity interventions a means to influence both factors. Two reviews of the current literature concluded that group-based interventions are most effective in preventing social isolation in comparison to one-on-one interventions. They are more effective when they involve some form of educational training or social activity that targets specific groups (Cattan, White, Bond, & Learmouth, 2005; Dickens, Richards, Greaves, & Campbell, 2011). A lifestyle intervention, including physical activity (intervention group) and a physical activity alone group (control group) showed equal improvements regarding well-being and social participation in both groups (Lund, Michelet, Sandvik, Wyller, & Sveen, 2012). The social aspect of the lifestyle group might be an opportunity for social contact, but the key element for success might have been the physical activity intervention. The results of article 3 pointed in the same direction. Older adults spent most outdoor physical activity in company with others. A recent review by Robins and colleagues (2016) focused on interventions that combined physical activity and social isolation. Participation in group-based physical activity programs were also effective in addressing social isolation. The authors concluded that physical activity might be effective in addressing both health and social issues.

Article 1 provides the first hints that the same functional limitation (knee OA) has a varying impact on physical activity across different European countries. An infrastructure that enables older adults to continue to be physically active might be achievable if the built environment serves the needs

of people with knee OA. Politicians and health professionals should consider both personal and environmental barriers and the fit between both in the lives of older adults. In the Netherlands, we observed over the last decade a continuing effort to maintain and construct a cycling infrastructure (Pucher & Buehler, 2008). This might explain why in article 1 people with knee OA had a higher probability of cycling than people without the condition.

7.6 Conclusion

"Traditionally, old age has been associated with retirement, illness and dependency. Policies and programmes that are stuck in this outdated paradigm do not reflect reality. Indeed, most people remain independent into very old age" (World Health Organization, 2002, p. 43). Active aging applies to both individuals and the society. On the one hand, it refers to the individual behavioral habits and characteristics. On the other hand, it also considers the context – the focus of this thesis – in which aging takes place. Friends, neighbors and family members are important resources in active aging since it takes place in interdependency and intergenerational solidarity. Social and physical environments that are age-friendly can make the difference between independence and dependence, particularly for those growing older. If the environment meets the individual's needs, active aging is possible.

This thesis should further encourage researchers, physicians and health professionals to focus not only on individual characteristics. Physical and social contexts are at least as important for everyday health behavior and the way people cope with functional limitations in old age. Research on the social burden of chronic diseases might shift the perspective from individual factors and might intensify efforts to describe peoples' social and physical environmental facilitators in relation to having a physical active lifestyle.

References

Adams, S. A., Matthews, C. E., Ebbeling, C. B., Moore, C. G., Cunningham, J. E., Fulton, J., & Hebert, J. R. (2005). The effect of social desirability and social approval on self-reports of physical activity. *American Journal of Epidemiology*, *161*(4), 389–398. https://doi.org/10.1093/aje/kwi054

Altman, R., Asch, E., Bloch, D., Bole, G., Borenstein, D., Brandt, K., … Wolfe, F. (1986). Development of criteria for the classification and reporting of osteoarthritis - classification of osteoarthritis of the knee. *Arthritis and Rheumatism*, *29*(8), 1039–1049. https://doi.org/10.1002/art.1780290816

American College of Sports Medicine. (1975). *Guidelines for graded exercise testing and exercise prescription*. Philadelphia: Lea & Febiger.

Antonucci, T. C., Ajrouch, K. J., & Birditt, K. S. (2014). The convoy model: Explaining social relations from a multidisciplinary perspective. *Gerontologist*, *54*(1), 82–92. https://doi.org/10.1093/geront/gnt118

Antonucci, T. C., & Akiyama, H. (1987). Social networks in adult life and a preliminary examination of the convoy model. *Journals of Gerontology*, *42*(5), 519–527. https://doi.org/10.1093/geronj/42.5.519

Aoyagi, Y., & Shephard, R. J. (2010). Habitual physical activity and health in the elderly: The Nakanojo Study. *Geriatrics & Gerontology International*, *10*(Suppl 1), 236–243. https://doi.org/10.1111/j.1447-0594.2010.00589.x

Baert, V., Gorus, E., Mets, T., Geerts, C., & Bautmans, I. (2011). Motivators and barriers for physical activity in the oldest old: A systematic review. *Ageing Research Reviews*, *10*(4), 464–474. https://doi.org/10.1016/j.arr.2011.04.001

Balzi, D., Lauretani, F., Barchielli, A., Ferrucci, L., Bandinelli, S., Buiatti, E., … Guralnik, J. M. (2010). Risk factors for disability in older persons over 3-year follow-up. *Age and Ageing*, *39*(1), 92–98. https://doi.org/10.1093/ageing/afp209

Baranowski, T. (1988). Validity and reliability of self report measures of physical activity: An information-processing perspective. *Research Quarterly for Exercise and Sport*, *59*(4), 314–327. https://doi.org/10.1080/02701367.1988.10609379

Bassey, E. J. (2000). The benefits of exercise for the health of older people. *Reviews in Clinical Gerontology*, *10*(1), 17–31. https://doi.org/10.1017/S0959259805001711

Bauman, A., Bull, F., Chey, T., Craig, C. L., Ainsworth, B. E., Sallis, J. F., … Pratt, M. (2009). The International Prevalence Study on physical activity: Results from 20 countries. *The International Journal of Behavioral Nutrition and Physical Activity*, *6*, 21. https://doi.org/10.1186/1479-5868-6-21

Bauman, A., Merom, D., Bull, F. C., Buchner, D. M., & Singh, M. A. F. (2016). Updating the evidence for physical activity: Summative reviews of the epidemiological evidence, prevalence, and interventions to promote "Active Aging." *The Gerontologist*, *56*(Suppl 2), 268–280. https://doi.org/10.1093/geront/gnw031

Bellamy, N., Buchanan, W. W., Goldsmith, C. H., Campbell, J., & Stitt, L. W. (1988). Validation study of WOMAC: A health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. *The Journal of Rheumatology*, *15*(12), 1833–1840.

Bellew, B., Bauman, A., Martin, B., Bull, F., & Matsudo, V. (2011). Public policy actions needed to promote physical activity. *Current Cardiovascular Risk Reports*, *5*(4), 340–349. https://doi.org/10.1007/s12170-011-0180-6

Berkman, L. F., Glass, T., Brissette, I., & Seeman, T. E. (2000). From social integration to health: Durkheim in the new millennium. *Social Science & Medicine*, *51*(6), 843–857. https://doi.org/10.1016/S0277-9536(00)00065-4

Berkman, L. F., Kawachi, I., & Glymour, M. (2015). *Social epidemiology* (Second edition). Oxford [u.a.]: Oxford University Press.

Bize, R., Johnson, J. A., & Plotnikoff, R. C. (2007). Physical activity level and health-related quality of life in the general adult population: A systematic review. *Preventive Medicine*, *45*(6), 401–415. https://doi.org/10.1016/j.ypmed.2007.07.017

Bongaarts, J. (2009). Human population growth and the demographic transition. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1532), 2985–2990. https://doi.org/10.1098/rstb.2009.0137

Booth, F. W., Roberts, C. K., & Laye, M. J. (2012). Lack of exercise is a major cause of chronic diseases. *Comprehensive Physiology*, *2*(2), 1143–1211. https://doi.org/10.1002/cphy.c110025

Booth, M. L., Owen, N., Bauman, A., Clavisi, O., & Leslie, E. (2000). Social-cognitive and perceived environment influences associated with physical activity in older Australians. *Preventive Medicine*, *31*(1), 15–22. https://doi.org/10.1006/pmed.2000.0661

Boyle, P., Buchman, A., Wilson, R., Bienias, J., & Bennett, D. (2007). Physical activity is associated with incident disability in community-based older persons. *Journal of the American Geriatrics Society*, *55*(2), 195–201. https://doi.org/10.1111/j.1532-5415.2007.01038.x

Brooke, E., Taylor, P., McLoughlin, C., & Di Biase, T. (2013). Managing the working body: Active ageing and limits to the "flexible" firm. *Ageing & Society*, *33*(8), 1295–1314. https://doi.org/10.1017/S0144686X12000426

Brummett, B. H., Barefoot, J. C., Siegler, I. C., Clapp-Channing, N. E., Lytle, B. L., Bosworth, H. B., … Mark, D. B. (2001). Characteristics of socially isolated patients with coronary artery disease who are at elevated risk for mortality. *Psychosomatic Medicine*, *63*(2), 267–272. https://doi.org/10.1097/00006842-200103000-00010

Busija, L., Bridgett, L., Williams, S. R. M., Osborne, R. H., Buchbinder, R., March, L., & Fransen, M. (2010). Osteoarthritis. *Best Practice & Research Clinical Rheumatology*, *24*(6), 757–768. https://doi.org/10.1016/j.berh.2010.11.001

Busija, L., Buchbinder, R., & Osborne, R. H. (2013). A grounded patient-centered approach generated the personal and societal burden of osteoarthritis model. *Journal of Clinical Epidemiology*, *66*(9), 994–1005. https://doi.org/10.1016/j.jclinepi.2013.03.012

Byberg. (2010). Total mortality after changes in leisure time physical activity in 50 year old men: 35 year follow-up of population based cohort. *BMJ*, *341: c6005*. https://doi.org/doi:10.1136/bmj.b688

Carstensen, L. L., Fung, H. H., & Charles, S. T. (2003). Socioemotional selectivity theory and the regulation of emotion in the second half of life. *Motivation and Emotion*, *27*(2), 103–123. https://doi.org/10.1023/A:1024569803230

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports*, *100*(2), 126–131.

Castell, M. V., van der Pas, S., Otero, A., Siviero, P., Dennison, E., Denkinger, M., … Deeg, D. (2015). Osteoarthritis and frailty in elderly individuals across six European countries: results from the European Project on OSteoArthritis (EPOSA). *BMC Musculoskeletal Disorders*, *16: 359*. https://doi.org/10.1186/s12891-015-0807-8

Cattan, M., White, M., Bond, J., & Learmouth, A. (2005). Preventing social isolation and loneliness among older people: A systematic review of health promotion interventions. *Ageing & Society*, *25*(1), 41–67. https://doi.org/10.1017/S0144686X04002594

Cerin, E., Cain, K. L., Conway, T. L., Van Dyck, D., Hinckson, E., Schipperijn, J., … Sallis, J. F. (2014). Neighborhood environments and objectively measured physical activity in 11 countries. *Medicine and Science in Sports and Exercise*, *46*(12), 2253–2264. https://doi.org/10.1249/MSS.0000000000000367

Chan, C. B., & Ryan, D. A. (2009). Assessing the effects of weather conditions on physical activity participation using objective measures. *International Journal of Environmental Research and Public Health*, *6*(10), 2639–2654. https://doi.org/10.3390/ijerph6102639

Chang, P.-J., Wray, L., & Lin, Y. (2014). Social relationships, leisure activity, and health in older adults. *Health Psychology*, *33*(6), 516–523. https://doi.org/10.1037/hea0000051

Chuang, Y.-C., Chuang, K.-Y., & Yang, T.-H. (2013). Social cohesion matters in health. *International Journal for Equity in Health*, *12: 87*. https://doi.org/10.1186/1475-9276-12-87

Clarke, P., & Nieuwenhuijsen, E. R. (2009). Environments for healthy ageing: A critical review. *Maturitas*, *64*(1), 14–19. https://doi.org/10.1016/j.maturitas.2009.07.011

Cornwell, E. Y., & Waite, L. J. (2009). Social disconnectedness, perceived isolation, and health among older adults. *Journal of Health and Social Behavior*, *50*(1), 31–48. https://doi.org/10.1177/002214650905000103

Crombie, I. K., Irvine, L., Williams, B., McGinnis, A. R., Slane, P. W., Alder, E. M., & McMurdo, M. E. T. (2004). Why older people do not participate in leisure time physical activity: A survey of activity levels, beliefs and deterrents. *Age and Ageing*, *33*(3), 287–292. https://doi.org/10.1093/ageing/afh089

Davis, M., Ettinger, W., & Neuhaus, J. (1990). Obesity and osteoarthritis of the knee: Evidence from the National Health and Nutrition Examination Survey (NHANES I). *Seminars in Arthritis and Rheumatism*, *20*(3), 34–41. https://doi.org/10.1016/0049-0172(90)90045-H

Deindl, C., Brandt, M., & Hank, K. (2016). Social networks, social cohesion, and later-life health. *Social Indicators Research*, *126*(3), 1175–1187. https://doi.org/10.1007/s11205-015-0926-5

Denkinger, M., Franke, S., Rapp, K., Weinmayr, G., Duran-Tauleria, E., Nikolaus, T., … ActiFE Ulm Study Group. (2010). Accelerometer-based physical activity in a large observational cohort - study protocol and design of the activity and function of the elderly in Ulm (ActiFE Ulm) study. *BMC Geriatrics*, *10: 50*. https://doi.org/10.1186/1471-2318-10-50

Dickens, A. P., Richards, S. H., Greaves, C. J., & Campbell, J. L. (2011). Interventions targeting social isolation in older people: A systematic review. *BMC Public Health*, *11: 647*. https://doi.org/10.1186/1471-2458-11-647

Dillon, C. F., Hirsch, R., Rasch, E. K., & Gu, Q. (2006). Symptomatic hand osteoarthritis in the United States. *American Journal of Physical Medicine & Rehabilitation*, *86*(1), 12–21. https://doi.org/10.1097/PHM.0b013e31802ba28e

Dorleijn, D. M. J., Luijsterburg, P. A. J., Burdorf, A., Rozendaal, R. M., Verhaar, J. A. N., Bos, P. K., & Bierma-Zeinstra, S. M. A. (2014). Associations between weather conditions and clinical symptoms in patients with hip osteoarthritis: A 2-year cohort study. *Pain*, *155*(4), 808–813. https://doi.org/10.1016/j.pain.2014.01.018

Dumith, S. C., Hallal, P. C., Reis, R. S., & Kohl, H. W. (2011). Worldwide prevalence of physical inactivity and its association with human development index in 76 countries. *Preventive Medicine*, *53*(1–2), 24–28. https://doi.org/10.1016/j.ypmed.2011.02.017

Durkheim, É. (1963). *Suicide: a study in sociology* (Repr.). London: Routledge & Kegan Paul.

Dyrstad, S. M., Hansen, B. H., Holme, I. M., & Anderssen, S. A. (2014). Comparison of self-reported versus accelerometer-measured physical activity. *Medicine and Science in Sports and Exercise*, *46*(1), 99–106. https://doi.org/10.1249/MSS.0b013e3182a0595f

Edwards, M. H., van der Pas, S., Denkinger, M. D., Parsons, C., Jameson, K. A., Schaap, L., … Dennison, E. (2014). Relationships between physical performance and knee and hip osteoarthritis: Findings from the European Project on Osteoarthritis (EPOSA). *Age and Ageing*, *43*(6), 806–813. https://doi.org/10.1093/ageing/afu068

Eronen, J., von Bonsdorff, M., Rantakokko, M., & Rantanen, T. (2014). Environmental facilitators for outdoor walking and development of walking difficulty in community-dwelling older adults. *European Journal of Ageing*, *11*(1), 67–75. https://doi.org/10.1007/s10433-013-0283-7

Esser, S., & Bailey, A. (2011). Effects of exercise and physical activity on knee osteoarthritis. *Current Pain and Headache Reports*, *15*(6), 423–430. https://doi.org/10.1007/s11916-011-0225-z

European Commission. (1999). *Towards a Europe for all ages. Promoting prosperity and intergenerational solidarity* (No. COM(1999) 221 final). Brussels. Retrieved from http://ec.europa.eu/employment_social/social_situation/docs/com221_en.pdf

European Commission. (2012). *Pension adequacy in the European Union 2010–2050*. Luxembourg: European Union.

Feinglass, J., Lee, J., Semanik, P., Song, J., Dunlop, D., & Chang, R. (2011). The effects of daily weather on accelerometer-measured physical activity. *Journal of Physical Activity & Health*, *8*(7), 934–943. https://doi.org/10.1123/jpah.8.7.934

Felson, D. T., Naimark, A., Anderson, J., Kazis, L., Castelli, W., & Meenan, R. F. (1987). The prevalence of knee osteoarthritis in the elderly: The Framingham Osteoarthritis Study. *Arthritis & Rheumatism*, *30*(8), 914–918. https://doi.org/10.1002/art.1780300811

Fiori, K. L., Antonucci, T. C., & Cortina, K. S. (2006). Social network typologies and mental health among older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *61*(1), P25–P32. https://doi.org/10.1093/geronb/61.1.P25

Fiori, K. L., Smith, J., & Antonucci, T. C. (2007). Social network types among older adults: A multidimensional approach. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences*, *62*(6), P322–P330. https://doi.org/10.1093/geronb/62.6.P322

Fischer, C. (1982). *To Dwell among Friends*. Chicago: University of Chicago Press.

Franco, M. R., Tong, A., Howard, K., Sherrington, C., Ferreira, P. H., Pinto, R. Z., & Ferreira, M. L. (2015). Older people's perspectives on participation in physical activity: A systematic review and thematic synthesis of qualitative literature. *British Journal of Sports Medicine*, *49*(19), 1268–76. https://doi.org/10.1136/bjsports-2014-094015

Fried, L. P., Tangen, C. M., Walston, J., Newman, A. B., Hirsch, C., Gottdiener, J., … Cardiovascular Health Study Collaborative Research Group. (2001). Frailty in older adults: Evidence for a phenotype. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *56*(3), M146-156. https://doi.org/10.1093/gerona/56.3.M146

Gao, J., Fu, H., Li, J., & Jia, Y. (2015). Association between social and built environments and leisure-time physical activity among Chinese older adults - a multilevel analysis. *BMC Public Health*, *15: 1317*. https://doi.org/10.1186/s12889-015-2684-3

Guralnik, J. M., Ferrucci, L., Simonsick, E. M., Salive, M. E., & Wallace, R. B. (1995). Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *New England Journal of Medicine*, *332*(9), 556–562. https://doi.org/10.1056/NEJM199503023320902

Guthold, R., Ono, T., Strong, K. L., Chatterji, S., & Morabia, A. (2008). Worldwide variability in physical inactivity a 51-country survey. *American Journal of Preventive Medicine*, *34*(6), 486–494. https://doi.org/10.1016/j.amepre.2008.02.013

Hamer, M., Lavoie, K. L., & Bacon, S. L. (2014). Taking up physical activity in later life and healthy ageing: The English longitudinal study of ageing. *British Journal of Sports Medicine*, *48*(3), 239–243. https://doi.org/10.1136/bjsports-2013-092993

Haskell, W. L., Lee, I.-M., Pate, R. R., Powell, K. E., Blair, S. N., Franklin, B. A., … Bauman, A. (2007). Physical activity and public health: Updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Medicine and Science in Sports and Exercise*, *39*(8), 1423–1434. https://doi.org/10.1249/mss.0b013e3180616b27

Havighurst, R., Neugarten, B., & Tobin, S. (1968). Disengagement and patterns of aging. In B. Neugarten (Ed.), *Middle Age and Aging: A Reader in Social Psychology*. Chicago: University of Chicago Press.

Hawkley, L., Thisted, R., & Cacioppo, J. (2009). Loneliness predicts reduced physical activity: Cross-sectional & longitudinal analyses. *Health Psychology*, *28*(3), 354–363. https://doi.org/10.1037/a0014400

Helmerhorst, H. J. F., Brage, S., Warren, J., Besson, H., & Ekelund, U. (2012). A systematic review of reliability and objective criterion-related validity of physical activity questionnaires. *International Journal of Behavioral Nutrition and Physical Activity*, *9: 103*. https://doi.org/10.1186/1479-5868-9-103

Hochberg, M. C., Altman, R. D., April, K. T., Benkhalti, M., Guyatt, G., McGowan, J., … American College of Rheumatology. (2012). American College of Rheumatology 2012 recommendations for the use of nonpharmacologic and pharmacologic therapies in osteoarthritis of the hand, hip, and knee. *Arthritis Care & Research*, *64*(4), 465–474. https://doi.org/10.1002/acr.21596

Holla, J. F. M., Sanchez-Ramirez, D. C., van der Leeden, M., Ket, J. C. F., Roorda, L. D., Lems, W. F., … Dekker, J. (2014). The avoidance model in knee and hip osteoarthritis: A systematic review of the evidence. *Journal of Behavioral Medicine*, *37*(6), 1226–1241. https://doi.org/10.1007/s10865-014-9571-8

Holme, I., & Anderssen, S. A. (2015). Increases in physical activity is as important as smoking cessation for reduction in total mortality in elderly men: 12 years of follow-up of the Oslo II study. *British Journal of Sports Medicine*, *49*(11), 743–748. https://doi.org/10.1136/bjsports-2014-094522

House, J. S. (2001). Social isolation kills, but how and why? *Psychosomatic Medicine*, *63*(2), 273–274. https://doi.org/10.1097/00006842-200103000-00011

Hsu, K.-Y., Tsai, Y.-F., Lin, Y.-P., & Liu, H.-T. (2015). Primary family caregivers' observations and perceptions of their older relatives' knee osteoarthritis pain and pain management: a qualitative study. *Journal of Advanced Nursing*, *71*(9), 2119–2128. https://doi.org/10.1111/jan.12684

Hupin, D., Roche, F., Gremeaux, V., Chatard, J.-C., Oriol, M., Gaspoz, J.-M., … Edouard, P. (2015). Even a low-dose of moderate-to-vigorous physical activity reduces mortality by 22% in adults aged >= 60 years: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *49*(19), 1262–7. https://doi.org/10.1136/bjsports-2014-094306

Iliffe, S., Kharicha, K., Harari, D., Swift, C., Gillmann, G., & Stuck, A. E. (2007). Health risk appraisal in older people 2: The implications for clinicians and commissioners of social isolation risk in older people. *The British Journal of General Practice*, *57*(537), 277–282.

Iwarsson, S. (2005). A long-term perspective on person-environment fit and ADL dependence among older Swedish adults. *Gerontologist*, *45*(3), 327–336.

Iwarsson, S., & Stahl, A. (2003). Accessibility, usability and universal design-positioning and definition of concepts describing person-environment relationships. *Disability and Rehabilitation*, *25*(2), 57–66. https://doi.org/10.1080/713813473

Jiang, L., Rong, J., Zhang, Q., Hu, F., Zhang, S., Li, X., … Tao, T. (2012). Prevalence and associated factors of knee osteoarthritis in a community-based population in Heilongjiang, Northeast China. *Rheumatology International*, *32*(5), 1189–1195. https://doi.org/10.1007/s00296-010-1773-y

Jong-wook, L. (2005). Public health is a social issue. *The Lancet*, *365*(9464), 1005–1006. https://doi.org/10.1016/S0140-6736(05)71115-6

Jordan, J., Luta, G., Renner, J., Dragomir, A., Hochberg, M., & Fryer, J. (1997). Knee pain and knee osteoarthritis severity in self-reported task specific disability: The Johnston County Osteoarthritis Project. *Journal of Rheumatology*, *24*(7), 1344–1349.

Kahn, R. L., & Antonucci, T. C. (1980). Convoys over the life course: Attachment, roles, and social support. In P. B. Baltes & O. Brim (Eds.), *Life-span development and behavior* (3rd ed., pp. 253–286). New York: Academic Press.

Kaye, L. W., Butler, S. S., & Webster, N. M. (2003). Toward a productive ageing paradigm for geriatric practice. *Ageing International*, *28*(2), 200–213. https://doi.org/10.1007/s12126-003-1024-6

Kerr, J., Sallis, J. F., Owen, N., De Bourdeaudhuij, I., Cerin, E., Sugiyama, T., … Bracy, N. (2013). Advancing science and policy through a coordinated international study of physical activity and built environments: IPEN adult methods. *Journal of Physical Activity & Health*, *10*(4), 581–601. https://doi.org/10.1123/jpah.10.4.581

Klenk, J., Büchele, G., Rapp, K., Franke, S., Peter, R., & ActiFE Study Group. (2012). Walking on sunshine: Effect of weather conditions on physical activity in older people. *Journal of Epidemiology and Community Health*, *66*(5), 474–476. https://doi.org/10.1136/jech.2010.128090

Klokker, L., Osborne, R., Waehrens, E. E., Norgaard, O., Bandak, E., Bliddal, H., & Henriksen, M. (2015). The concept of physical limitations in knee osteoarthritis: as viewed by patients and health professionals. *Quality of Life Research*, *24*(10), 2423–2432. https://doi.org/10.1007/s11136-015-0976-9

Koeneman, M. A., Verheijden, M. W., Chinapaw, M. J. M., & Hopman-Rock, M. (2011). Determinants of physical activity and exercise in healthy older adults: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *8: 142*. https://doi.org/10.1186/1479-5868-8-142

Kucklick, C. (2014). *Die granulare Gesellschaft: Wie das Digitale unsere Wirklichkeit auflöst*. Berlin: Ullstein.

Laborde, J. M., Dando, W. A., & Powers, M. J. (1986). Influence of weather on osteoarthritics. *Social Science & Medicine (1982)*, *23*(6), 549–554. https://doi.org/10.1016/0277-9536(86)90147-4

Lampert, T., Mensink, G. B. M., & Müters, S. (2012). [Physical and sporting activity among adults in Germany. Results from the "German Health Update 2009" survey]. *Bundesgesundheitsblatt,*

Gesundheitsforschung, Gesundheitsschutz, *55*(1), 102–110. https://doi.org/10.1007/s00103-011-1401-3

Lassen, A. J. (2015). Keeping disease at arm's length – how older Danish people distance disease through active ageing. *Ageing & Society*, *35*(07), 1364–1383. https://doi.org/10.1017/S0144686X14000245

Lawton, M. P. (1977). The impact of the environment on aging and behavior. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 276–301). New York: Van Nostran.

Lawton, M. P. (1982). Competence, environmental press, and the adaptation of older people. In M. P. Lawton, P. G. Windley, & T. O. Byerts (Eds.), *Aging and the environment* (pp. 33–59). New York: Springer.

Lawton, M. P. (1986). *Environment and aging* (2. ed.). Albany, NY: Center for the Study of Aging.

Lawton, M. P., & Nahemow, L. (1973). Ecology and the aging process. In C. Eisdorfer & M. P. Lawton (Eds.), *The psychology of adult development and aging*. Washington, DC: American Psychological Association.

Leask, C. F., Harvey, J. A., Skelton, D. A., & Chastin, S. F. M. (2015). Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). *European Review of Aging and Physical Activity*, *12:4*. https://doi.org/10.1186/s11556-015-0146-7

Lee, I.-M., & Paffenbarger, R. S. (2000). Associations of light, moderate, and vigorous intensity physical activity with longevity: The Harvard Alumni Health Study. *American Journal of Epidemiology*, *151*(3), 293–299. https://doi.org/10.1093/oxfordjournals.aje.a010205

Lee, J., Song, J., Hootman, J. M., Semanik, P. A., Chang, R. W., Sharma, L., … Dunlop, D. D. (2013). Obesity and other modifiable factors for physical inactivity measured by accelerometer in adults with knee osteoarthritis. *Arthritis Care & Research*, *65*(1), 53–61. https://doi.org/10.1002/acr.21754

Legh-Jones, H., & Moore, S. (2012). Network social capital, social participation, and physical inactivity in an urban adult population. *Social Science & Medicine*, *74*(9), 1362–1367. https://doi.org/10.1016/j.socscimed.2012.01.005

Li, T., & Zhang, Y. (2015). Social network types and the health of older adults: Exploring reciprocal associations. *Social Science & Medicine*, *130*, 59–68. https://doi.org/10.1016/j.socscimed.2015.02.007

Lin, N. (2003). *Social capital: a theory of social structure and action* (Repr.). Cambridge [u.a.]: Cambridge University Press.

Lipsitz, L. A., & Goldberger, A. L. (1992). Loss of "complexity" and aging. Potential applications of fractals and chaos theory to senescence. *JAMA*, *267*(13), 1806–1809. https://doi.org/10.1001/jama.267.13.1806

Litwin, H. (1998). Social network type and health status in a national sample of elderly Israelis. *Social Science & Medicine*, *46*(4–5), 599–609. https://doi.org/10.1016/S0277-9536(97)00207-4

Litwin, H. (2001). Social network type and morale in old age. *Gerontologist*, *41*(4), 516–524. https://doi.org/10.1093/geront/41.4.516

Litwin, H. (2003). Social predictors of physical activity in later life: The contribution of social-network type. *Journal of Aging and Physical Activity*, *11*(3), 389–406. https://doi.org/10.1123/japa.11.3.389

Litwin, H. (2007). What really matters in the social network-mortality association? A multivariate examination among older Jewish-Israelis. *European Journal of Ageing*, *4*(2), 71–82. https://doi.org/10.1007/s10433-007-0048-2

Litwin, H., & Shiovitz-Ezra, S. (2006). Network type and mortality risk in later life. *Gerontologist*, *46*(6), 735–743. https://doi.org/10.1093/geront/46.6.735

Liu, S.-H., Driban, J. B., Eaton, C. B., McAlindon, T. E., Harrold, L. R., & Lapane, K. L. (2016). Objectively measured physical activity and symptoms change in knee osteoarthritis. *American Journal of Medicine*, *129*(5), 497–505. https://doi.org/10.1016/j.amjmed.2015.12.029

Lund, A., Michelet, M., Sandvik, L., Wyller, T., & Sveen, U. (2012). A lifestyle intervention as supplement to a physical activity programme in rehabilitation after stroke: A randomized controlled trial. *Clinical Rehabilitation*, *26*(6), 502–512. https://doi.org/10.1177/0269215511429473

Macintyre, S., Maciver, S., & Sooman, A. (1993). Area, class and health: Should we be focusing on places or people? *Journal of Social Policy*, *22*(2), 213–234. https://doi.org/10.1017/S0047279400019310

Martinez-Gonzalez, M. A., Varo, J. J., Santos, J. L., De Irala, J., Gibney, M., Kearney, J., & Martinez, J. A. (2001). Prevalence of physical activity during leisure time in the European Union. *Medicine and Science in Sports and Exercise*, *33*(7), 1142–1146. https://doi.org/10.1097/00005768-200107000-00011

McKee, G., Kearney, P. M., & Kenny, R. A. (2015). The factors associated with self-reported physical activity in older adults living in the community. *Age and Ageing*, *44*(4), 586–592. https://doi.org/10.1093/ageing/afv042

McKinlay, J. B. (1995). The new public health approach to improving physical activity and autonomy in older populations. In E. Heikkinen, J. Kuusinen, & I. Ruoppila (Eds.), *Preparation for aging* (pp. 87–103). New York: Plenum Press.

McMurdo, M. E. T., Argo, I., Crombie, I. K., Feng, Z., Sniehotta, F. F., Vadiveloo, T., … Donnan, P. T. (2012). Social, environmental and psychological factors associated with objective physical activity levels in the over 65s. *Plos One*, *7*(2), e31878. https://doi.org/10.1371/journal.pone.0031878

McNeill, L. H., Kreuter, M. W., & Subramanian, S. V. (2006). Social environment and physical activity: A review of concepts and evidence. *Social Science & Medicine (1982)*, *63*(4), 1011–1022. https://doi.org/10.1016/j.socscimed.2006.03.012

Mohnen, S. M., Volker, B., Flap, H., & Groenewegen, P. P. (2012). Health-related behavior as a mechanism behind the relationship between neighborhood social capital and individual health - a multilevel analysis. *BMC Public Health*, *12: 116*. https://doi.org/10.1186/1471-2458-12-116

Mohnen, S. M., Volker, B., Flap, H., Subramanian, S. V., & Groenewegen, P. P. (2015). The influence of social capital on individual health: Is it the neighbourhood or the network? *Social Indicators Research*, *121*(1), 195–214. https://doi.org/10.1007/s11205-014-0632-8

Moran, M., Van Cauwenberg, J., Hercky-Linnewiel, R., Cerin, E., Deforche, B., & Plaut, P. (2014). Understanding the relationships between the physical environment and physical activity in older adults: A systematic review of qualitative studies. *International Journal of Behavioral Nutrition and Physical Activity*, *11: 79*. https://doi.org/10.1186/1479-5868-11-79

Nelson, A. E., Allen, K. D., Golightly, Y. M., Goode, A. P., & Jordan, J. M. (2014). A systematic review of recommendations and guidelines for the management of osteoarthritis: The Chronic Osteoarthritis Management Initiative of the U.S. Bone and Joint Initiative. *Seminars in Arthritis and Rheumatism*, *43*(6), 701–712. https://doi.org/10.1016/j.semarthrit.2013.11.012

Nelson, M. E., Rejeski, W. J., Blair, S. N., Duncan, P. W., Judge, J. O., King, A. C., … Castaneda-Sceppa, C. (2007). Physical activity and public health in older adults: Recommendation from the American College of Sports Medicine and the American Heart Association. *Medicine and Science in Sports and Exercise*, *39*(8), 1435–1445. https://doi.org/10.1249/mss.0b013e3180616aa2

Neogi, T., & Zhang, Y. (2013). Epidemiology of osteoarthritis. *Rheumatic Diseases Clinics of North America*, *39*(1), 1–19. https://doi.org/10.1016/j.rdc.2012.10.004

Nevit, M., Felson, D., & Lester, G. (2006). The Osteoarthritis Initiative: Protocol for the cohort study. Retrieved May 23, 2016, from http://oai.epi-ucsf.org/datarelease/docs/StudyDesignProtocol.pdf

Newman, M. L. (2013). *Health and social relationships: the good, the bad, and the complicated* (1. ed.). Washington, DC: American Psychological Assoc.

O'Neill, K., & Reid, G. (1991). Perceived barriers to physical-activity by older adults. *Canadian Journal of Public Health*, *82*(6), 392–396.

Parsons, C., Clynes, M., Syddall, H., Jagannath, D., Litwic, A., van der Pas, S., … EPOSA research group. (2015). How well do radiographic, clinical and self-reported diagnoses of knee osteoarthritis agree? Findings from the Hertfordshire cohort study. *SpringerPlus*, *4*(1), 177. https://doi.org/10.1186/s40064-015-0949-z

Pereira, D., Peleteiro, B., Araujo, J., Branco, J., Santos, R. A., & Ramos, E. (2011). The effect of osteoarthritis definition on prevalence and incidence estimates: A systematic review. *Osteoarthritis and Cartilage*, *19*(11), 1270–1285. https://doi.org/10.1016/j.joca.2011.08.009

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Gorber, S. C., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: A systematic review. *International Journal of Behavioral Nutrition and Physical Activity*, *5: 56*. https://doi.org/10.1186/1479-5868-5-56

Prohaska, T., Belansky, E., Belza, B., Buchner, D., Marshall, V., McTigue, K., … Wilcox, S. (2006). Physical activity, public health, and aging: Critical issues and research priorities. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences*, *61*(5), S267–S273. https://doi.org/10.1093/geronb/61.5.s267

Pucher, J., & Buehler, R. (2008). Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany. *Transport Reviews*, *28*(4), 495–528. https://doi.org/10.1080/01441640701806612

Ribeiro, A. I., Mitchell, R., Carvalho, M. S., & de Pina, M. de F. (2013). Physical activity-friendly neighbourhood among older adults from a medium size urban setting in Southern Europe. *Preventive Medicine*, *57*(5), 664–670. https://doi.org/10.1016/j.ypmed.2013.08.033

Robbins, S. M., Jones, G. R., Birmingham, T. B., & Maly, M. R. (2013). Quantity and quality of physical activity are influenced by outdoor temperature in people with knee osteoarthritis. *Physiotherapy Canada*, *65*(3), 248–254. https://doi.org/10.3138/ptc.2012-39

Robins, L. M., Jansons, P., & Haines, T. (2016). The impact of physical activity interventions on social isolation among community - dwelling older adults: A systematic review. *Research & Reviews: Journal of Nursing and Health Sciences*, *2*(1), 62–71.

Rowe, J. W., & Kahn, R. L. (1997). Successful aging. *The Gerontologist*, *37*(4), 433–440.

Sallis, J. F., & Saelens, B. E. (2000). Assessment of physical activity by self-report: Status, limitations, and future directions. *Research Quarterly for Exercise and Sport*, *71*(2), S1–S14. https://doi.org/10.1080/02701367.2000

Sartini, C., Wannamethee, S. G., Iliffe, S., Morris, R. W., Ash, S., Lennon, L., … Jefferis, B. J. (2015). Diurnal patterns of objectively measured physical activity and sedentary behaviour in older men. *BMC Public Health*, *15: 609*. https://doi.org/10.1186/s12889-015-1976-y

Scheidt, R. J., & Norris-Baker, C. (2003). The general ecological model revisited: Evolution, current status, and continuing challenges. *Annual Review of Gerontology and Geriatrics*, *23*, 34–58.

Schoeni, R. F., Freedman, V. A., & Martin, L. G. (2008). Why is late-life disability declining? *The Milbank Quarterly*, *86*(1), 47–89. https://doi.org/10.1111/j.1468-0009.2007.00513.x

Schuna, J. M., Johnson, W. D., & Tudor-Locke, C. (2013). Adult self-reported and objectively monitored physical activity and sedentary behavior: NHANES 2005-2006. *International Journal of Behavioral Nutrition and Physical Activity*, *10: 126*. https://doi.org/10.1186/1479-5868-10-126

Schutzer, K. A., & Graves, B. S. (2004). Barriers and motivations to exercise in older adults. *Preventive Medicine*, *39*(5), 1056–1061. https://doi.org/10.1016/j.ypmed.2004.04.003

Segura-Jimenez, V., Alvarez-Gallardo, I. C., Romero-Zurita, A., Camiletti-Moiron, D., Munguia-Izquierdo, D., Carbonell-Baeza, A., & Ruiz, J. R. (2014). Comparison of physical activity using questionnaires (leisure time physical activity instrument and physical activity at home and work instrument) and accelerometry in fibromyalgia patients: The Al-Ándalus project. *Archives of Physical Medicine and Rehabilitation*, *95*(10), 1903–1911. https://doi.org/10.1016/j.apmr.2014.05.015

Shih, M., Hootman, J. M., Kruger, J., & Helmick, C. G. (2006). Physical activity in men and women with arthritis - National Health Interview Survey, 2002. *American Journal of Preventive Medicine*, *30*(5), 385–393. https://doi.org/10.1016/j.amepre.2005.12.005

Shiovitz-Ezra, S., & Litwin, H. (2012). Social network type and health-related behaviors: Evidence from an American national survey. *Social Science & Medicine*, *75*(5), 901–904. https://doi.org/10.1016/j.socscimed.2012.04.031

Sjöström, M., Oja, P., Hagströmer, M., Smith, B. J., & Bauman, A. (2006). Health-enhancing physical activity across European Union countries: The Eurobarometer study. *Journal of Public Health*, *14*(5), 291–300. https://doi.org/10.1007/s10389-006-0031-y

Sleimen-Malkoun, R., Temprado, J.-J., & Hong, S. L. (2014). Aging induced loss of complexity and dedifferentiation: Consequences for coordination dynamics within and between brain, muscular and behavioral levels. *Frontiers in Aging Neuroscience*, *6: 140*. https://doi.org/10.3389/fnagi.2014.00140

Slymen, D. J., Ayala, G. X., Arredondo, E. M., & Elder, J. P. (2006). A demonstration of modeling count data with an application to physical activity. *Epidemiologic Perspectives & Innovations*, *3*(1), 1–9. https://doi.org/10.1186/1742-5573-3-3

Spector, T., & Hochberg, M. (1994). Methodological problems in the epidemiological study of osteoarthritis. *Annals of the Rheumatic Diseases*, *53*(2), 143–146. https://doi.org/10.1136/ard.53.2.143

Stathi, A., Gilbert, H., Fox, K. R., Coulson, J., Davis, M., & Thompson, J. L. (2012). Determinants of neighborhood activity of adults age 70 and over: A mixed-methods study. *Journal of Aging and Physical Activity*, *20*(2), 148–170. https://doi.org/10.1123/japa.20.2.148

Stehr, M. D., & von Lengerke, T. (2012). Preventing weight gain through exercise and physical activity in the elderly: A systematic review. *Maturitas*, *72*(1), 13–22. https://doi.org/10.1016/j.maturitas.2012.01.022

Stel, V. S., Smit, J. H., Pluijm, S. M. F., Visser, M., Deeg, D. J. H., & Lips, P. (2004). Comparison of the LASA Physical Activity Questionnaire with a 7-day diary and pedometer. *Journal of Clinical Epidemiology*, *57*(3), 252–258. https://doi.org/10.1016/j.jclinepi.2003.07.008

Stenholm, S., Koster, A., Valkeinen, H., Patel, K. V., Bandinelli, S., Guralnik, J. M., & Ferrucci, L. (2016). Association of physical activity history with physical function and mortality in old age. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *71*(4), 496–501. https://doi.org/10.1093/gerona/glv111

Stubbs, B., Hurley, M., & Smith, T. (2015). What are the factors that influence physical activity participation in adults with knee and hip osteoarthritis? A systematic review of physical activity correlates. *Clinical Rehabilitation*, *29*(1), 80–94. https://doi.org/10.1177/0269215514538069

Sugiyama, T., Thompson, C. W., & Alves, S. (2009). Associations between neighborhood open space attributes and quality of life for older people in Britain. *Environment and Behavior*, *41*(1), 3–21. https://doi.org/10.1177/0013916507311688

Sumukadas, D., Witham, M., Struthers, A., & McMurdo, M. (2009). Day length and weather conditions profoundly affect physical activity levels in older functionally impaired people. *Journal of Epidemiology and Community Health*, *63*(4), 305–309. https://doi.org/10.1136/jech.2008.080838

Sun, F., Norman, I. J., & While, A. E. (2013). Physical activity in older people: A systematic review. *BMC Public Health*, *13: 449*. https://doi.org/10.1186/1471-2458-13-449

Sun, K., Song, J., Lee, J., Chang, R. W., Eaton, C. B., Ehrlich-Jones, L., … Dunlop, D. D. (2014). Relationship of meeting physical activity guidelines with health-related utility. *Arthritis Care & Research*, *66*(7), 1041–1047. https://doi.org/10.1002/acr.22262

Szoeke, C. E. I., Dennerstein, L., Wluka, A. E., Guthrie, J. R., Taffe, J., Clark, M. S., & Cicuttini, F. M. (2008). Physician diagnosed arthritis, reported arthritis and radiological non-axial osteoarthritis. *Osteoarthritis and Cartilage*, *16*(7), 846–850. https://doi.org/10.1016/j.joca.2007.12.001

Tak, E., Kuiper, R., Chorus, A., & Hopman-Rock, M. (2013). Prevention of onset and progression of basic ADL disability by physical activity in community dwelling older adults: A meta-analysis. *Ageing Research Reviews*, *12*(1), 329–338. https://doi.org/10.1016/j.arr.2012.10.001

Terwee, C. B., Bouwmeester, W., van Elsland, S. L., de Vet, H. C. W., & Dekker, J. (2011). Instruments to assess physical activity in patients with osteoarthritis of the hip or knee: A systematic review of measurement properties. *Osteoarthritis and Cartilage*, *19*(6), 620–633. https://doi.org/10.1016/j.joca.2011.01.002

Timmermans, E. J., Schaap, L. A., Herbolsheimer, F., Dennison, E. M., Maggi, S., Pedersen, N. L., … Deeg, D. J. H. (2015). The influence of weather conditions on joint pain in older people with osteoarthritis: Results from the European Project on OSteoArthritis. *Journal of Rheumatology*, *42*(10), 1885–1892. https://doi.org/10.3899/jrheum.141594

Timmermans, E. J., van der Pas, S., Schaap, L. A., Sánchez-Martínez, M., Zambon, S., Peter, R., … Deeg, D. J. (2014). Self-perceived weather sensitivity and joint pain in older people with osteoarthritis in six European countries: results from the European Project on OSteoArthritis (EPOSA). *BMC Musculoskeletal Disorders*, *15*(1), 66. https://doi.org/10.1186/1471-2474-15-66

Touhy, T. A., & Jett, K. F. (2009). *Ebersole and Hess' Gerontological Nursing & Healthy Aging* (0003 ed.). St. Louis, Mo: C V Mosby Co.

Troiano, R. P., McClain, J. J., Brychta, R. J., & Chen, K. Y. (2014). Evolution of accelerometer methods for physical activity research. *British Journal of Sports Medicine*, *48*(13), 1019–23. https://doi.org/10.1136/bjsports-2014-093546

Tucker, P., & Gilliland, J. (2007). The effect of season and weather on physical activity: A systematic review. *Public Health*, *121*(12), 909–922. https://doi.org/10.1016/j.puhe.2007.04.009

Urquhart, D. M., Tobing, J. F. L., Hanna, F. S., Berry, P., Wluka, A. E., Ding, C., & Cicuttini, F. M. (2011). What is the effect of physical activity on the knee joint? A systematic review. *Medicine and Science in Sports and Exercise*, *43*(3), 432–442. https://doi.org/10.1249/MSS.0b013e3181ef5bf8

van der Pas, S., Castell, M. V., Cooper, C., Denkinger, M., Dennison, E. M., Edwards, M. H., … Deeg, D. J. (2013). European Project on OSteoArthritis: Design of a six-cohort study on the personal and societal burden of osteoarthritis in an older European population. *BMC Musculoskeletal Disorders*, *14:138*. https://doi.org/10.1186/1471-2474-14-138

van der Pas, S., Schaap, L. A., Castell, M. V., Cooper, C., Denkinger, M., Edwards, M. H., … Deeg, D. J. H. (2016). Availability and use of neighborhood resources by older people with osteoarthritis: Results from the European Project on OSteoArthritis. *Health & Place*, *37*, 1–7. https://doi.org/10.1016/j.healthplace.2015.10.006

van Dyk, S. (2014). The appraisal of difference: Critical gerontology and the active-ageing-paradigm. *Journal of Aging Studies*, *31*, 93–103. https://doi.org/10.1016/j.jaging.2014.08.008

Van Holle, V., Deforche, B., Van Cauwenberg, J., Goubert, L., Maes, L., Van de Weghe, N., & De Bourdeaudhuij, I. (2012). Relationship between the physical environment and different

domains of physical activity in European adults: a systematic review. *BMC Public Health*, *12: 807*. https://doi.org/10.1186/1471-2458-12-807

van Schoor, N. M., Zambon, S., Castell, M. V., Cooper, C., Denkinger, M., Dennison, E. M., … Deeg, D. J. H. (2016). Impact of clinical osteoarthritis of the hip, knee and hand on self-rated health in six European countries: The European Project on OSteoArthritis. *Quality of Life Research*, *25*(6), 1423–32. https://doi.org/10.1007/s11136-015-1171-8

Verbrugge, L. M., & Jette, A. M. (1994). The disablement process. *Social Science & Medicine*, *38*(1), 1–14. https://doi.org/10.1016/0277-9536(94)90294-1

Victor, C., Scambler, S., Bond, J., & Bowling, A. (2000). Being alone in later life: Loneliness, social isolation and living alone. *Reviews in Clinical Gerontology*, *10*(4), 407–417. https://doi.org/10.1017/s0959259800104101

Vignon, E., Valat, J., Rossignol, M., Avouac, B., Rozenberg, S., Thoumie, P., … Hilliquin, P. (2006). Osteoarthritis of the knee and hip and activity: A systematic international review and synthesis (OASIS). *Joint Bone Spine*, *73*(4), 442–455. https://doi.org/10.1016/j.jbspin.2006.03.001

Vos, T., Flaxman, A. D., Naghavi, M., Lozano, R., Michaud, C., Ezzati, M., … Murray, C. J. (2012). Years lived with disability (YLDs) for 1160 sequelae of 289 diseases and injuries 1990–2010: A systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, *380*(9859), 2163–2196. https://doi.org/10.1016/S0140-6736(12)61729-2

Wahl, H.-W., Iwarsson, S., & Oswald, F. (2012). Aging well and the environment: Toward an integrative model and research agenda for the future. *The Gerontologist*, *52*(3), 306–16. https://doi.org/10.1093/geront/gnr154

Wahl, H.-W., & Oswald, F. (2010). Environmental perspectives on ageing. In D. Dannefer & C. Phillipson (Eds.), *The SAGE handbook of social gerontology* (pp. 111–124). London: SAGE Publications Ltd.

Walker, A. (2002). A strategy for active ageing. *International Social Security Review*, *55*(1), 121–139. https://doi.org/10.1111/1468-246X.00118

Walker, A., & Maltby, T. (2012). Active ageing: A strategic policy solution to demographic ageing in the European Union. *International Journal of Social Welfare*, *21*(1), S117–S130. https://doi.org/10.1111/j.1468-2397.2012.00871.x

Wallis, J. A., Webster, K. E., Levinger, P., & Taylor, N. F. (2013). What proportion of people with hip and knee osteoarthritis meet physical activity guidelines? A systematic review and meta-analysis. *Osteoarthritis and Cartilage*, *21*(11), 1648–1659. https://doi.org/10.1016/j.joca.2013.08.003

Warburton, D. E., Charlesworth, S., Ivey, A., Nettlefold, L., & Bredin, S. S. (2010). A systematic review of the evidence for Canada's Physical Activity Guidelines for Adults. *The International Journal of Behavioral Nutrition and Physical Activity*, *7: 39*. https://doi.org/10.1186/1479-5868-7-39

Warren, J. M., Ekelund, U., Besson, H., Mezzani, A., Geladas, N., Vanhees, L., & Experts Panel. (2010). Assessment of physical activity - a review of methodologies with reference to epidemiological research: A report of the exercise physiology section of the European Association of Cardiovascular Prevention and Rehabilitation. *European Journal of Cardiovascular Prevention and Rehabilitation*, *17*(2), 127–139. https://doi.org/10.1097/HJR.0b013e32832ed875

Washburn, R. A. (2000). Assessment of physical activity in older adults. *Research Quarterly for Exercise and Sport*, *71*(2), S79–S88. https://doi.org/10.1080/02701367.2000.11082790

Wilder, F. V., Hall, B. J., & Barrett, J. P. (2003). Osteoarthritis pain and weather. *Rheumatology*, *42*(8), 955–958. https://doi.org/10.1093/rheumatology/keg264

Wilkinson, R. G. (1996). *Unhealthy Societies: The Afflictions of Inequality*. London ; New York: Routledge.

Winckers, A. N. E., Mackenbach, J. D., Compernolle, S., Nicolaou, M., van der Ploeg, H. P., De Bourdeaudhuij, I., … Lakerveld, J. (2015). Educational differences in the validity of self-reported physical activity. *BMC Public Health*, *15: 1299*. https://doi.org/10.1186/s12889-015-2656-7

Witham, M. D., Donnan, P. T., Vadiveloo, T., Sniehotta, F. F., Crombie, I. K., Feng, Z., & McMurdo, M. E. T. (2014). Association of day length and weather conditions with physical activity levels in older community dwelling people. *Plos One*, *9*(1), e85331. https://doi.org/10.1371/journal.pone.0085331

Wood, V. (1971). Age-appropriate behavior for older people. *The Gerontologist*, *11*(4), 74–78. https://doi.org/10.1093/geront/11.4_Part_2.74

Woolf, A. D., & Pfleger, B. (2003). Burden of major musculoskeletal conditions. *Bulletin of the World Health Organization*, *81*(9), 646–656.

World Health Organisation. (2003). The burden of musculoskeletal conditions at the start of the new millennium. *World Health Organization Technical Report Series*, *919*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14679827

World Health Organization. (2002). Active ageing : a policy framework. Retrieved June 1, 2016, from http://apps.who.int/iris/bitstream/10665/67215/1/WHO_NMH_NPH_02.8.pdf

World Health Organization. (2013). Diet and physical activity factsheet. Secondary diet and physical activity factsheet. Retrieved November 27, 2016, from http://www.who.int/dietphysicalactivity/factsheet_inactivity/en/

Yasunaga, A., Togo, F., Watanabe, E., Park, H., Park, S., Shephard, R. J., & Aoyagi, Y. (2008). Sex, age, season, and habitual physical activity of older Japanese: The Nakanojo Study. *Journal of Aging and Physical Activity*, *16*(1), 3–13. https://doi.org/10.1123/japa.16.1.3

Zhang, W., Doherty, M., Peat, G., Bierma-Zeinstra, M. A., Arden, N. K., Bresnihan, B., … Bijlsma, J. W. (2010). EULAR evidence-based recommendations for the diagnosis of knee osteoarthritis. *Annals of the Rheumatic Diseases*, *69*(3), 483–489. https://doi.org/10.1136/ard.2009.113100

Zhang, W., Nuki, G., Moskowitz, R. W., Abramson, S., Altman, R. D., Arden, N. K., … Tugwell, P. (2010). OARSI recommendations for the management of hip and knee osteoarthritis Part III: Changes in evidence following systematic cumulative update of research published through January 2009. *Osteoarthritis and Cartilage*, *18*(4), 476–499. https://doi.org/10.1016/j.joca.2010.01.013

Zhang, Y., Xu, L., Nevitt, M., Aliabadi, P., Yu, W., Qin, M., … Felson, D. (2001). Comparison of the prevalence of knee osteoarthritis between the elderly Chinese population in Beijing and whites in the United States - The Beijing Osteoarthritis Study. *Arthritis and Rheumatism*, *44*(9), 2065–2071. https://doi.org/10.1002/1529-0131(200109)44:9<2065::AID-ART356>3.0.CO;2-Z

List of Abbreviations

ActiFE	Activity and Function in the Elderly in Ulm
EPOSA	European Project on OSteoArthritis
Etc.	Et cetera
e.g.	For example
IPAQ	International Physical Activity Questionnaire
i.e.	This is
LAPAQ	LASA Physical Activity Questionnaire
LASA	Longitudinal Aging Study Amsterdam
LOC	Loss of Complexity
OA	Osteoarthritis
p.	Page
P-E	Person – Environnent fit
vs.	Versus

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Affidavit

Hiermit versichere ich, Florian Herbolsheimer, dass ich die hier vorliegende, zur Promotion eingereichte Arbeit mit dem Titel *"A physically active lifestyle in old age – the role of the physical and social environment"* selbstständig angefertigt habe und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt, sowie wörtlich oder inhaltlich übernommene Stellen als solche kenntlich gemacht und die aktuell gültige Satzung der Universität Ulm zur Sicherung guter wissenschaftlicher Praxis beachtet habe (§ 6 Abs. 2 Satz 1 Promotionsordnung). Ich versichere an Eides statt, dass diese Angaben wahr sind und dass ich nichts verschwiegen habe. Ich erkläre außerdem, dass die von mir vorgelegte Dissertation bisher nicht im In- oder Ausland in dieser oder ähnlicher Form in einem anderen Promotionsverfahren vorgelegt wurde. Ich versichere ferner die Richtigkeit der im Lebenslauf gemachten Angaben.

Ulm, den 26. Dezember 2016

Article 1

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ORIGINAL ARTICLE

Physical Activity Patterns Among Older Adults With and Without Knee Osteoarthritis in Six European Countries

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Objective. **To investigate patterns of physical activity in older adults with knee osteoarthritis (OA) compared to older adults without knee OA across 6 European countries. We expect country-specific differences in the physical activity levels between persons with knee OA compared to persons without knee OA. A varying degree of physical activity levels across countries would express a facilitating or impeding influence of the social, environmental, and other contextual factors on a physically active lifestyle.**

Methods. **Baseline cross-sectional data from the European Project on Osteoarthritis were analyzed. In total, 2,551 participants from 6 European countries (Germany, Italy, The Netherlands, Spain, Sweden, and the UK) were included.**

Results. **Participants with knee OA were less likely to follow physical activity recommendations and had poorer overall physical activity profiles than those without knee OA (mean 62.9 versus 81.5 minutes/day, respectively; $P = 0.015$). The magnitude of this difference varied across countries. Detailed analysis showed that low physical activity levels in persons with knee OA could be attributed to less everyday walking time (odds ratio 1.31, 95% confidence interval 1.07–1.62).**

Conclusion. **This study highlighted the fact that having knee OA is associated with a varying degree of physical activity patterns in different countries. This national variation implies that low levels of physical activity among persons with knee OA cannot be explained exclusively by individual or disease-specific factors, but that social, environmental, and other contextual factors should also be taken into account.**

INTRODUCTION

Osteoarthritis (OA) is the most prevalent form of arthritis and a major source of disability (1). In 2004, OA was considered to be responsible for 97% of all knee replacements in the US. In an international comparison, Europe and the Western Pacific region ranked highest in OA disease burden using disability-adjusted life years (2).

Health benefits of physical activity are well established. Engaging in a physically active lifestyle delays disability and promotes OA-specific benefits, including maintaining physical function and decreasing pain, depression, and fatigue (3–6). Physical activity has been shown to delay the progression of OA and of functional limitations (7).

The Indicators for Monitoring COPD and Asthma–Activity and Function in the Elderly in Ulm study was supported by the European Union (No. 2005121) and the Ministry of Science, Baden-Württemberg. The Italian cohort study is part of the National Research Council Project on Aging. The Longitudinal Aging Study Amsterdam was supported by the Dutch Ministry of Health, Welfare and Sports. The Peñagrande study was partially supported by the National Fund for Health Research (Fondo de Investigaciones en Salud) of Spain (project numbers FIS PI 05/1898, FIS RETICEF RD06/0013/1013, and FIS PS09/02143). The Swedish Twin Registry was supported in part by the Swedish Ministry of Higher Education. The Hertfordshire Cohort Study was supported by the Medical Research Council, UK.

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Significance & Innovations

- Knee osteoarthritis (OA) is associated with lower physical activity levels.
- There are country-specific variations in the associations of physical activity and knee OA.
- Physical activity differences between persons with and without knee OA could be traced back to less daily walking time.
- Social, environmental, and other contextual factors influence limitations of physical activity levels in people with knee OA.

Some evidence suggests that lack of physical activity leads to muscle strength destabilization of the knee, with a greater risk of developing or worsening OA (8). Accordingly, aerobic exercise (9) and resistance exercise (10,11) have been shown to be beneficial for OA patients and have resulted in improved gait and function. Moderate levels of physical activity are recommended for persons with OA, provided the activity is not painful (12). The American College of Rheumatology (ACR) has identified exercise programs as first-line nonpharmacologic treatment and physical activity as one of the main targets in arthritis management programs for OA patients (13,14). This corresponds with a recent review of guidelines and recommendations for the management of OA. The authors of that review found a broad agreement for the beneficial effect of low-intensity exercise for knee and hip OA in 12 of 15 recommendations (15).

Despite these varied beneficial effects of physical activity, research has shown that people with OA engage less in physical activities than persons without OA (16). This finding is consistent with epidemiologic data from the US that has repeatedly documented a high prevalence of inactivity among adults with arthritis (17,18). Earlier studies revealed that half of all persons with radiographic knee OA were inactive, and only 10.2% met physical activity recommendations of 150 minutes of moderate-to-vigorous physical activity (MVPA) per week (16). Similarly, early-stage OA patients spent more time on moderate than on vigorous physical activity, with only a minority of 30% achieving recommended levels (19).

Previous studies have shown a substantial variation in population estimates of physical activity (20,21). Country-specific prevalence rates of physical inactivity ranged internationally from 1.6% to 51.7% in a World Health Survey (22). However, most studies have focused on a single country when examining the association between physical activity and knee OA. Consequently, there is little knowledge about country-specific differences in both physical activity and knee OA. We would expect the same patterns of physical activity and knee OA across all 6 European countries if this association is solely caused by disease-specific factors. However, we hypothesize that country-specific variations remain in the association between physical inactivity and knee OA that cannot be explained exclusively by disease-specific factors.

This study investigates differences in physical activity levels between persons with and without OA in the knee across 6 European countries, using the same assessments for knee OA and physical activity in all countries. We assume that the same pathophysiologic process does not necessary lead to the same physical activity patterns in those living with knee OA. Instead, different social factors (i.e., social networks, descriptive norms in peer groups), environmental factors (i.e., climate), public policies promoting physical activity, and other contextual factors in the different countries can probably facilitate or impede a person's ability to cope with the disease and build up a physically active lifestyle. Therefore, we hypothesize that the association between knee OA and physical activity differs among the 6 European countries. We additionally studied different domains of physical activity to examine more closely in which countries persons with knee OA differ most from persons without knee OA.

SUBJECTS AND METHODS

Data source. The analyses used cross-sectional data of the European Project on Osteoarthritis (EPOSA) that included 2,942 participants. EPOSA is an observational, population-based study including data from 6 European cohort studies (Germany, Italy, The Netherlands, Spain, Sweden, and the UK) on older community-dwelling persons ages 65–85 years in all cohorts except for the UK, which has an age range of 71–79 years. A detailed description of the cohorts and the measurements is published elsewhere (23).

Using a complete-case design, we excluded 13% of the participants from further analysis because at least 1 study variable was missing (Figure 1). The excluded persons were significantly older ($\delta = 1.5$ years; $P < 0.001$) and had more comorbidities ($P = 0.005$). They did not differ in education level, sex ratio, body mass index (BMI), and the percentage of having knee OA.

Variables. Data collection started between November 2010 and March 2011 in all 6 countries and ended between September and November 2011. Trained study nurses interviewed all participants at home or in a clinical center. The study incorporated a standardized questionnaire as well as a clinical examination.

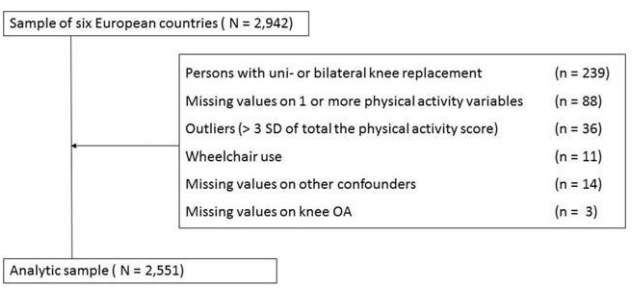


Figure 1. Strengthening the Reporting of Observational Studies in Epidemiology diagram showing criteria for excluding participants. OA = osteoarthritis.

Physical activities were measured using the validated Longitudinal Aging Study Amsterdam (LASA) Physical Activity Questionnaire (LAPAQ). The LAPAQ was found to be highly correlated with a diary covering 7 days ($r = 0.68$, $P < 0.001$) as well as moderately correlated with a pedometer ($r = 0.56$, $P < 0.001$) (24). The questionnaire consists of frequencies (i.e., How many times did you walk during the past 2 weeks?) and duration (i.e., How long did you usually walk each time?) of 6 activities in the previous 2 weeks. The activities are daily walking, daily cycling, gardening, light household work, heavy household work, and a maximum of 2 types of sports. Daily walking and daily cycling were not classified as types of sports if they were a means to perform everyday activities, like walking or cycling to the supermarket. In order to calculate the daily activity, the frequency and duration were multiplied and divided by 14 days. A total activity score was calculated by adding up walking, cycling, gardening, and sports. Light and heavy household activities were excluded from calculation because a factor analysis (not shown) revealed that household activities load on a different factor than all other activities. It is questionable whether household activities provide all of the benefits that are normally associated with meeting the physical activity guidelines (25). Extreme outliers (>3 SD, n = 36) were separately identified for each country and subsequently removed from further analysis.

We additionally provided information if participants followed recommended levels of physical activity. Current physical activity guidelines for adults and older adults recommend at least 150 minutes per week of MVPA (26). Time spent for sport activities as well as everyday cycling was summed up if the particular physical activity was coded equal to or greater than 3 metabolic equivalents (METs) (27). We decided to classify daily walking activity as a low-intensity physical activity with MET scores <3 (i.e., walking 2.0 mph on a firm surface).

Knee OA was diagnosed based on the criteria of the ACR designed for use in epidemiologic studies (28,29). The knee OA clinical diagnosis required pain in the knee as evaluated by the Western Ontario and McMaster Universities Arthritis Index (WOMAC) pain subscale score, plus 3 of the following criteria: age >50 years; morning stiffness lasting <30 minutes, evaluated by the WOMAC stiffness subscale; crepitus on active motion on at least 1 side; bony tenderness on at least 1 side; bony enlargement on at least 1 side; and no palpable warmth of synovium in both knees. The EPOSA study group has chosen a WOMAC pain cut point of ≥3 (23).

Other studies have shown that confounders regarding the association between physical activity and knee OA influence results substantially (30). To address this issue, the following variables were considered as potential confounders in the analyses: age in years, sex, and educational attainment, which summarizes the highest achieved level of school education, classified as elementary school not completed (none), elementary school completed (low), vocational or general secondary education (middle), and college or university education (high). Further confounders were clinical diagnosis of hip OA (23) and the average daily temperature (in degrees Celsius) recorded for each day and each participant, summarized for the previous 14 days. These data were extracted from local weather stations within a maximum distance from the participant's residence of 80 km. Additionally, we have explored BMI from measured height and weight (kg/m^2). If 1 item was missing (n = 39), self-reported height or weight was used instead. The comorbidity index summarizes the number of chronic diseases (chronic nonspecific lung disease, cardiovascular diseases, peripheral arterial disease, stroke, diabetes mellitus, osteoporosis, and cancer) and ranges from 0 to 7. At the end of the physical activity questionnaire we asked the participants if the past 2 weeks were or were not normal compared to the rest of the previous year. Based on this question, we created 3 dummy variables indicating reasons (disease, depression, or nice weather) for deviating from physical activity levels.

Statistical analysis. Differences in characteristics between adults with and without knee OA were tested using one-way analysis of variance for normally distributed variables, the Kruskal-Wallis tests for skewed variables, and Pearson's chi-square tests for categorical variables. Country differences in total physical activity level were analyzed with a multivariate linear regression analysis. The different subdomains of the total physical activity score (e.g., walking, cycling, and gardening) were divided into tertiles in order to account for the skewed distribution of these variables. Ordinal logistic regression models were applied with the lowest tertile as reference. Furthermore, a logistic regression was calculated predicting the probability of achieving the recommendation of 150 minutes of MVPA per week.

We examined the associations between the total physical activity score and knee OA and adjusted for all known potential confounding factors, such as sex, age, comorbidity, BMI, hip OA, average temperature, and 3 dichotomous variables indicating reasons for irregular physical activity. To examine country differences, we calculated our model in 2 steps: first, we added the 2 main effects of knee OA and country fixed effects into the model by using country dummy variables and applying the UK as reference category. In a second step, we added the interaction effect of country and knee OA, again using the UK as reference. In a further step, stratified analyses were performed by country if some of the interaction effects of knee OA and country reached significance. Afterwards, we calculated the effect of knee OA on different domains of physical activity, including walking, cycling, and gardening. The data were analyzed using STATA software, version 10.1.

RESULTS

Compared to older adults without knee OA, participants with knee OA were more likely to be less educated, obese, and female, to have more chronic diseases, and to engage in significantly lower levels of sport and walking activities. This tendency is reflected in a significantly lower total activity score and a significantly lower percentage of persons following recommendations for physical activity (Table 1).

Knee OA was significantly associated with a low physical activity score (Table 2). Subjects with knee OA were on average 10.2 minutes/day ($P = 0.011$) less physically

Table 1. Demographic characteristics and physical activity by OA status*

Characteristics	No knee OA (n = 2,141)	Knee OA (n = 410)	*P*
Demographics			
Age at time of interview, years	73.9 ± 5.1	74.4 ± 5.1	0.088
Female	48.3	66.3	< 0.001
Education, highest level			< 0.001
Primary school incomplete	9.6	18.8	
Primary school	33.4	34.9	
Secondary school/college	34.8	32.4	
University	22.2	13.9	
Physical health			
Comorbidity index (range 1–7)	1.0 ± 1.0	1.2 ± 1.1	< 0.001
BMI (kg/m^2)	27.3 ± 4.2	29.4 ± 4.8	< 0.001
Irregular physical activity in past 2 weeks†			
Disease	8.0	11.0	0.050
Depression	0.6	0.5	0.772
Nice weather	1.7	2.7	0.167
Average temperature, °C‡	12.0 ± 5.5	12.3 ± 5.6	0.279
Physical activity, minutes/day			
Total physical activity§	96.1 ± 86.6	75.1 ± 71.3	< 0.001
Walking	33.7 ± 40.1	29.0 ± 40.4	0.007
Cycling	5.7 ± 17.9	4.3 ± 13.3	0.177
Sport activities	30.1 ± 42.0	20.0 ± 36.3	0.009
Gardening	32.3 ± 61.4	22.0 ± 42.6	0.011
Following physical activity recommendations¶	40.1	34.9	0.046

* Values are mean ± SD or percentage, unless otherwise indicated. OA = osteoarthritis; BMI = body mass index.
† Subjects were asked "Why were the past two weeks not normal (compared to the rest of the year)."
‡ Temperature of the last 2 weeks before the interview was conducted.
§ Total Longitudinal Aging Study Amsterdam Physical Activity Questionnaire score without household activities.
¶ >150 minutes per week of moderate-to-vigorous physical activity.

active than persons without the condition. The UK was selected as reference category in the following linear regression models, as the effect of knee OA was most strongly pronounced in this country. The analyses show that overall physical activity levels as well as the effect of knee OA on physical activity vary significantly between some countries. The Netherlands, Sweden, and Spain showed, compared to the UK, overall lower physical activity

Table 2. Adjusted means, t-values, and *P* values for linear regression models testing total physical activity by knee OA affected joints and country interactions*

	Model 1			Model 2		
	B	t-value	*P*	*B*	t-value	*P*
Intercept	268.26	10.03	< 0.001	273.02	10.20	< 0.001
Knee OA	−10.17	−2.54	0.011	−31.69	−3.08	0.002
Country						
UK (ref.)						
Spain	−32.51	−5.05	< 0.001	−35.67	−6.31	< 0.001
Germany	11.11	1.72	0.086	9.44	1.33	0.184
Sweden	−29.65	−5.35	< 0.001	−34.50	−5.68	< 0.001
Italy	−9.99	−1.43	0.154	−11.48	−1.47	0.143
The Netherlands	−42.80	−7.91	< 0.001	−47.35	−8.10	< 0.001
Interaction terms†						
Knee OA UK (ref.)						
Knee OA Spain				23.57	2.02	0.044
Knee OA Germany				11.70	0.76	0.449
Knee OA Sweden				33.50	2.61	0.009
Knee OA Italy				15.43	0.95	0.344
Knee OA The Netherlands				35.54	2.89	0.004
Adjusted R^2			0.151			0.153

* OA = osteoarthritis; ref. = reference.
† Adjusted for hip OA, hip and knee OA, body mass index, comorbidities, age, sex, average temperature in the previous 2 weeks, and disease, depression, or nice weather in the previous 2 weeks.

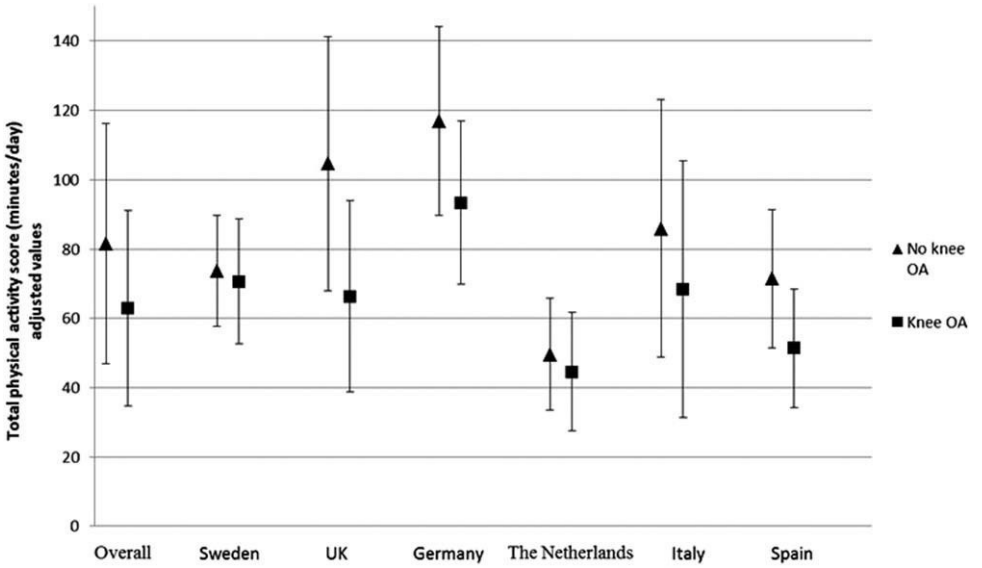


Figure 2. Association of total daily physical activity with knee osteoarthritis (OA) in 6 countries. Adjusted for sex, age, body mass index, and comorbidities, as well as average temperature, knee OA, hip OA, and irregular physical activity in the previous 2 weeks. Error bars represent 1 SD.

levels. Besides the main effects of knee OA and the main effect of country, we found country-specific variations of the effect of knee OA on physical activity that were significantly lower in The Netherlands, Sweden, and Spain compared to the UK. All models were adjusted for sex, age, BMI, hip OA, comorbidity, reasons for irregular physical activity, and

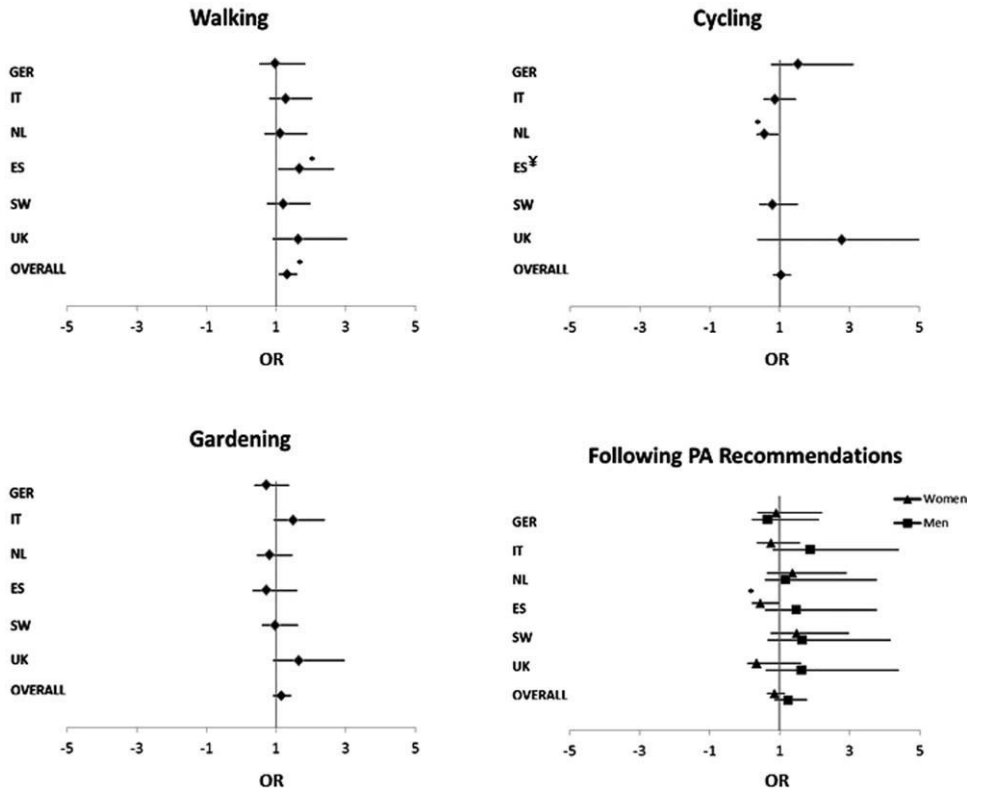


Figure 3. Odds ratios (ORs) with 95% confidence interval for being in the lowest tertile of physical activity in persons with and without knee osteoarthritis (OA) across countries and stratified by different domains of physical activity, adjusted for sex, age, body mass index, comorbidities, and average temperature, as well as hip OA, hip and knee OA, and irregular physical activity (PA) in the previous 2 weeks. GER = Germany; IT = Italy; NL = The Netherlands; ES = Spain; SW = Sweden; UK = - United Kingdom; * $P < 0.05$; ¥ = insufficient cases, model does not converge.

average temperature. Results did not change when using a bootstrapping procedure based on 500 bootstrapping samples in order to account for a non-normal distribution of the total physical activity levels.

Figure 2 illustrates the associations of adjusted total daily activity duration with knee OA stratified by country. The absolute amount of physical activity varies across Europe and ranges from mean ± SD 114.3 ± 27.7 minutes/day in Germany to 48.9 ± 16.3 minutes/day in The Netherlands. Country-specific analysis that compared individuals with and without knee OA showed substantially decreased physical activity levels in the UK ($P = 0.010$).

Figure 3 displays ordinal logistic regression estimates with the LAPAQ subscores (walking, cycling, and gardening) as dependent variables in persons with knee OA. The fourth graph represents the results of a logistic regression estimating the probability of achieving recommended physical activity levels as a dependent variable and was stratified by sex for exploratory reasons. Women are less likely to follow physical activity recommendations compared to men (in Spain: odds ratio [OR] 0.78, 95% confidence interval [95% CI] 0.65–0.91). The overall association between knee OA and doing less walking remained significant (OR 1.31, 95% CI 1.07–1.61) in the multivariate models. The strongest effect of being inactive in terms of walking was calculated for Spain (OR 1.68, 95% CI 1.06–2.67). Interestingly, the effect of cycling points in the opposite direction in The Netherlands. Dutch participants with knee OA had a lower probability of being in the lowest cycling tertile (OR 0.57, 95% CI 0.34–0.96). That means that people with knee OA in the Netherlands cycle more often than people without knee OA do.

DISCUSSION

This international cross-sectional study has demonstrated that persons with knee OA, compared to persons without knee OA, are physically more inactive and are less likely to follow physical activity recommendations. However, the association between knee OA and physical activity substantially differs across countries and the type of physical activity considered.

We found a strong association between physical inactivity and knee OA in the UK and Spain. In these 2 countries, persons with knee OA walked less than individuals without knee OA. Daily walking activity accounted for one-third of the total physical activity score. This finding is in line with a global study comparing physical activity levels. In this study, 20% of the entire daily physical activity was derived from walking in all countries. This share increased to more than 30% in countries with substantial rates of high physical activity (21). In our study, persons with knee OA report less walking, which may decrease pain and disability. Reasons participants avoided walking could be pain that is associated with walking activity, as well as uncertainty about the role of moderate exercise and physical activity, along with the fear of continuing or worsening wear and tear within the joint (31).

On the other hand, we found no association of physical inactivity with knee OA in The Netherlands and Sweden. Participants with knee OA were overall as physically active as persons without knee OA. A detailed analysis revealed that older adults with knee OA even cycle more often in The Netherlands than individuals without knee OA. Cycling is a joint-friendly type of physical activity that is advised for persons with arthritis to meet physical activity recommendations (32,33). Persons with knee OA may cycle because cycling causes less pain, it is recommended by physicians, and the infrastructure facilitates this kind of physical activity. Since the 1970s, The Netherlands have served as an example of how continuous maintenance and improvement of cycling facilities can encourage inhabitants to engage in light exercise (34). Bauman et al (21) assumed that countries "with an infrastructure or culture that supports walking can achieve high levels of physical activity with lesser contribution from vigorous activity."

These country-specific associations between physical inactivity and OA support our assumption that the low level of physical activity in individuals with knee OA found in other studies (16,35) cannot be explained by individual or disease-specific factors only. Instead, public policies that promote physical activity (36) might have contributed to our results. Sweden, for instance, provides primary care advice by the general practitioner to populations at risk of chronic disease. Furthermore, communities can strongly influence people's levels of physical activity by shaping cultural attitudes towards physical activity as well as by offering social support. In Sweden, 74% of people agreed that "local sport clubs and other providers offer many opportunities for physical activity," compared to 54% in Italy (37). Finally, environmental conditions such as local climate have been found to affect pain perceptions in persons with OA (38), with a greater impact in Southern Europe. In summary, contextual factors seem to influence individuals' behavior when it comes to coping with their disease and influence whether they can build up a physically active lifestyle.

To our knowledge, the present study is the first that has compared physical activity in older persons with and without knee OA across countries. The assessments of physical activity and OA were standardized across countries using a validated physical activity questionnaire and the ACR criteria for clinical knee OA. The large size of the EPOSA cohort is a major strength of the present study. All cohorts were recruited from population samples and have been shown to be representative of the populations from which they were drawn. Each cohort was interviewed in different seasons to account for variations in physical activity levels (39) as well as severity of pain (40) over the year. Our findings accorded with patterns of physical activity across Europe derived from previous research. A north-south gradient in leisure time physical activity (41) was partly apparent in this study. Germany and the UK showed the most active population followed by Italy, Sweden and Spain. However, The Netherlands usually ranked highest in comparable analyses (20,42), while our study estimated the lowest activity score. Partly, the data collection phase may have contributed to that difference. In The Netherlands, the data collection mainly took place in the winter and spring season. An additional strength of our study is that in contrast to previous studies, which

only assessed overall physical activity (35,43), we disaggregated the physical activity index score and calculated more detailed analysis for each type of physical activity. Thereby, we could show clearly that physical activities have to be disentangled and separated into their components, as demonstrated above.

Future health promotion activities on knee OA that incorporate these country-specific differences might be more effective. In order to invent targeted and substantial intervention programs, researchers first need to assess physical activity habits, which might be appreciably different in each country setting. For further research, we would recommend considering country- and context-specific activity patterns when designing interventions.

This study has some limitations. Self-reported physical activity may have been problematic due to the older participants having difficulties accurately recalling their daily activities (44). Questionnaires asking about a limited number of activities may not capture the activities in daily life in their entirety (45) or conversely may overestimate the duration of some daily activities. Accordingly, self-reports are likely to have a degree of measurement error (46) that is also reflected in our calculations by large confidence intervals. However, to our knowledge there is no evidence that physical activity misclassification would differ by OA status or any other demographic variable. If such a discrepancy was the case, results would be likely biased to the null (47). Accelerometers may be one suitable instrument in future studies that also indicate the intensity of each activity, which, in terms of knee OA, is an important indicator, besides the information from questionnaires.

One further limitation is that OA was not diagnosed with radiographic criteria but was defined based on the clinical ACR classification alone. However, to account for differences in radiographic and clinical OA, a subsample of the EPOSA cohort, who originally participated in the Hertfordshire Cohort Study, was closely investigated (48). The clinical definition was considered as correctly defining participants without OA (specificity of 91.5%). The majority of participants (66.1%) with clinical knee OA also had radiographic knee OA. On the other hand, far more participants were classified as having OA based on radiographic criteria than were identified with the clinical definition. This difference suggests that we underestimated the number of persons having radiographic OA but no clinical symptoms like pain. The aim of the EPOSA study was not to detect early structural joint cartilage changes but to find older persons with symptoms of OA, such as joint pain and functional limitations. In this setting, the clinical approach might reflect the burden of the condition more accurately. Furthermore, we do not have information about the history of previous knee injury or the exact compartment where knee OA is predominant. This knowledge would have provided additional valuable information on subgroups with even lower physical activity levels, but there is no reason this would cause an unequal distribution across the 6 countries participating in the study. The additional information would therefore only specify the effect of knee OA but would not explain country differences. In addition, our analyses did not distinguish between knee OA in 1 joint and the related pain levels. Joint pain is the dominant symptom of OA and consequently serves as 1 major component of the ACR definition. Another limitation could occur by dropping participants with joint replacements from our analyses. Studies showed that physical activity levels of people with joint replacements are neither comparable with persons without knee OA nor with persons with knee OA (35,49). Finally, causality cannot be inferred from cross-sectional data. Lower levels of physical activity could be a result not only of knee OA but could also be a consequence of other well known risk factors for the development of knee OA, such as obesity, bone deformities, or traumas (16,50).

This study contributes to public health efforts to provide evidence for contextual factors accounting for physical activity levels in individuals with knee OA. The application of standardized measures for knee OA and physical activity enabled us to compare the associations under study across all participating countries. We have shown that physical activity limitations differ across countries and the type of physical activity. The information presented in this article can greatly aid in informing public authorities about the value of an activity-supporting environment.

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AUTHOR CONTRIBUTIONS

All authors were involved in drafting the article or revising it critically for important intellectual content, and all authors approved the final version to be submitted for publication. Dr. Herbolsheimer had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study conception and design. Herbolsheimer, Schaap, Edwards, Maggi, Otero, Timmermans, Denkinger, van der Pas, Dekker, Cooper, Dennison, van Schoor, Peter.

Acquisition of data. Herbolsheimer, Schaap, Edwards, Maggi, Otero, Timmermans, Denkinger, van der Pas, Dennison, van Schoor, Peter.

Analysis and interpretation of data. Herbolsheimer, Otero, Timmermans, Denkinger, van der Pas, Dekker, Cooper, Dennison, van Schoor, Peter.

REFERENCES

1. Andersson G. The burden of musculoskeletal diseases in the United States: prevalence, societal and economic cost. New Rosemont, IL: American Academy of Orthopaedic Surgeons; 2008.
2. Woolf AD, Erwin J, March L. The need to address the burden of musculoskeletal conditions. Best Pract Res Clin Rheumatol 2012;26:183–224.

3. Esser S, Bailey A. Effects of exercise and physical activity on knee osteoarthritis. Curr Pain Headache Rep 2011;15:423–30.
4. Fransen M, McConnell S. Exercise for osteoarthritis of the knee. Cochrane Database Syst Rev 2008:CD004376.
5. Reimers N, Reimers CD. Exercise for lower back pain, hip and knee osteoarthritis, and fibromyalgia: effects on pain–a literature review. Akt Rheumatol 2012;37:174–88.
6. Urquhart DM, Tobing JF, Hanna FS, Berry P, Wluka AE, Ding C, et al. What is the effect of physical activity on the knee joint? A systematic review. Med Sci Sports Exerc 2011;43:432–42.
7. White DK, Tudor-Locke C, Zhang Y, Fielding R, LaValley M, Felson DT, et al. Daily walking and the risk of incident functional limitation in knee osteoarthritis: an observational study. Arthritis Care Res (Hoboken) 2014;66:1328–36.
8. O'Reilly SC, Jones A, Muir KR, Doherty M. Quadriceps weakness in knee osteoarthritis: the effect on pain and disability. Ann Rheum Dis 1998;57:588–94.
9. Escalante Y, Garcia-Hermoso A, Saavedra JM. Effects of exercise on functional aerobic capacity in lower limb osteoarthritis: a systematic review. J Sci Med Sport 2011;14:190–8.
10. Thomas KS, Muir KR, Doherty M, Jones AC, O'Reilly SC, Bassey EJ. Home based exercise programme for knee pain and knee osteoarthritis: randomised controlled trial. Br Med J 2002;325:752–5.
11. Vincent KR, Vincent HK. Resistance exercise for knee osteoarthritis. PM R 2012;4:S45–52.
12. Vignon E, Valat J, Rossignol M, Avouac B, Rozenberg S, Thoumie P, et al. Osteoarthritis of the knee and hip and activity: a systematic international review and synthesis (OASIS). Joint Bone Spine 2006;73:442–55.
13. Hochberg MC, Altman RD, April KT, Benkhalti M, Guyatt G, McGowan J, et al. American College of Rheumatology 2012 recommendations for the use of nonpharmacologic and pharmacologic therapies in osteoarthritis of the hand, hip, and knee. Arthritis Care Res (Hoboken) 2012;64:465–74.
14. Shih M, Hootman JM, Kruger J, Helmick CG. Physical activity in men and women with arthritis: National Health Interview Survey, 2002. Am J Prev Med 2006;30:385–93.
15. Nelson AE, Allen KD, Golightly YM, Goode AP, Jordan JM. A systematic review of recommendations and guidelines for the management of osteoarthritis: the Chronic Osteoarthritis Management Initiative of the U.S. Bone and Joint Initiative. Semin Arthritis Rheum 2014;43:701–12.
16. Lee J, Song J, Hootman JM, Semanik PA, Chang RW, Sharma L, et al. Obesity and other modifiable factors for physical inactivity measured by accelerometer in adults with knee osteoarthritis. Arthritis Care Res (Hoboken) 2013;65:53–61.
17. Hootman JM, Macera CA, Ham SA, Helmick CG, Sniezek JE. Physical activity levels among the general US adult population and in adults with and without arthritis. Arthritis Rheum 2003;49:129–35.
18. Centers for Disease Control and Prevention. State-specific prevalence of no leisure-time physical activity among adults with and without doctor-diagnosed arthritis–United States, 2009. MMWR Morb Mortal Wkly Rep 2011;60:1641–5.
19. Farr JN, Going SB, Lohman TG, Rankin L, Kasle S, Cornett M, et al. Physical activity levels in patients with early knee osteoarthritis measured by accelerometry. Arthritis Rheum 2008;59:1229–36.
20. Sjostrom M, Oja P, Hagstromer M, Smith BJ, Bauman A. Health-enhancing physical activity across European Union countries: the Eurobarometer study. J Public Health 2006;14:291–300.
21. Bauman A, Bull F, Chey T, Craig CL, Ainsworth BE, Sallis JF, et al. The International Prevalence Study on physical activity: results from 20 countries. Int J Behav Nutr Phys Act 2009;6:21.
22. Guthold R, Ono T, Strong KL, Chatterji S, Morabia A. Worldwide variability in physical inactivity: a 51-country survey. Am J Prev Med 2008;34:486–94.
23. Van der Pas S, Castell MV, Cooper C, Denkinger M, Dennison EM, Edwards MH, et al. European project on osteoarthritis: design of a six-cohort study on the personal and societal burden of osteoarthritis in an older European population. BMC Musculoskelet Disord 2013;14:138.
24. Stel VS, Smit JH, Pluijm SM, Visser M, Deeg DJ, Lips P. Comparison of the LASA Physical Activity Questionnaire with a 7-day diary and pedometer. J Clin Epidemiol 2004;57:252–8.
25. Murphy MH, Donnelly P, Breslin G, Shibli S, Nevill AM. Does doing housework keep you healthy? The contribution of domestic physical activity to meeting current recommendations for health. BMC Public Health 2013;13:966.
26. US Department of Health and Human Services. Physical activity guidelines for Americans: 2008. 2015. URL: http://www.health.gov/paguidelines/pdf/paguide.pdf.
27. Ainsworth BE, Haskell WL, Whitt MC, Irwin ML, Swartz AM, Strath SJ, et al. Compendium of physical activities: an update of activity codes and MET intensities. Med Sci Sports Exerc 2000;32:S498–504.
28. Zhang W, Doherty M, Peat G, Bierma-Zeinstra MA, Arden NK, Bresnihan B, et al. EULAR evidence-based recommendations for the diagnosis of knee osteoarthritis. Ann Rheum Dis 2010;69:483–9.
29. Altman R, Asch E, Bloch D, Bole G, Borenstein D, Brandt K, et al. Development of criteria for the classification and reporting of osteoarthritis: classification of osteoarthritis of the knee. Arthritis Rheum 1986;29:1039–49.
30. Sun K, Song J, Lee J, Chang RW, Eaton CB, Ehrlich-Jones L, et al. Relationship of meeting physical activity guidelines with health-related utility. Arthritis Care Res (Hoboken) 2014;66:1041–7.
31. Holden MA, Nicholls EE, Young J, Hay EM, Foster NE. Role of exercise for knee pain: what do older adults in the community think? Arthritis Care Res (Hoboken) 2012;64:1554–64.
32. Salacinski AJ, Krohn K, Lewis SF, Holland ML, Ireland K, Marchetti G. The effects of group cycling on gait and pain-related disability in individuals with mild-to-moderate knee osteoarthritis: a randomized controlled trial. J Orthop Sports Phys Ther 2012;42:985–95.
33. Westby MD. A health professional's guide to exercise prescription for people with arthritis: a review of aerobic fitness activities. Arthritis Rheum 2001;45:501–11.
34. Pucher J, Buehler R. Making cycling irresistible: lessons from the Netherlands, Denmark and Germany. Transp Rev 2008;28:495–528.
35. Ageberg E, Engstroem G, Verdier MG de, Rollof J, Roos EM, Lohmander LS. Effect of leisure time physical activity on severe knee or hip osteoarthritis leading to total joint replacement: a population-based prospective cohort study. BMC Musculoskelet Disord 2012;13:73.
36. Bellew B, Bauman A, Martin B, Bull F, Matsudo V. Public policy actions needed to promote physical activity. Curr Cardiovasc Risk Rep 2011;5:340–9.
37. European Opinion Research Group. Physical activity: 2003. 2015. URL: http://europa.eu.int/comm/public_opinion/archives/ebs/ebs_183_6_en.pdf.
38. Timmermans EJ, van der Pas S, Schaap LA, Sanchez-Martinez M, Zambon S, Peter R, et al. Self-perceived weather sensitivity and joint pain in older people with osteoarthritis in six European countries: results from the European Project on OSteoArthritis (EPOSA). BMC Musculoskeletal Disord 2014;15:66.
39. Klenk J, Buchele G, Rapp K, Franke S, Peter R, ActiFE Study Group. Walking on sunshine: effect of weather conditions on physical activity in older people. J Epidemiol Community Health 2012;66:474–6.
40. McAlindon T, Formica M, Schmid CH, Fletcher J. Changes in barometric pressure and ambient temperature influence osteoarthritis pain. Am J Med 2007;120:429–34.
41. Martinez-Gonzalez MA, Varo JJ, Santos JL, De Irala J, Gibney M, Kearney J, et al. Prevalence of physical activity during leisure time in the European Union. Med Sci Sports Exerc 2001;33:1142–6.
42. Rutten A, Abu-Omar K. Prevalence of physical activity in the European Union. Soz Praventivmed 2004;49:281–9.
43. Barbour KE, Hootman JM, Helmick CG, Murphy LB, Theis KA, Schwartz TA, et al. Meeting physical activity guidelines and the risk of incident knee osteoarthritis: a population-based prospective cohort study. Arthritis Care Res (Hoboken) 2014;66:139–46.

44. Ken-Dror G, Lerman Y, Segev S, Dankner R. Measurement and assessment of habitual physical activity in epidemiological studies. Harefuah 2005;144:200–5.
45. Durante R, Ainsworth BE. The recall of physical activity: using a cognitive model of the question-answering process. Med Sci Sports Exerc 1996;28:1282–91.
46. Ferrari P, Friedenreich C, Matthews CE. The role of measurement error in estimating levels of physical activity. Am J Epidemiol 2007;166:832–40.
47. Hernandez-Hernandez V, Ferraz-Amaro I, Diaz-Gonzalez F. Influence of disease activity on the physical activity of rheumatoid arthritis patients. Rheumatology 2014;53:722–31.
48. Parsons C, Clynes M, Syddall H, Jagannath D, Litwic A, Pas S van der, et al. How well do radiographic, clinical and self-reported diagnoses of knee osteoarthritis agree? Findings from the Hertfordshire cohort study. SpringerPlus 2015;4:177.
49. Brandes M, Ringling M, Winter C, Hillmann A, Rosenbaum D. Changes in physical activity and health-related quality of life during the first year after total knee arthroplasty. Arthritis Care Res (Hoboken) 2011;63:328–34.
50. Felson DT, Anderson JJ, Naimark A, Walker AM, Meenan RF. Obesity and knee osteoarthritis: the Framingham Study. Ann Intern Med 1988;109:18–24.

Article 2

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ORIGINAL RESEARCH

The Influence of Weather Conditions on Outdoor Physical Activity Among Older People With and Without Osteoarthritis in 6 European Countries

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Background: Older adults with osteoarthritis (OA) often report that their disease symptoms are exacerbated by weather conditions. This study examines the association between outdoor physical activity (PA) and weather conditions in older adults from 6 European countries and assesses whether outdoor PA and weather conditions are more strongly associated in older persons with OA than in those without the condition. **Methods:** The American College of Rheumatology classification criteria were used to diagnose OA. Outdoor PA was assessed using the LASA Physical Activity Questionnaire. Data on weather parameters were obtained from weather stations. **Results:** Of the 2439 participants (65–85 years), 29.6% had OA in knee, hand and/or hip. Participants with OA spent fewer minutes in PA than participants without OA (Median = 42.9, IQR = 20.0 to 83.1 versus Median = 51.4, IQR = 23.6 to 98.6; $P < .01$). In the full sample, temperature (B = 1.52; $P < .001$) and relative humidity (B = –0.77; $P < .001$) were associated with PA. Temperature was more strongly associated with PA in participants without OA (B = 1.98; $P < .001$) than in those with the condition (B = 0.48; $P = .47$). **Conclusions:** Weather conditions are associated with outdoor PA in older adults in the general population. Outdoor PA and weather conditions were more strongly associated in older adults without OA than in their counterparts with OA.

Keywords: Europe, older population, osteoarthritis, outdoor physical activity

Physical activity (PA) helps older people with osteoarthritis (OA) to reduce pain and improve functioning.[1,2] Despite the potential health benefits of PA, the majority of people with OA do not engage sufficiently in physical activities.[3–5] Environmental factors, such as weather conditions, are known to influence PA of healthy people. Only few studies have explored these factors in older people with OA, even though older people with OA often report that their disease symptoms are exacerbated by the weather.[6–8] 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.[9] Knowledge on the relationship between PA and environmental factors, such as weather conditions, could be used in the prevention of mobility limitations and management of pain, which are both very relevant in older people and to an even greater extent to older people suffering from OA.[10]

Two recent studies focused on the association between objectively measured PA and weather conditions in people with knee OA.[8,11] A study by Robbins et al showed that warmer weather was associated with both greater frequency of daily PA and increased time engaging in moderate and vigorous PA of people with knee OA.[8] Feinglass et al found that light or heavy rain, and cold (< –7°C) or hot (> 24°C) temperature were negatively associated with PA.[11] Caution should be taken, however, when interpreting the results of Feinglass et al. In this study, the participants received interventions aimed at increasing PA.[11] As a consequence, the participants in this study may have been more physically active than the general population of people with knee OA. This may have biased the relationship between PA and weather conditions in people with knee OA.

In the studies of Feinglass et al and Robbins et al, no distinction was made between indoor and outdoor PA.[8,11] The characteristics of housing, use of air conditioning and exposure time to the actual weather conditions were not taken into account, which may have diminished the effects of weather conditions on PA in their study. Previous research addressed the influence of weather conditions on the type, participation rate, frequency and duration of physical active leisure engagement in the general population.[12] To our knowledge, research on the influence of weather conditions on PA in specific

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outdoor activities by older people with OA in the general population does not exist. The most important outdoor activities for older people are walking, cycling, and gardening.[13] Participation in each of these activities may be influenced differently by weather conditions.[14]

This study aims to examine the association of outdoor PA with weather conditions in older adults and to assess whether outdoor PA and weather conditions are more strongly associated in older persons with OA than in those without the condition. The current study extends previous research by examining the relationship between outdoor PA and weather conditions in a large-scale population-based study, including older people without OA as well as older people with knee, hand and/or hip OA from 6 European countries. This study focuses on the relationship between PA and various objectively measured weather parameters, including outdoor temperature, precipitation, atmospheric pressure, relative humidity and wind speed. In addition, this study focuses explicitly on the association between weather conditions and outdoor activities, including walking, cycling and gardening.

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Methods

Design and Study Sample

Baseline data from the European Project on OSteoArthritis (EPOSA) were used. The EPOSA study focuses on the personal and societal burden and its determinants of OA in older persons. A detailed description of the study design and data collection of the EPOSA study is described elsewhere, but to summarize, random samples were taken from existing population-based cohorts in 5 European countries (Germany, the Netherlands, Spain, Sweden and the United Kingdom (UK)).[15] In Italy, a new sample was drawn. A total of 2942 respondents (response rate, ranging from 64.6% to 82.2%, averaging 72.8%) were included. The age-range was between 65 to 85 years in most countries except for the UK, which had an age-range of 71 to 80 years. All participants were interviewed by a trained researcher at home or in a clinical center, using a standardized questionnaire and a clinical exam. The interview lasted about 1.5 hours. All participants completed an informed consent. For all 6 countries, the study design and procedures were approved by the Medical Ethics committee of the respective centers.

Individuals with cognitive impairments (Mini-Mental State Examination score ≤ 23) were excluded from the analyses.[16] Moreover, those who had missing data on outdoor PA and/or the presence of OA were necessarily omitted from the analyses. In total, 2439 (82.9%) were included in the current study. The excluded participants (n = 503) were older, lower educated and had more chronic diseases and functional limitations than the included participants. Furthermore, the proportion of women was higher in the excluded group than in the included group.

Dependent Variable

Outdoor Physical Activity. Physical activity was measured using the LASA Physical Activity Questionnaire (LAPAQ), an instrument validated against diaries and pedometer measurements in older persons.[13] The LAPAQ was completed by the participants in the period between December 2010 and December 2011. The LAPAQ covers frequency and duration of different activities during the previous 2 weeks. Activities covered in the LAPAQ include walking outside, cycling, gardening, light and heavy household work and a maximum of 2 sports. To calculate average daily outdoor PA in minutes, the frequency and duration of walking, cycling and gardening were multiplied and divided by 14 days. Sport activities were not included in this outdoor PA measure, because certain sports could be performed indoors as well as outdoors.

Independent Variables

Weather Data. Local weather stations provided daily (24-hour) average values for temperature [in degrees Celsius (°C)], precipitation [in millimeters (mm)], barometric pressure [in hectopascals (hPa)], relative humidity (in percentages), and wind speed (in meters per second (m/s)) for the location of all participants, for each of the 14 days before the completion of the LAPAQ. The maximum distance between a weather station and a participants' residence was within 80 kilometers. For each participant, averages of the weather parameters in the 2-week period for which they reported their outdoor PA were calculated. The 2-week averages of each weather parameter were calculated by dividing the sum of all daily (24-hour) weather parameter values by 14 days.

Potential Confounders. We considered the following potential confounders: age, sex (0 = men, 1 = women), educational level (0 = lower educated than secondary education, 1 = secondary education or a higher level), number of chronic diseases, Body Mass Index (BMI), anxiety, depression, mastery, PA pattern, and functional limitations.

Number of chronic conditions was measured through self-reported presence of the following chronic diseases or symptoms that lasted for at least 3 months or diseases for which the participant had been treated or monitored by a physician: chronic nonspecific lung disease, cardiovascular diseases, peripheral artery diseases, stroke, diabetes, cancer, and osteoporosis. The number of chronic diseases other than OA was categorized into 0, 1, 2, or more chronic diseases.

Body Mass Index (BMI) was calculated as weight in kilograms (kg) divided by height in squared meters (m). Weight was measured to the nearest 0.1 kg using a calibrated scale. Height was measured to the nearest 0.001 m using a stadiometer.

Emotional distress is associated with inclement weather conditions and physical inactivity in older adults.[17,18] To account for the effects of emotional distress on outdoor PA, analyses were adjusted for anxiety and depression. Anxiety and depressive symptoms were examined by the Hospital Anxiety Depression Scales (HADS).[19] The HADS is a self-report questionnaire comprising 14 4-point Likert scaled items, 7 for anxiety (HADS-A) and 7 for depression (HADS-D). Both scales have a range from 0 to 21. A higher score on the HADS-A and HADS-D indicates greater anxiety and depression respectively. HADS-A and HADS-D were used as categorical variables with cut-off level of 8 or more for presence of anxiety and depression.[19]

Mastery is the extent to which individuals consider themselves to be in control of events and ongoing situations. Mastery is a psychological resource when coping with stressful life events.[20] Mastery was measured by means of an abbreviated 6-item version of the Pearlin Mastery Scale.[20] The questionnaire consists of 6 statements such as "I can do almost everything, if I want to." and "I have little control about things that happen to me." Original response categories range from 0 = strongly disagree to 4 = strongly agree. Response categories of individual items were rescaled in a way that higher scores represent a higher sense of mastery. The summed items range from 0 to 24, with higher scores indicating a higher sense of mastery.

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The LAPAQ also assessed whether the PA pattern of the participants was normal as compared with the rest of the past year.[13] If participants answered 'no' then they were asked for what reason. Physical activity pattern was categorized into "activity pattern was normal as compared to the rest of the past year," "activity pattern was not normal as compared to the rest of the past year because of weather conditions," and "activity pattern was not normal as compared to the rest of the past year because another reason than weather conditions." The categories were dummy coded and the first category ("activity pattern was normal as compared to the rest of the past year") was used as reference category.

To assess the severity of OA, functional limitations were assessed by the physical function subscales of the Australian/Canadian Osteoarthritis Hand Index (AUSCAN) and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC).[21,22] The AUSCAN physical function subscale contains 9 items concerning degree of difficulty with hand function experienced in the previous 48 hours. The WOMAC physical function subscale contains 17 items relating to difficulty with knee and/or hip function experienced in the previous 48 hours. The AUSCAN and WOMAC responses were scaled on a 5-point Likert scale ranging from none (0) to extreme difficulty (4). For both the AUSCAN and WOMAC, missing values were imputed according to the user manual, and subscale scores were normalized resulting in subscale scores ranging from 0 (no difficulties) to 100 (extreme difficulties).[21,22] Because of the high number of persons scoring 0 on the AUSCAN and WOMAC physical function subscale, and the highly skewed distribution of these variables, these variables were dichotomized: quartiles 1 to 3 (0) versus quartile 4 (people having most difficulties (1)). This dichotomization corresponds to earlier studies.[23,24]

Potential Effect Modifiers

Osteoarthritis. Algorithms for clinical OA of the hip, knee, and hand were developed based on the American College of Rheumatology (ACR) classification criteria and were based on both self-report and physical examination.[25] The diagnosis of hip OA was present in case of: pain in the hip as evaluated by the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) pain subscale score (cut-off score = 3, range = 0 to 20), plus all of: pain associated with hip internal rotation in at least 1 side; morning stiffness lasting more than 60 minutes as evaluated by the WOMAC stiffness subscale (score from 'mild' to 'extreme'; and over 50 years of age.[22] The diagnosis of knee OA was present in the case of: pain in the knee as evaluated by the WOMAC pain subscale score (cut-off score = 3, range = 0 to 20), plus any 3 of: over 50 years of age; morning stiffness lasting more than 30 minutes as evaluated by the WOMAC stiffness subscale (score from 'mild' to 'extreme'); crepitus on active motion in at least 1 side; bony tenderness in at least 1 side; bony enlargement in at least 1 side; no palpable warmth of synovium in both knees.[22] The diagnosis of hand OA was present in case of: pain, aching or stiffness of the hand as evaluated by the Australian /Canadian Osteoarthritis Hand Index (AUSCAN) pain (cut-off score = 3, range = 0 to 20) and stiffness (score 'mild' to extreme') subscale, plus any 2 of: hard tissue enlargement of 2 or more of the second and third distal interphalengeal (DIPs), second and third proximal interphalangeal (PIPs), first carpometacarpal (CMC) joints of at least 1 hand; hard tissue enlargement of 2 or more DIPs of at least 1 hand; deformity of at least 1 of the second and third DIPs, second and third PIPs, first CMC joints of at least 1 hand.[21] Swelling of the metacarpophalangeal joints, which is also included in the ACR classification criteria as a control to exclude rheumatic arthritis, was only measured in the UK and Germany. Osteoarthritis was defined as present when the participant had clinical OA in hip, knee and/or hand.

Country of Residence. Weather conditions and levels of outdoor PA may differ across countries. Therefore, it was examined whether country of residence modifies the relationship between weather conditions and outdoor PA. Participants were living in 6 European countries, including Germany, Italy, Netherlands, Spain, Sweden and the UK.

Statistical Analyses

Differences in characteristics between older people with and without OA were examined using independent *t*-tests for continuous data and chi-square tests for categorical data. For skewed continuous variables, differences between older adults with and without OA were tested using a Mann-Whitney *U* test. Kruskal-Wallis tests were performed to examine differences in PA measures and meteorological exposure across countries. In addition, linearity between outdoor PA and individual weather parameters were assessed. All descriptive statistics, except age, sex and country, were weighted to the European standard population in 2010. The weights were calculated per sex and per 5-year age category, using the formula: W = Nexp/Nobs, with the Nobs being the number of persons in a specific age/sex category in the cohort, and Nexp being the number of persons in a specific age/sex category in the European standard population in 2010.[26]

Linear regression analyses were used to examine cross-sectional associations of total outdoor PA with each of the weather parameters. Furthermore, linear regression analyses were used to examine whether the weather parameters were associated with daily PA in each of the 3 outdoor activities. To examine whether OA modified the relationship between outdoor PA and weather parameters, the interaction effects between OA and each individual weather parameter were assessed in fully adjusted models. Furthermore, country of residence was assessed for potential effect modification by examining interaction effects between country and each individual weather parameter on total outdoor PA in fully adjusted models. In these analyses, country was analyzed in dummies with Sweden as reference category, because the Swedish participants reported, on average, to be physically less active in the outdoor environment. The interaction effects were considered as significant at a p-value below 0.10.[27] If an interaction term was significant, group-specific associations between outdoor PA and weather parameters were calculated as described in Figueiras and colleagues.[28] In case the interaction effect was not significant, a pooled analysis (also adjusted for OA and/or country) was performed.

All associations between PA and individual weather parameters were examined in models constructed step by step. Model 1 tested the effects of the weather parameters on outdoor PA, adjusted for the covariates age and sex. Model 2 tested the effects of each individual weather parameter on outdoor PA, additionally adjusted for the covariates educational level, number of chronic diseases, BMI, anxiety, depression, mastery, PA pattern, and functional limitations. In all models, the p-value was set to 0.05. Statistical analyses were performed in IBM SPSS Statistics (version 20.0).

Results

The mean age of the 2439 participants was 73.8 (SD = 5.0) years. Of all participants, 1235 (50.6%) were female. Seven hundred and three persons (29.6%) fulfilled the ACR classification criteria for

knee, hand, and/or hip OA. The characteristics of the participants with and without OA are presented in Table 1.

Outdoor Physical Activity

In the full sample, participants spent 47.1 minutes (Interquartile range (IQR) = 21.4 to 93.2) per day doing outdoor PA. The time spent on outdoor PA significantly differed across countries (Table 2). In the full sample, the participants with OA spent significantly less time in outdoor PA than those without OA (Median = 42.9, IQR = 20.0 to 83.1 versus Median = 51.4, IQR = 23.6 to 98.6; $P < .01$) (Table 3). Total time spent on walking, cycling and gardening, however, did not differ significantly between both groups (Table 3).

Weather Conditions

The distribution of the meteorological exposures in the study sample showed significant differences in daily weather conditions between the 6 countries (Table 4). Average daily temperature was highest in Spain and lowest in the Netherlands. Daily precipitation was highest in Sweden and lowest in the Netherlands. Atmospheric pressure was highest in the Netherlands and lowest in Sweden. Relative humidity was lowest in Spain and highest in Sweden. Wind speed was highest and lowest in the Netherlands and Italy respectively.

Total Outdoor Physical Activity and Weather Conditions

After adjustment for all confounders, the association of total outdoor PA with temperature (B = 1.52; $P < .001$) was statistically significant in the full sample (Table 5; Model 2). For example, this means that daily outdoor PA increases with 1.52 minutes when the temperature increases with 1.0°C.

After adjustment for all confounders, also a statistically significant association between outdoor PA and relative humidity (B = –0.77; $P < .001$) was observed in the full sample (Table 5; Model 2). The association between total outdoor PA and relative humidity differed across countries. Relative humidity was negatively associated with total outdoor PA in all countries, except in Spain (Germany: B = –1,12; $P = .10$, Italy: B = –2.82; $P < .001$, the Netherlands: B

Table 1 Characteristics of the Study Sample Stratified for Osteoarthritis

	Participants with OA (n = 703)		Participants without OA (n = 1736)		
	n		n		*P*
Age in years [Mean (SD)]	703	73.9 (4.9)	1736	73.6 (5.0)	0.21
Sex (female) [n (%)]	703	479 (68.1)	1736	756 (43.5)	<0.001
Educational level (≥ secondary education) [n (%)]	702	366 (51.5)	1734	1084 (61.6)	<0.001
Country of residence [n (%)]	703		1736		<0.001
Germany		84 (11.9)		307 (17.7)	
Italy		129 (18.3)		193 (11.1)	
The Netherlands		118 (16.8)		384 (22.1)	
Spain		135 (19.2)		290 (16.7)	
Sweden		130 (18.5)		271 (15.6)	
United Kingdom		107 (15.3)		291 (16.8)	
Chronic diseases [n (%)]	697		1728		
0		222 (32.7)		699 (41.6)	
1		250 (35.2)		649 (36.6)	
≥2		225 (32.0)		380 (21.8)	
Body mass index in kg/m^2 [Mean (SD)]	692	28.4 (4.8)	1703	27.1 (4.0)	<0.001
Anxiety (HADS-A ≥ 8) [n (%)]	685	209 (31.2)	1689	220 (13.2)	<0.001
Depression (HADS-D ≥ 8) [n (%)]	686	141 (16.7)	1690	142 (7.2)	<0.001
6-Item Pearlin Mastery score (0–24) [Mean (SD)]	678	16.3 (4.7)	1651	17.6 (4.1)	<0.001
Physical activity pattern [n (%)]	689		1694		<0.001
Normal PA pattern		492 (70.5)		1286 (75.1)	
Abnormal PA pattern because of weather conditions		25 (3.8)		77 (4.6)	
Abnormal PA pattern because of another reason than weather conditions		172 (25.7)		331 (20.3)	
AUSCAN functional limitations (fourth quartile) [n (%)]	702	413 (59.1)	1735	249 (15.3)	<0.001
WOMAC functional limitations (fourth quartile) [n (%)]	702	424 (60.7)	1734	181 (10.8)	<0.001

Note. Descriptive statistics are weighted (except age, sex and country); n is nonweighted.

Abbreviations: AUSCAN, Australian/Canadian Osteoarthritis Hand Index; HADS-A, Hospital Anxiety Depression Scales—Anxiety; HADS-D, Hospital Anxiety Depression Scales—Depression; IQR, Interquartile range; n, Number; OA, Osteoarthritis; PA, Physical activity; SD, Standard deviation; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.

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Table 2 Outdoor Physical Activity in Minutes per Day Stratified for Country

	Full sample (n = 2439)	Germany (n = 391)	Italy (n = 322)	The Netherlands (n = 502)	Spain (n = 425)	Sweden (n = 401)	United Kingdom (n = 398)	*P*
Outdoor physical activity								
Total outdoor PA in minutes/day [Median (IQR)]	47.1 (21.4–93.2)	77.6 (38.8–128.6)	61.2 (25.7–139.4)	31.1 (15.0–61.2)	45.0 (25.7–83.6)	30.0 (15.0–60.0)	68.6 (34.3–140.0)	<0.001
Walked in past 2 weeks (yes) [n (%)]	2205 (90.0)	352 (90.3)	242 (75.0)	455 (90.6)	422 (99.2)	346 (86.5)	388 (97.4)	<0.001
Walking in minutes/day [Median (IQR)]	25.7 (11.4–60.0)	30.9 (17.1–60.0)	25.7 (8.6–53.7)	15.0 (7.1–30.0)	45.0 (25.7–60.0)	20.0 (8.8–30.0)	25.7 (12.9–60.0)	<0.001
Cycled in past 2 weeks (yes) [n (%)]	657 (26.9)	186 (47.0)	136 (42.8)	292 (57.3)	6 (1.4)	9 (2.3)	28 (6.5)	<0.001
Cycling in minutes/day [Median (IQR)]	12.9 (5.4–25.7)	17.1 (8.6–35.9)	8.6 (3.6–20.0)	10.7 (5.6–21.4)	1.0 (0.1–18.4)	25.5 (18.9–51.4)	4.8 (2.9–14.9)	<0.001
Gardened in past 2 weeks (yes) [n (%)]	1309 (52.2)	247 (61.7)	253 (78.6)	194 (37.4)	54 (13.2)	212 (52.8)	349 (87.1)	<0.001
Gardening in minutes/day [Median (IQR)]	32.1 (12.9–77.1)	42.9 (21.4–90.0)	51.4 (17.1–120.0)	17.1 (6.4–38.6)	25.2 (12.9–34.3)	25.7 (8.6–60.0)	38.6 (16.9–90.0)	<0.001

Note. Descriptive statistics of the full sample are weighted; n is nonweighted.

Abbreviations: IQR, Interquartile range; n, Number; PA, Physical activity.

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Table 3 Outdoor Physical Activity in Minutes per Day Stratified for Osteoarthritis

	Participants with OA (n = 703)		Participants without OA (n = 1736)		
	n		n		*P*
Outdoor physical activity					
Total outdoor PA in minutes/day [Median (IQR)]	703	42.9 (20.0–83.1)	1736	51.4 (23.6–98.6)	<0.01
Walking in minutes/day [Median (IQR)]	616	25.7 (10.7–45.0)	1589	28.6 (11.4–60.0)	0.28
Cycling in minutes/day [Median (IQR)]	165	12.9 (5.7–29.8)	492	11.4 (5.4–25.7)	0.29
Gardening in minutes/day [Median (IQR)]	356	32.1 (12.9–64.3)	953	32.1 (12.9–85.7)	0.36

Abbreviations: IQR, Interquartile range; n, Number; C; OA, Osteoarthritis; PA, Physical activity.

Table 4 Distribution of Meteorological Exposure in the Study Sample

	Full sample	Germany	Italy	The Netherlands	Spain	Sweden	United Kingdom	*P*
Weather parameters								
Temperature (in °C) [Mean (SD)]	12.0 (5.3)	13.1 (4.5)	13.8 (6.5)	7.6 (4.6)	14.4 (5.4)	10.4 (4.1)	14.1 (2.3)	<0.001
Precipitation (in mm) [Median (IQR)]	1.6 (0.6–2.9)	1.7 (1.0–2.8)	2.2 (0.7–6.1)	0.9 (0.4–1.8)	1.9 (0.9–3.6)	2.6 (1.6–4.4)	1.3 (0.5–1.9)	<0.001
Atmospheric pressure (in hPa) [Mean (SD)]	1016.9 (4.8)	1018.0 (3.2)	1018.1 (3.5)	1018.4 (4.5)	1017.4 (3.8)	1014.0 (7.0)	1015.5 (3.5)	<0.001
Relative humidity (in %) [Mean (SD)]	74.4 (10.9)	79.2 (7.5)	72.5 (7.8)	79.5 (9.5)	59.7 (9.3)	81.8 (7.9)	74.3 (3.8)	<0.001
Wind speed (in m/s) [Mean (SD)]	2.4 (1.3)	1.3 (0.4)	0.8 (0.2)	4.1 (1.2)	3.3 (0.6)	2.4 (0.8)	1.8 (0.4)	<0.001

Abbreviations: °C, Degrees Celsius; hPa, Hectopascals; IQR, Interquartile range; mm, Millimeters; m/s, Meters per second; SD, Standard deviation.

Table 5 Associations Between Total Outdoor Physical Activity in Minutes per Day in the Study Sample

Weather parameter	Model	B (SE)
Temperature (in °C)	Model 1	**2.67 (0.34)**
	Model 2	**1.52 (0.40)**[a]
Precipitation (in mm)	Model 1	–0.28 (0.85)
	Model 2	–1.48 (0.92)
Atmospheric pressure (in hPa)	Model 1	–0.10 (0.39)
	Model 2	–0.33 (0.43)
Relative humidity (in %)	Model 1	**–0.65 (0.17)**
	Model 2	**–0.77 (0.19)**[b]
Wind speed (in m/s)	Model 1	**–14.53 (1.36)**
	Model 2	–0.89 (2.59)

Abbreviations: °C, Degrees Celsius; B, Unstandardized coefficient; hPa, Hectopascals; mm, Millimeters; m/s, Meters per second; OA, Osteoarthritis; SE, Standard error.

Note. Model 1 was adjusted for age and sex (reference category: men). Model 2 was additionally adjusted for country (reference category: Sweden), educational level (reference category: not better educated than secondary education), Body Mass Index, number of chronic diseases (reference category: no chronic diseases other than osteoarthritis), anxiety (reference category: not anxious), depression (reference category: not depressed), mastery, physical activity pattern (reference category: normal physical activity pattern), functional limitations (reference category: quartiles 1–3), and osteoarthritis (reference category: no osteoarthritis). In all models, all variables were included simultaneously. Bold indicates significance ($P < .05$).

[a] There was a statistically significant OA by temperature interaction effect on total outdoor physical activity in minutes per day in the full sample. Therefore, the association in this model was not additionally adjusted for osteoarthritis.

[b] There was a statistically significant country by humidity interaction effect on total outdoor physical activity in minutes per day in the full sample. Therefore, the association in this model was not adjusted for country.

= –2.16; $P < .001$; Spain: B = 0.19; $P = .70$; Sweden: B = –0.43; $P = .49$, and UK: B = –0.92; $P = .48$). In Italy and the Netherlands, the negative association of total outdoor PA with relative humidity was stronger and statistically significant.

A significant OA by temperature interaction effect ($P = .05$) on total outdoor PA was found in the full sample. The association between total outdoor PA and temperature was stronger in older adults without OA (B = 1.98; $P < .001$) than in those with OA (B = 0.48; $P = .47$) (Figure 1).

Outdoor Walking and Weather Conditions

After adjustment for all confounders, the association between outdoor walking and relative humidity (B = –0.34; $P = .02$) was statistically significant in the full sample. A significant OA by humidity interaction effect ($P = .08$) on outdoor walking was observed. The association of outdoor walking with relative humidity was stronger in older adults without OA (B = –0.46; $P = .01$) than in those with the condition (B = –0.03; $P = .88$) (Figure 2).

Cycling and Weather Conditions

There were no statistically significant associations between cycling and weather parameters. The associations between cycling and weather parameters did not differ between older people with and without OA.

Gardening and Weather Conditions

After adjustment for all confounders, the associations between gardening in minutes per day and temperature (B = 1.23; $P = .02$), precipitation (B = –2.31; $P = .03$) and relative humidity (B = –1.07; $P < .01$) were statistically significant in the full sample. The associations between gardening and weather parameters did not differ between older people with and without OA.

Discussion

This study examined the association of outdoor PA with weather conditions in a large sample of older people with and without OA in 6 European countries, focusing on specific outdoor activities. The results showed that higher temperatures were associated with increased outdoor PA, and that increased humidity levels were associated with decreased outdoor PA. Temperature was more strongly associated with outdoor PA in older people without OA than in those with OA. Furthermore, it was found that with increased humidity levels, older people without OA spent less time walking outdoors than those with the condition.

Our findings provide evidence that weather conditions are associated with outdoor PA in older people. The finding that warmer temperatures were associated with increased PA in older people was in line with previous studies.[29–33] Our finding that outdoor PA in older people decreased with an increase in relative humidity was also in line with previous research.[33] Increased humidity makes it more difficult to cool down in warm weather conditions.[34] Older people may decrease their outdoor PA in humid weather conditions, because of their increased frailty and reduced ability to thermoregulate.[35] The current study showed that the association between outdoor PA and relative humidity was not similar across countries. Only in Spain, a positive association between outdoor PA and relative humidity was observed. In comparison with 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. To our knowledge, there is no clear explanation for the stronger negative associations between outdoor PA and relative humidity in Italy and the Netherlands. Contrary to other studies, our study did not show significant associations of total outdoor PA with precipitation, atmospheric pressure and wind speed.[14,36]

Our findings did not confirm that outdoor PA was more strongly associated with weather conditions in older people with OA than in those without OA. Older people with OA frequently report that their disease symptoms, such as stiffness and joint pain, are influenced by weather conditions.[6–8] Several physiological mechanisms have been suggested to account for an increase in stiffness and joint pain, which could affect outdoor PA in older people with OA. For example, it has been suggested that humidity and temperature have an effect on the expansion and contraction of different tissues in the affected joint, which may elicit a pain response.[7,37,38] In addition, lower temperature may increase the viscosity of synovial fluid, thereby making joints stiffer and perhaps more sensitive to the pain of mechanical stresses.[37,38] Furthermore, it has been proposed that high atmospheric pressure leads to extrusion of synovial fluid through articular defects, which also may lead to more stiffness and joint pain.[39] A recent study by Dorleijn et al showed that barometric pressure and relative humidity influence perceived OA symptoms, such as pain and disability.[40] Dorleijn and colleagues found that the contribution of these weather parameters to the severity of OA

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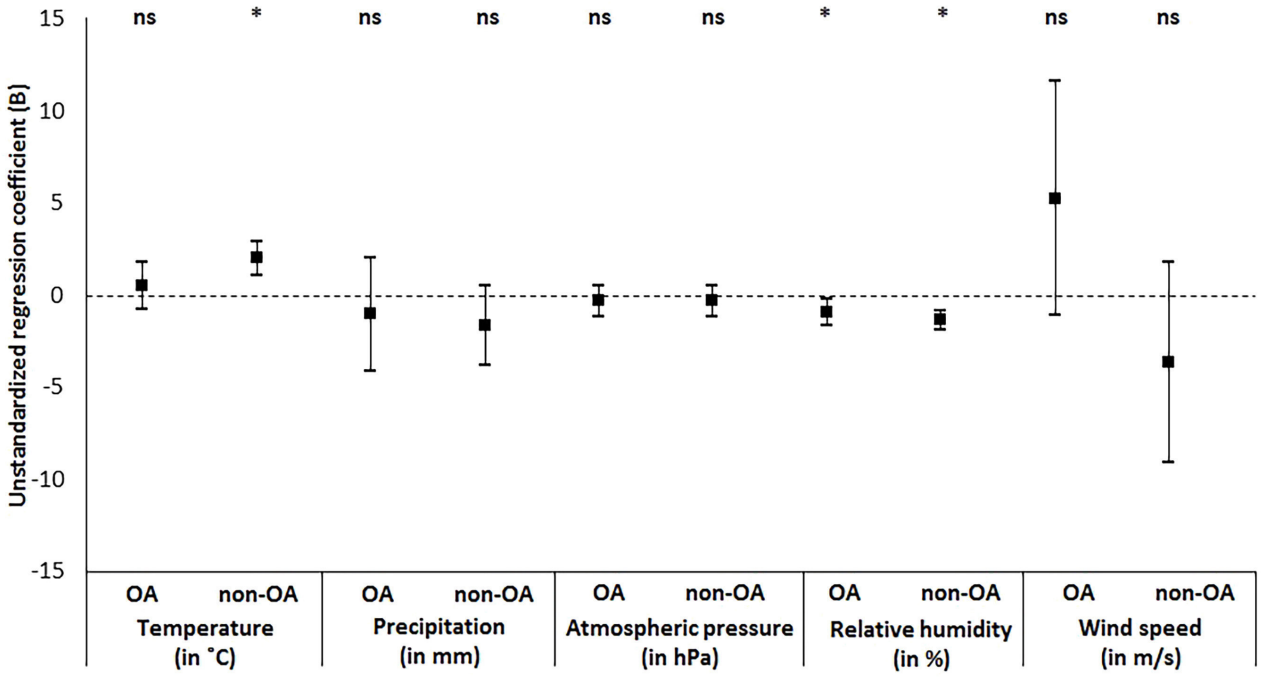


Figure 1 — Associations between total outdoor physical activity in minutes per day and weather parameters in older people with and without osteoarthritis. Abbreviations: °C, Degrees Celsius; hPa, Hectopascals; mm, Millimeters; m/s, Meters per second; OA, Osteoarthritis; ns, not significant. *Note.* Error bars represent 95%-confidence intervals. * $P < 0.05$. The associations are adjusted for age, sex (reference category: men), country (reference category: Sweden), educational level (reference category: not better educated than secondary education), body mass index, number of chronic diseases (reference category: no chronic diseases), anxiety (reference category: not anxious), depression (reference category: not depressed), mastery, physical activity pattern (reference category: normal physical activity pattern), and functional limitations (reference category: quartiles 1 to 3).

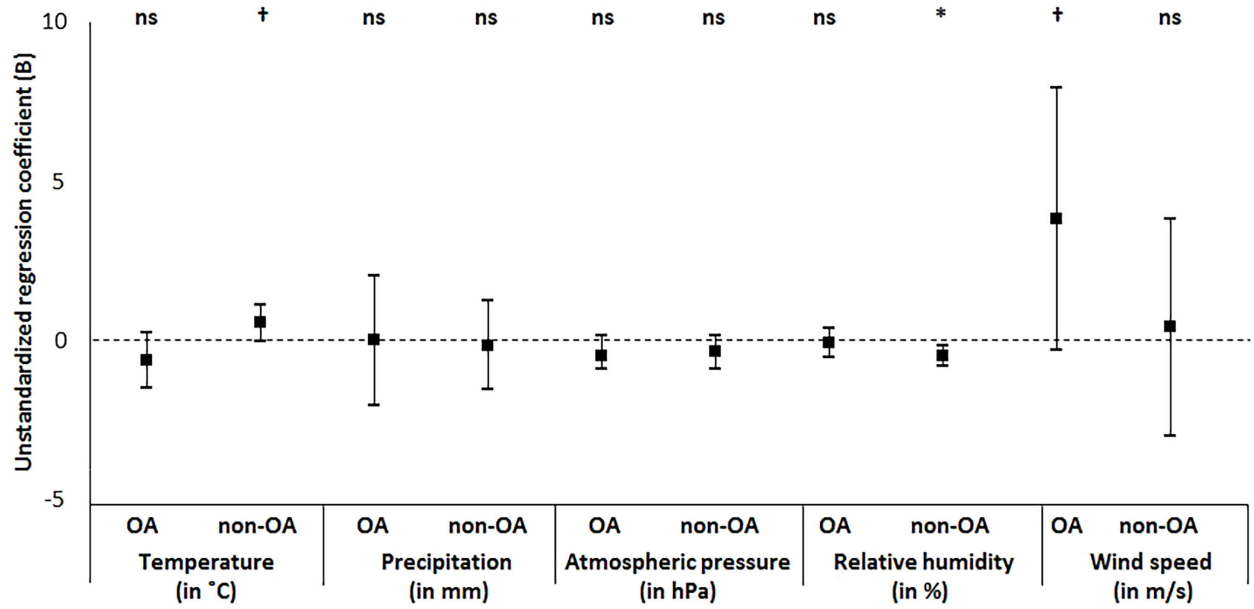


Figure 2 — Associations between outdoor walking in minutes per day and weather parameters in older people with and without osteoarthritis. Abbreviations: °C, Degrees Celsius; hPa, Hectopascals; mm, Millimeters; m/s, Meters per second; OA, Osteoarthritis; ns, not significant. *Note.* Error bars represent 95% confidence intervals. * $P < 0.05$; † $0.05 \geq P < 0.10$. The associations are adjusted for age, sex (reference category: men), country (reference category: Sweden), educational level (reference category: not better educated than secondary education), body mass index, number of chronic diseases (reference category: no chronic diseases), anxiety (reference category: not anxious), depression (reference category: not depressed), mastery, physical activity pattern (reference category: normal physical activity pattern), and functional limitations (reference category: quartiles 1 to 3).

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symptoms was not clinically relevant.[40] Although older people with OA often report that their disease symptoms are influenced by weather conditions and the potential mechanisms are well described in literature, the results of this study showed that temperature was more strongly associated with total outdoor PA in older people without OA than in those with OA.[7,37,38] Furthermore, it was found that relative humidity was more strongly associated with outdoor walking in older adults without OA than in those with the condition. A possible explanation could be that older people without OA might be better able to adapt their behavior to the environment and they might be better able or more willing to perform outdoor activities in favorable weather conditions.[41]

Outdoor PA in older people with OA may also be affected by aspects of the social and built environment that were not considered in the current study.[10,41] Older people with OA might have a smaller social network than their counterparts without OA.[42] Older people with OA who receive less encouragement of others might be less motivated to spend time in outdoor PA despite favorable weather conditions.[10] Furthermore, older people with OA may perceive the built environment (eg, the presence and condition of sidewalks, bike paths and rest places) more as a barrier for outdoor PA than older people without OA.[39] As a consequence, older people with OA might be less likely to spend time in outdoor PA despite favorable weather conditions.

To our best knowledge, this is the first large-scale population-based study that examines whether the relationships between PA and objective weather conditions are different between older people with and without OA in Europe. Previous research on the relationship between PA and weather conditions in people with OA did not make a distinction between indoor and outdoor PA and mainly focused on the influence of temperature and precipitation on PA.[8,11] This study explicitly examined the associations between outdoor PA and a variety of objectively measured weather parameters, including temperature, precipitation, atmospheric pressure, relative humidity and wind speed. Another strength of this study is that the diagnosis of OA was standardized across all countries by using the ACR classification criteria.[24]

Some limitations of this study have to be acknowledged as well. First, although we had data available on a range of confounding factors, we lacked more detailed information on duration of disease and disease control with treatment, which might have affected outdoor physical activity. Individuals who have OA for a longer period and those who do not receive treatments may be less physically active. Second, total outdoor PA in minutes per day was calculated as the average daily time spent on walking, cycling, and gardening in the previous 2 weeks. Although outdoor PA could include other activities, this measure does include the most important outdoor activities in older persons.[13] Third, the average weather parameters were objectively measured for each day in the current study, whereas outdoor PA in minutes per day was assessed retrospectively by self-reports using the LAPAQ. The LAPAQ assesses daily average PA in minutes per day based on the frequency and duration of PA in the previous 2 weeks and does not provide detailed information about PA on specific days.[13] Fourth, although we excluded individuals with cognitive impairments, participants might have had difficulties to compare their PA pattern over the last 2 weeks with their PA pattern over the last year, which may have caused recall bias in the PA pattern variable. Finally, the use of a self-reported measure of PA might have caused a social desirability bias. Alternatively, it would be better to outdoor PA on a day-to-day basis by using objective PA measures, such as accelerometers.

In this study, outdoor PA was not measured over time, covering subsequent different weather conditions. However, outdoor PA was assessed during different seasons across participants, resulting in meteorological variety. Longitudinal studies are needed to examine the effects of daily average weather conditions on daily PA of older people with and without OA over a longer time period. In addition, future research should focus on indoor as well as outdoor PA simultaneously and should account for differences in weather parameters between the indoor and outdoor environment. Furthermore, the use of objective measures of PA, such as accelerometers, would not only give further insight in the quantity of PA, but also into the intensity of PA. Future research is also needed to examine whether PA of older adults with OA are more strongly influenced by other environmental factors than weather conditions, such as proximity of facilities in the neighborhood environment and presence and condition of sidewalks.

In conclusion, our results showed potentially important relationships between weather conditions and outdoor PA in older people in the general population. 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. 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 current findings suggest that weather conditions should be taken into consideration when designing and interpreting the results of interventions aimed at increasing PA of older people in the general population.

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References

1. Dunlop DD, Semanik P, Song J, Manheim LM, Shih V, Chang RW. Risk factors for functional decline in older adults with arthritis. *Arthritis Rheum*. 2005;52:1274–1282. PubMed doi:10.1002/art.20968
2. Dunlop DD, Song J, Semanik PA, Sharma L, Chang RW. Physical activity and functional performance in the osteoarthritis initiative: a graded relationship. *Arthritis Rheum*. 2011;63:127–136. PubMed doi:10.1002/art.27760
3. de Groot IB, Bussmann JB, Stam HJ, Verhaar JA. Actual everyday physical activity in patients with end-stage hip or knee osteoarthritis compared with healthy controls. *Osteoarthritis Cartilage*. 2008;16:436–442. PubMed doi:10.1016/j.joca.2007.08.010
4. Farr JN, Going SB, Lohman TG, et al. Physical activity levels in early knee osteoarthritis patients measured by accelerometry. *Arthritis Rheum*. 2008;59:1229–1236. PubMed doi:10.1002/art.24007
5. Veenhof C, Huisman PA, Barten JA, Takken T, Pisters MF. Factors associated with physical activity in patients with osteoarthritis of the hip or knee: a systematic review. *Osteoarthritis Cartilage*. 2012;20:6–12. PubMed doi:10.1016/j.joca.2011.10.006
6. Aikman H. The association between arthritis and the weather. *Int J Biometeorol*. 1997;40:192–199. PubMed doi:10.1007/s004840050041
7. Ng J, Scott D, Taneja A, Gow P, Gosai A. Weather changes and pain in rheumatology patients. *APLAR J Rheumatol*. 2007;7:204–206. doi:10.1111/j.1479-8077.2004.00099.x
8. Robbins SM, Jones GR, Birmingham TB, Maly MR. Quantity and quality of physical activity are influenced by outdoor temperature in people with knee osteoarthritis. *Physiother Can*. 2013;65:248–254. PubMed doi:10.3138/ptc.2012-39
9. Tucker P, Gilliland J. The effect of season and weather on physical activity: a systematic review. *Public Health*. 2007;121:909–922. PubMed doi:10.1016/j.puhe.2007.04.009
10. Pettursdottir U, Arnadottir SA, Halldorsdottir S. Facilitators and barriers to exercising among people with osteoarthritis: a phenomenological study. *Phys Ther*. 2010;90:1014–1025. PubMed doi:10.2522/ptj.20090217
11. Feinglass J, Lee J, Semanik P, Song J, Dunlop DD, Chang RW. The effects of daily weather on accelerometer-measured physical activity among adults with arthritis. *J Phys Act Health*. 2011;8:934–943. PubMed doi:10.1123/jpah.8.7.934
12. Spinney JEL, Millward H. Weather impacts on leisure activities in Halifax, Nova Scotia. *Int J Biometeorol*. 2011;55:133–145. PubMed doi:10.1007/s00484-010-0319-z
13. Stel VS, Smit JH, Pluijm SM, Visser M, Deeg DJ, Lips P. Comparison of the LASA Physical Activity Questionnaire with a 7-day diary and pedometer. *J Clin Epidemiol*. 2004;57:252–258. PubMed doi:10.1016/j.jclinepi.2003.07.008
14. Prins RG, Van Lenthe FJ. The hour-to-hour influence of weather conditions on walking and cycling among Dutch older adults. *Age Ageing*. 2015;44:886–890. PubMed doi:10.1093/ageing/afv103
15. van der Pas S, Castell MV, Cooper C, et al. European project on osteoarthritis: design of a six-cohort study on the personal and societal burden of osteoarthritis in an older European population. *BMC Musculoskelet Disord*. 2013;14:138. PubMed doi:10.1186/1471-2474-14-138
16. Tombaugh TN, McIntyre NL. The mini mental state examination: a comprehensive review. *J Am Geriatr Soc*. 1992;40:922–935. PubMed doi:10.1111/j.1532-5415.1992.tb01992.x
17. Rosemann T, Kuehlin T, Laux G, Szecsenyi J. Osteoarthritis of the knee and hip: a comparison of factors associated with physical activity. *Clin Rheumatol*. 2007;26:1811–1817. PubMed doi:10.1007/s10067-007-0579-0
18. Sulman FG. The impact of weather on human health. *Rev Environ Health*. 1984;4:83–119. PubMed
19. Zigmond A, Snaith R. The Hospital Anxiety and Depression Scale. *Acta Psychiatr Scand*. 1983;67:361–370. PubMed doi:10.1111/j.1600-0447.1983.tb09716.x
20. Pearlin LI, Schooler C. The structure of coping. *J Health Soc Behav*. 1978;19:2–21. PubMed doi:10.2307/2136319
21. Bellamy N. Clinimetric properties of the AUSCAN Osteoarthritis Hand Index: an evaluation of reliability, validity and responsiveness. *Osteoarthritis Cartilage*. 2002;10:863–869. PubMed doi:10.1053/joca.2002.0838
22. Bellamy N. *WOMAC Osteoarthritis Index: A User's Guide*. Ontario: London Health Services Centre; 1996.
23. Kim I, Kim HA, Seo YI, et al. Tibiofemoral osteoarthritis affects quality of life and function in elderly Koreans, with women more adversely affected than men. *BMC Musculoskelet Disord*. 2010;11:129. PubMed doi:10.1186/1471-2474-11-129
24. Van Schoor NM, Zambon S, Castell MV, et al. Impact of clinical osteoarthritis of the hip, knee and hand on self-rated health in six European countries: the European Project on OSteoArthritis. *Qual Life Res*. 2016;25:1423–1432. PubMed doi:10.1007/s11136-015-1171-8
25. Altman RD. Classification of disease: osteoarthritis. *Semin Arthritis Rheum*. 1991;20:40–47. PubMed doi:10.1016/0049-0172(91)90026-V
26. Eurostat. Database - Population - Demography - National data - population. European Commission. http://epp.eurostat.ec.europa.eu/portal/page/portal/population/data/database. Accessed February 1, 2013.
27. Aiken LS, West SG. *Multiple Regression: Testing and Interpreting Interactions*. Thousand Oaks, CA: SAGE Publications, Inc; 1991.
28. Figueiras A, Domenech-Masons JM, Cadarso C. Regression models: calculating the confidence interval of effects in the presence of interactions. *Stat Med*. 1998;17:2099–2105. PubMed doi:10.1002/(SICI)1097-0258(19980930)17:18<2099::AID-SIM905>3.0.CO;2-6
29. Chan CB, Ryan DAJ, Tudor-Locke C. Relationships between objective measures of physical activity and weather: a longitudinal study. *Int J Behav Nutr Phys Act*. 2006;3:21. PubMed doi:10.1186/1479-5868-3-21
30. Witham MD, Donnan PT, Vadiveloo T, et al. Association of day length and weather conditions with physical activity levels in older community dwelling people. *PLoS One*. 2014;9:e85331. PubMed doi:10.1371/journal.pone.0085331
31. Sumukadas D, Witham M, Struthers A, McMurdo M. Day length and weather conditions profoundly affect physical activity levels in older functionally impaired people. *J Epidemiol Community Health*. 2009;63:305–309. PubMed doi:10.1136/jech.2008.080838
32. Togo F, Watanabe E, Park H, Shephard RJ, Aoyagi Y. Meteorology and the physical activity of the elderly: the Nakanojo study. *Int J Biometeorol*. 2005;50:83–89. PubMed doi:10.1007/s00484-005-0277-z
33. Klenk J, Büchele G, Rapp K, Franke S, Peter R, the ActiFE Study Group. Walking on sunshine: effect of weather conditions on physically activity in older people. *J Epidemiol Community Health*. 2012;66:474–476. PubMed doi:10.1136/jech.2010.128090
34. Ashcroft FM. *Life at the Extremes: The Science of Survival*. London: Flamingo; 2001.
35. Horowitz M, Robinson SD. Heat shock proteins and the heat shock response during hyperthermia and its modulation by altered physiological conditions. In: Sharma HS, ed., *Progress in Brain Research Neurobiology of Hyperthermia*. Amsterdam: Elsevier; 2007:433–446. doi:10.1016/S0079-6123(06)62021-9

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36. Chan CB, Ryan DA. Assessing the effects of weather conditions on physical activity participation using objective measures. *Int J Environ Res Public Health*. 2009;6:2639–2654. PubMed doi:10.3390/ijerph6102639
37. Jamison RN, Anderson KO, Slater MA. Weather changes and pain: perceived influence of local climate on pain complaint in chronic pain patients. *Pain*. 1995;61:309–315. PubMed doi:10.1016/0304-3959(94)00215-Z
38. Quick DC. Joint pain and weather. A critical review of the literature. *Minn Med*. 1997;80:25–29. PubMed
39. Brennan SA, Harney T, Queally JM, O'Connor McGoona J, Gormley IC, Shannon FJ. Influence of weather variables on pain severity in end-stage osteoarthritis. *Int Orthop*. 2012;36:643–646. PubMed doi:10.1007/s00264-011-1304-9
40. Dorleijn DMJ, Luijsterburg PAJ, Burdorf A, et al. Associations between weather conditions and clinical symptoms in patients with hip osteoarthritis: a 2-year study. *Pain*. 2014;155:808–813. PubMed doi:10.1016/j.pain.2014.01.018
41. Rosenberg DE, Huang DL, Simonovich SD, Belza B. Outdoor built environment barriers and facilitators to activity among midlife and older adults with mobility disabilities. *Gerontologist*. 2012;53:268–279. PubMed doi:10.1093/geront/gns119
42. Penninx BWJH, Van Tilburg T, Kriegsman DMW, Boeke AJP, Deeg DJH, Van Eijk JTM. Social network, social support, and loneliness in older persons with different chronic diseases. *J Aging Health*. 1999;11:151–168. PubMed doi:10.1177/089826439901100202

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Article 3

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Based on the International Committee of Medical Journal Editors guidelines for authorship criteria, I contributed to the article by doing the literature research, collecting the data, analyzing and interpreting the data as well as preparing the manuscript under supervision by Richard Peter in cooperation with Mosler I wrote the first draft of the manuscript and made the revisions after review in cooperation with the co-authors. This manuscript was accepted for publication in the Journal of Aging and Physical Activity on October 31, 2016.

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Relationship between Social Isolation and Indoor and Outdoor Physical Activity in Community-Dwelling Older Adults in Germany: Findings from the ActiFE Study

Abstract

Objectives: Social relationships have a powerful effect on physical activity. However, it is unclear how physical activity patterns are associated with perceived social isolation. ***Methods:*** A cohort study was performed on 1,162 community-dwelling older adults. In cross-sectional analyses, social isolation was screened using the Lubben Social Network Scale (LSNS-6). Physical activity was measured by an accelerometer (activPAL). Participants kept a contemporary physical activity diary to report outdoor physical activity timeframes. ***Results:*** Low levels of physical activity were associated with perceived social isolation. Low indoor physical activity was associated with being socially isolated from family and low outdoor physical activity was associated with being socially isolated from friends and neighbors (-4.5 minutes; p=.012). ***Discussion:*** These findings suggest the need for a more nuanced assessment of non-kin networks and a differentiated analysis of the locations in which physical activity is done in order to understand how social isolation affects everyday physical activity.

Keywords: Accelerometer, Physical activity, Social isolation, Outdoor activity, Friendship networks, Older adults

Poor health among socially isolated older adults has been continually reported over the last decades (House, Landis, & Umberson, 1988): Older adults who are socially isolated suffer from higher rates of depression (Santini, Koyanagi, Tyrovolas, Mason, & Maria Haro, 2015), re-hospitalization (Giuli et al., 2012), decreased immune function (Shankar, McMunn, Banks, & Steptoe, 2011), functional decline (Avlund, Lund, Holstein, & Due, 2004), and all-cause mortality (Holt-Lunstad, Smith, Baker, Harris, & Stephenson, 2015; Steptoe, Shankar, Demakakos, & Wardle, 2013). A meta-analysis of determinants of mortality showed that the effects of social isolation were comparable with those of smoking and even exceed other well-known risk factors for mortality (Holt-Lunstad, Smith, & Layton, 2010).

Physical activity might be one factor that mediates the relationship between social isolation and health-related effects. A model that explains the mechanism between certain social structures and individual health has been proposed by Berkman and colleagues (2000). Among other proposed health-related behaviors like health service utilization and medical adherence, exercise and physical activity can be regarded as key mechanisms in the downstream pathways from social structure to health. The model points out that social network structures are conditioned by social and cultural context. Network structures in turn provide and determine social support, social provision and material goods, as well as promoting social attachment. Our study was primarily interested in the individual level dealing with social isolation in relation to physical activity. Physical activity is regarded as one of the most important changeable health behaviors and has been shown to be associated with several chronic diseases, such as cardiovascular disease, obesity, type 2 diabetes, and hypertension (World Health Organization, 2003). Older adults who followed the official physical activity recommendation showed lower mortality rates (Stenholm et al., 2016). Even physical activity beyond the recommended threshold was shown to be beneficial (Hupin et al., 2015).

Empirical evidence supporting the link between restricted social networks and physical activity has been provided in several studies of older adults. Legh-Jones and Moore (2012) used a position generator for assessing a person's ties to others and found that greater network density was associated with high physical activity. Another study distinguished between different network compositions and revealed that older adults in family-centered networks were least physically active whereas individuals in networks composed of friends and neighbors showed one of the highest physical activity rates (Litwin, 2003). The results have been replicated for an older American population. Restricted networks were again associated with low physical activity levels (Shiovitz-Ezra & Litwin, 2012). In both studies, friendship ties were found to be more important for late life physical activity than family ties. Friendship networks might make a difference because they are entered voluntarily and maintained if they continue to provide benefits (Litwin, 2007). However, all of the aforementioned studies applied self-reported physical activity using either a single item (Litwin, 2003; Shiovitz-Ezra & Litwin, 2012) or a physical activity questionnaire (Legh-Jones & Moore, 2012). Relying on participants' self-reported physical activity caused problems because they sometimes forgot activities, had difficulties accurately recalling daily activities and were prone to bias their recollections (Cumming & Klineberg, 1994), which tended to be conform with perceived social norms (Irwin, Ainsworth, & Conway, 2001).

Studies have shown that going outdoors can have long term health benefits like improved mental well-being, greater enjoyment of physical activity and the intent to repeat the performed activity in the future (Jacobs et al., 2008; Thompson Coon et al., 2011). Besides these positive effects, outdoor physical activity also made a great contribution to overall physical activity levels. Older adults who were physically active in outdoor locations accumulated at least half an hour more moderate-to-vigorous physical activity than persons who were physically active only in outdoor locations and moved through greater life-space areas (Kerr et al., 2012; Portegijs, Tsai, Rantanen, & Rantakokko, 2015). A recent study of 36

older adults revealed that sedentary time mostly occurred when the participants spent their time alone. Most sedentary time was accumulated in participants' own homes (Leask, Harvey, Skelton, & Chastin, 2015). The relationship between physical activity and social isolation might vary depending on the location of physical activity. However, so far no studies have been conducted about whether or not social isolation is differently associated with physical activity in different locations.

This article builds upon literature that has repeatedly shown low physical activity levels in socially isolated older adults by considering social isolation as a lack of perceived social support by family and friends/neighbors (Lubben et al., 2006). To better understand the relationship between physical activity and social isolation in old age, we investigated the following: (a) whether older adults' (objectively-assessed) physical activity levels are differently associated with the two sources of social isolation (i.e., friend/neighbors and family) and (b) whether indoor and outdoor physical activity is differently related to social isolation .

Methods

Study population.

A sample of community-dwelling older persons (mean age = 75.6; *SD* = 6.6) from the greater area of Ulm in Germany was recruited in the Activity and Function in the Elderly in Ulm (ActiFE) study. Participants aged between 65 and 90 were randomly selected by local statistics offices. Inclusion criteria for the ActiFE study were as follows: participants were required (i) not to be institutionalized, (ii) to be German speaking and (iii), not to use a wheelchair. A stratified sample was drawn from three age groups (65 - 69; 70 - 79; 80 - 90). Individuals from the oldest age group were oversampled. A detailed description of the cohort and the measures taken is published elsewhere (Denkinger et al., 2010). In total 1,506 interviews were conducted between April 2009 and June 2010. Interviews for 285 cases were

not analyzed due to missing physical activity data. More particularly, in these cases there was missing diary data, missing accelerometer data, a mismatch between accelerometer and diary or less than three days of physical activity recordings. Furthermore, 58 participants had missing information on various background variables and one individual was found be a significant influential outlier (supplement 1). The final study sample consisted of 1,162 persons.

Participants included in the final analysis did not significantly differ in terms of sex (p = .299) or isolation from the family (p = .142) from persons who had missing data. However, excluded participants were older (p < .001) and more often socially isolated from neighbors and friends (p < .001).

Measures

Physical Activity.

A uni-axial accelerometer (activPAL, PAL Technologies Ltd., Glasgow, UK) measured daily walking duration. Technical details for the activPAL^{TM} are provided elsewhere (Ryan, Grant, Tigbe, & Granat, 2006). In short, this model of single-axis accelerometer is based on posture detection in combination with vertical acceleration and sample body accelerations at 10 Hz (10 times per second). Therefore, the activPAL^{TM} generates three forms of activity data: walking, quiet standing and sitting/lying. In previous studies, the activPAL^{TM} instrument demonstrated high accuracy (Taraldsen et al., 2011) and showed high inter device reliability (Ryan et al., 2006).

Only walking data were used in our analyses. Participants were asked to wear an accelerometer which was attached to the leg for 24 hours a day for seven days. Data were excluded from further analysis if the accelerometer recorded less than 24 hours a day. Average physical activity time was calculated as total walking duration divided by the number of valid days, and was expressed as minutes per day.

Outdoor activity diary.

An outdoor activity diary supplemented accelerometer estimates in order to distinguish outdoor from indoor physical activity. Concurrently with the accelerometer assessment, participants documented the timeframes they spent outdoors. Study nurses explained to participants how to fill in daily diary entries. Additionally, a written manual was delivered that provided clarifications on common diary misunderstandings. Participants returned their completed diaries along with the accelerometer after a period of seven days. Among other things, participants were asked to document when they left and returned home and the purpose of the out-of-house activity.

These documented periods served as the basis for calculating total outdoor physical activity time and calculating separate periods of outdoor physical activity spent fulfilling certain purposes (e.g., shopping, walking, or gardening). We were able to match the information of the activPAL^{TM} and the diary in 87 percent of all accelerometer-recorded days, though 21 individuals with no overlap between these two measures were dropped. Following recommendations for monitoring physical activity (Hart, Swartz, Cashin, & Strath, 2011), we dropped individuals from the analyses if the number of available days fell below three after the matching process.

Social isolation.

Perceptions of social isolation were assessed using the Lubben Social Network Scale (LSNS-6) (Lubben et al., 2006). The LSNS-6 covered three different characteristics of social networks: network size, closeness of contact, and perception of help (i.e., "How many relatives do you feel close to such that you could call on them for help?"). Participants answered questions regarding their friends/neighbors and family. Participants were asked to

rate perceived isolation on a 6-point Likert scale ranging from 0 (zero persons) to 5 (nine or more persons). The total LSNS-6 score was calculated by summing up across all items ranging from 0 to 30. High scores reflected a perception of good integration in social networks, whereas low scores reflected isolation from the social environment. A score of less than 12 points indicated that a person was socially isolated (Lubben et al., 2006). Additionally, we split the total scale into family and friend/neighbor subscales. These two subscales consisted of three items each and ranged from 0 to 15. We dichotomized the LSNS-6 subscales for all following analyses. A score of less than six points indicated that a person had limited social networks and a higher risk for social isolation. The cutoff was chosen in agreement with other studies that also applied LSNS-6 subscales (Blozik et al., 2009; Crooks, Lubben, Petitti, Little, & Chiu, 2008).

Covariates.

Other studies identified the following confounders that substantially influence the association between physical activity and social isolation: sex, age, highest level of education, depression, multimorbidity, body mass index (BMI), disabilities, and average outdoor temperature (Hakola et al., 2015; Klenk et al., 2012). Level of education was summarized as the highest achieved level of school education and was classified into primary school or less (low; <= 9 years), secondary school (middle; 10 years), and grammar school (high; > 10 years). Multimorbidity was assessed using the Functional Comorbidity Index developed for use in the general population with physical function as the outcome of interest ranging from 0 to 18 (Groll, To, Bombardier, & Wright, 2005). In our study, BMI and depression were excluded from the multimorbidity index because these two measurements were regarded as separate measures in the following analyses. Depression was assessed using the depression subscale of the Hospital Anxiety and Depression Scale (HADS-D) (Bjelland, Dahl, Haug, & Neckelmann, 2002), which reliably measures depression in primary care patients and in the general

population. The scale consists of seven items that cover depressive symptoms on a 4-point Likert scale with a possible range from 0 to 21. BMI was used as an indicator of overall body composition. BMI was calculated by dividing weight (in kilograms) by height (in meters squared). Difficulties or inabilities to perform activities of daily living (ADL) were measured with five items (going up and down stairs, dressing, getting up from a chair, walking on the same level, and bathing). Responses to each item were recorded using a 5-point Likert scale (0 – 4) corresponding to the response of "none", "mild", "moderate", "severe", or "cannot do, need help". As a result, the ADL disability index ranged from 0 (complete independence) to 20 (total dependence) (Denkinger et al., 2010; Saliba, Orlando, Wenger, Hays, & Rubenstein, 2000). A local weather station provided the maximum temperature (°C) for each day on which physical activity was recorded. Calculations included the averaged maximum temperatures during the measurement period of the accelerometer. The maximum distance between a weather station and a participant's residence was 40 km. Furthermore, sex and age (in years) were reported.

Missing Values.

Complete data were provided by 77.2 percent of all participants. An imputation procedure was applied for the depression scale if one of seven items was missing (n = 60). We conducted multiple imputations (regression estimate) in the software package Stata 10.1 (StataCorp LP, College Station, TX). Results are nearly identical in supplementary analyses using listwise deletion. However, the analytic sample includes the imputed data as it reduces concerns about sample size and the potential biases imposed by dropping cases with item-specific missing data.

Statistical analysis.

Linear regression analyses were applied to examine the association between the outcome of daily walking duration and the Lubben Social Network Scale (LSNS – 6) as well as two subscales (i.e. family and friends/neighbors) as main predictor variables. The assumptions of linearity, homogeneity of variance, absence of multicollinearity, and normality were met for the following analyses. The first model analyzed the association between perceived social isolation and physical activity, followed by models that distinguished between two social isolation subscales and two physical activity locations providing unstandardized and standardized coefficients. Main predictor models were presented first followed by adjusted models. We adjusted the final multivariate regression models for diverse indicators of socio-demographics (age, sex, and education), physical and mental health (disability, multimorbidity, depression, and body mass index), and temperature. Lastly, adjusted means were presented to differentiate how social isolation was associated with the duration spent doing different outdoor activities.

Results

Table 1 presents the means, standard deviations and percentages of the independent and dependent variables in our study. Most participants had an active lifestyle, which is represented by a mean daily walking duration of 106.7 minutes (*SD* = 39.4) that strongly varied from 8.9 to 290.7 minutes of daily walking activity. Participants spent on average 4.1 hours (*SD* = 1.8) outside the house and accumulated in this period 53.7 minutes of physical activity per day (*SD* = 30.1) which was almost half of all entire daily physical activity. The majority of respondents were male, lived with a partner and had an educational level less than a college education.

Insert Table 1 about here

The overall prevalence of social isolation in this study was 18.4 percent. Two percent of participants reported no contact with family members, and four percent had no contact with friends or neighbors. About thirteen percent fell below the threshold of less than six points on the three item LSNS-6 family subscale, and twenty-eight percent had marginal friend/neighbor ties regarding the three item LSNS-6 friend and neighbor subscale.

Insert Table 2 about here

Socially isolated older adults were physically inactive (-7.8 minutes; p = .007) compared to non-isolated persons (table 2). However, the association disappeared after adjusting for all aforementioned covariates. Overall, we noted that low physical activity levels were associated with increasing age, rising BMI, and multimorbidity as well as disability and colder temperature.

The social isolation subscales worked differently for indoor and outdoor physical activity. Persons who were socially isolated from family were more likely to be sedentary indoors (B = -4.5 minutes, p = .014) (table 3). Social isolation from friends and neighbors pointed in the opposite direction. Older adults showed low physical activity levels outside the house if they were socially isolated from friends and neighbors (B = -4.5 minutes, p = .012).

Insert Table 3 about here

Comparing the indoor and outdoor full adjusted models (table 3), the outdoor model explained more variance with considerably stronger effect sizes for almost all predictors. As an example, the standardized effect of the oldest age group in the indoor physical activity model was very small compared to the outdoor physical activity model (β_{indoor} = -.08 vs. β

$_{outdoor}$ = -.35). We also found that men engaged in more physical activity outside than women, but were more sedentary inside the house.

Older adults who were socially isolated from friends and neighbors reported significantly less outdoor physical activity compared to non-isolated individuals ($M_{not\text{-}isolated}$ = 54.9 vs. $M_{isolated}$ = 45.6 minutes/day; $p < .001$). The socially isolated group spent significantly less time physically active outdoors for social contacts ($p = .003$), for gardening ($p = .010$) and participating in cultural activities ($p = .043$) (table 4). Additionally, the outdoor activity diary allowed participants to state more than one purpose for going outdoors. This allowed calculating combinations of different purposes for going outdoors. Older adults who reported going outdoors for social contacts also documented concurrent shopping (4.6 percent of all cases), and in 4.1 percent of all cases, social contact was reported in combination with going for a walk.

Insert Table 4 about here

Discussion

The present study contributes insight towards a better understanding of the relationship between physical activity and perceived social isolation in older adults. Low physical activity in outdoor locations was strongly associated with perceived social isolation from friends and neighbors. Diary data revealed that socially isolated (regarding friends and neighbors) older adults engaged in less outdoor physical activity involving meeting people or visiting cultural events in comparison to non-isolated individuals. This substantiated claim that differences in outdoor physical activity are associated with social relations. Furthermore, social contacts were also closely connected to other outdoor activities, such as shopping or going for a walk.

In support of previous studies, we confirmed the relationship between low physical activity and social isolation and replicated findings that varying physical activity levels are related to the composition of social networks (Litwin, 2003; Shiovitz-Ezra & Litwin, 2012). Being socially isolated from friends and neighbors was associated with comparably lower outdoor physical activity levels than being isolated from one's family. These results confirmed prior research that reported more beneficial physiological outcomes and more activities (e.g., sports or exercise, and travel) within friend-focused network types in comparison with individuals belonging to restricted or family-focused networks (Fiori, Smith, & Antonucci, 2007; Li & Zhang, 2015). Social support provided by friends was related to greater amounts of leisure time physical activity than social support from the family (Orsega-Smith, Payne, Mowen, Ho, & Godbey, 2007).

We found that low outdoor physical activity was significantly associated with a shortage of contacts with friends and neighbors regardless of socio-demographic and health-related factors. Social isolation from friends and neighbors might affect one's life in limiting informal social activities and health-promoting behaviours like physical activity. The outdoor environment seems to be of particular importance, since meeting with friends and neighbors and engaging in social activities often take place outside the house and can be concurrently be associated with high levels of physical activity. Research on environmental constrains to a person's physical activity have long focused on aspects of the physical environment (Cerin et al., 2014). Today, the influence of social factors like social isolation is widely recognized in research that studies the effect of the environment on individuals physical activity levels (McNeill, Kreuter, & Subramanian, 2006).

When focusing on indoor physical activity, perceived social isolation from family mattered most. Interestingly, all well-known predictors (e.g., age, sex, BMI, and functional limitations) had only small effects on indoor physical activity and explained a small proportion of the variation in indoor physical activity level, resulting in a poor statistical

model fit. Indoor physical activity might be a rather basic behaviour pattern (e.g., going to the toilet) that will be maintained until functional limitations or health problems severely restrict a persons' mobility. The adaption to poor health might first affect outdoor rather than indoor physical activity. Individuals with functional limitations or health problems may not be able to be physically active for as long and assess outdoor locations.

There are some limitations to this study. First, the cross-sectional design of our analyses did not allow for examining the direction of the relationship between physical activity and perceived social isolation. Both measures should be tracked over time to avoid reversed causality. Future analyses using a longitudinal design would allow for the examination of changing conditions in partner status, the size of social network, and how physical activity responds to these changes. Second, the Lubben Social Network Scale was designed as a clinical instrument to evaluate social isolation. Information about the quality and the supportive structures of networks is lacking. The quality as well as the quantity of social networks may influence the relationship between social isolation and perceived health (Fiorillo & Sabatini, 2011). Third, the accelerometer only captured lower body movements (e.g., walking or cycling) and missed upper body physical activity. However, lower body physical activity like walking is the primary form of physical activity in the general population (Watson et al., 2016). An international study comparing physical activity levels found that in four of twenty countries with substantial rates of high physical activity, more than 30 percent of overall physical activity is derived from walking (Bauman et al., 2009). Lastly, this study might underestimate the duration of outdoor physical activity because some participants made errors in properly documenting their outdoor activity time (i.e., the beginning or the end of the outdoor periods were missing). However, there is no reason to assume that these missing values might differ between isolated and non-isolated persons.

With these limitations in mind, we believe that the strength of this study is reflected in a population sample with prevalences of social isolation comparable to that of other

international studies, including a German study (Lubben et al., 2006; Shimada et al., 2014). The operationalization of objectively assessed outdoor and indoor physical activity provides valuable information about the relation of social context and physical activity in older age. The outdoor physical activity diary provided additional insight into the type and duration of outdoor physical activities. In combination with an accelerometer device that is not prone to recall and response biases (Taber et al., 2009), such as self-report assessments, we were able to portray different domains of physical activity.

This study contributed to understanding how low physical activity is linked to social isolation. The importance of non-kin networks suggests that there would be a significant benefit to changing natural networks, in a way bringing people (other than family members) together or opening up facilities for social or recreational group activities (Cohen & Janicki-Deverts, 2009). Future studies on social isolation in older adults could be improved by fostering peer and group-based interventions that include physical activity. A meta-analysis has shown that group-based and participatory interventions targeting social isolation were most beneficial in comparison to one-to-one or non-participatory intervention (Dickens, Richards, Greaves, & Campbell, 2011). A recent review by Robins and colleagues (2016) found that group physical activity interventions were associated with decreasing social isolation among community-dwelling older adults. The authors' findings suggested combining physical activity interventions with social interaction. That combination might have an impact on social isolation greater than focusing on social activities alone. The importance of physical activity locations suggests a distinction between indoor and outdoor physical activity locations. Including an inactive indoor and outdoor control condition in future interventions would help to tease out the effect of the physical activity location while controlling for social interactions.

In conclusion, this study found a significant association between perceived social isolation and outdoor physical activity among older adults using objectively assessed physical

activity. A greater understanding of the mechanisms of the association between different kinds of physical activity and perceived social isolation can be used to create and improve physical activity programs. Such programs might be most beneficial if they target friend, neighbor and peer networks as a means to improve individual physical activity.

References

Avlund, K., Lund, R., Holstein, B. E., & Due, P. (2004). Social relations as determinant of onset of disability in aging. *Archives of Gerontology and Geriatrics*, *38*(1), 85–99. https://doi.org/10.1016/j.archger.2003.08.003

Bauman, A., Bull, F., Chey, T., Craig, C. L., Ainsworth, B. E., Sallis, J. F., … Pratt, M. (2009). The International Prevalence Study on physical activity: Results from 20 countries. *The International Journal of Behavioral Nutrition and Physical Activity*, *6*, 21. https://doi.org/10.1186/1479-5868-6-21

Berkman, L. F., Glass, T., Brissette, I., & Seeman, T. E. (2000). From social integration to health: Durkheim in the new millennium. *Social Science & Medicine*, *51*(6), 843–857. https://doi.org/10.1016/S0277-9536(00)00065-4

Bjelland, I., Dahl, A. A., Haug, T. T., & Neckelmann, D. (2002). The validity of the Hospital Anxiety and Depression Scale. An updated literature review. *Journal of Psychosomatic Research*, *52*(2), 69–77. https://doi.org/10.1016/S0022-3999(01)00296-3

Blozik, E., Wagner, J. T., Gillmann, G., Iliffe, S., von Renteln-Kruse, W., Lubben, J., … Clough-Gorr, K. M. (2009). Social network assessment in community-dwelling older persons: results from a study of three European populations. *Aging Clinical and Experimental Research*, *21*(2), 150–157. https://doi.org/10.1007/BF03325223

Cerin, E., Cain, K. L., Conway, T. L., Van Dyck, D., Hinckson, E., Schipperijn, J., … Sallis, J. F. (2014). Neighborhood environments and objectively measured physical activity in 11 countries. *Medicine and Science in Sports and Exercise*, *46*(12), 2253–2264. https://doi.org/10.1249/MSS.0000000000000367

Cohen, S., & Janicki-Deverts, D. (2009). Can we improve our physical health by altering our social networks? *Perspectives on Psychological Science : A Journal of the Association for Psychological Science*, *4*(4), 375–378. https://doi.org/10.1111/j.1745-6924.2009.01141.x

Crooks, V. C., Lubben, J., Petitti, D. B., Little, D., & Chiu, V. (2008). Social network, cognitive function, and dementia incidence among elderly women. *American Journal of Public Health*, *98*(7), 1221–1227. https://doi.org/10.2105/AJPH.2007.115923

Cumming, R., & Klineberg, R. (1994). A Study of the reproducibility of long-term recall in the elderly. *Epidemiology*, *5*(1), 116–119. https://doi.org/10.1097/00001648-199401000-00017

Denkinger, M., Franke, S., Rapp, K., Weinmayr, G., Duran-Tauleria, E., Nikolaus, T., … ActiFE Ulm Study Group. (2010). Accelerometer-based physical activity in a large observational cohort - study protocol and design of the activity and function of the elderly in Ulm (ActiFE Ulm) study. *BMC Geriatrics*, *10: 50*. https://doi.org/10.1186/1471-2318-10-50

Dickens, A. P., Richards, S. H., Greaves, C. J., & Campbell, J. L. (2011). Interventions targeting social isolation in older people: A systematic review. *BMC Public Health*, *11: 647*. https://doi.org/10.1186/1471-2458-11-647

Fiori, K. L., Smith, J., & Antonucci, T. C. (2007). Social network types among older adults: A multidimensional approach. *Journals of Gerontology Series B-Psychological Sciences and Social Sciences*, *62*(6), P322–P330. https://doi.org/10.1093/geronb/62.6.P322

Fiorillo, D., & Sabatini, F. (2011). Quality and quantity: The role of social interactions in self-reported individual health. *Social Science & Medicine*, *73*(11), 1644–1652. https://doi.org/10.1016/j.socscimed.2011.09.007

Giuli, C., Spazzafumo, L., Sirolla, C., Abbatecola, A. M., Lattanzio, F., & Postacchini, D. (2012). Social isolation risk factors in older hospitalized individuals. *Archives of Gerontology and Geriatrics*, *55*(3), 580–585. https://doi.org/10.1016/j.archger.2012.01.011

Groll, D. L., To, T., Bombardier, C., & Wright, J. G. (2005). The development of a comorbidity index with physical function as the outcome. *Journal of Clinical Epidemiology*, *58*(6), 595–602. https://doi.org/10.1016/j.jclinepi.2004.10.018

Hakola, L., Hassinen, M., Komulainen, P., Lakka, T. A., Savonen, K., & Rauramaa, R. (2015). Correlates of low physical activity levels in aging men and women: The DR's EXTRA Study (ISRCTN45977199). *Journal of Aging and Physical Activity*, *23*(2), 247–255. https://doi.org/10.1123/japa.2013-0169

Hart, T. L., Swartz, A. M., Cashin, S. E., & Strath, S. J. (2011). How many days of monitoring predict physical activity and sedentary behaviour in older adults? *The International Journal of Behavioral Nutrition and Physical Activity*, *8*, 62. https://doi.org/10.1186/1479-5868-8-62

Holt-Lunstad, J., Smith, T. B., Baker, M., Harris, T., & Stephenson, D. (2015). Loneliness and social isolation as risk factors for mortality: A meta-analytic review. *Perspectives on Psychological Science*, *10*(2), 227–237. https://doi.org/10.1177/1745691614568352

Holt-Lunstad, J., Smith, T. B., & Layton, J. B. (2010). Social relationships and mortality risk: A meta-analytic review. *PLoS Medicine*, *7*, e1000316. https://doi.org/10.1371/journal.pmed.1000316

House, J., Landis, K., & Umberson, D. (1988). Social relationships and health. *Science*, *241*(4865), 540–545. https://doi.org/10.1126/science.3399889

Hupin, D., Roche, F., Gremeaux, V., Chatard, J.-C., Oriol, M., Gaspoz, J.-M., … Edouard, P. (2015). Even a low-dose of moderate-to-vigorous physical activity reduces mortality by 22% in adults aged >= 60 years: A systematic review and meta-analysis. *British Journal of Sports Medicine*, *49*(19), 1262–7. https://doi.org/10.1136/bjsports-2014-094306

Irwin, M. L., Ainsworth, B. E., & Conway, J. M. (2001). Estimation of energy expenditure from physical activity measures: Determinants of accuracy. *Obesity Research*, *9*(9), 517–525. https://doi.org/10.1038/oby.2001.68

Jacobs, J., Cohen, A., Hammerman-Rozenberg, R., Azoulay, D., Maaravi, Y., & Stessman, J. (2008). Going outdoors daily predicts long-term functional and health benefits among ambulatory older people. *Journal of Aging and Health*, *20*(3), 259–272. https://doi.org/10.1177/0898264308315427

Kerr, J., Sallis, J. F., Saelens, B. E., Cain, K. L., Conway, T. L., Frank, L. D., & King, A. C. (2012). Outdoor physical activity and self rated health in older adults living in two regions of the US. *International Journal of Behavioral Nutrition and Physical Activity*, *9*, 89. https://doi.org/10.1186/1479-5868-9-89

Klenk, J., Büchele, G., Rapp, K., Franke, S., Peter, R., & ActiFE Study Group. (2012). Walking on sunshine: Effect of weather conditions on physical activity in older people. *Journal of Epidemiology and Community Health*, *66*(5), 474–476. https://doi.org/10.1136/jech.2010.128090

Leask, C. F., Harvey, J. A., Skelton, D. A., & Chastin, S. F. M. (2015). Exploring the context of sedentary behaviour in older adults (what, where, why, when and with whom). *European Review of Aging and Physical Activity*, *12:4*. https://doi.org/10.1186/s11556-015-0146-7

Legh-Jones, H., & Moore, S. (2012). Network social capital, social participation, and physical inactivity in an urban adult population. *Social Science & Medicine*, *74*(9), 1362–1367. https://doi.org/10.1016/j.socscimed.2012.01.005

Li, T., & Zhang, Y. (2015). Social network types and the health of older adults: Exploring reciprocal associations. *Social Science & Medicine*, *130*, 59–68. https://doi.org/10.1016/j.socscimed.2015.02.007

Litwin, H. (2003). Social predictors of physical activity in later life: The contribution of social-network type. *Journal of Aging and Physical Activity*, *11*(3), 389–406. https://doi.org/10.1123/japa.11.3.389

Litwin, H. (2007). What really matters in the social network-mortality association? A multivariate examination among older Jewish-Israelis. *European Journal of Ageing*, *4*(2), 71–82. https://doi.org/10.1007/s10433-007-0048-2

Lubben, J., Blozik, E., Gillmann, G., Iliffe, S., von Renteln Kruse, W., Beck, J. C., & Stuck, A. E. (2006). Performance of an abbreviated version of the Lubben Social Network Scale among three European community-dwelling older adult populations. *The Gerontologist*, *46*(4), 503–513. https://doi.org/10.1093/geront/46.4.503

McNeill, L. H., Kreuter, M. W., & Subramanian, S. V. (2006). Social environment and physical activity: A review of concepts and evidence. *Social Science & Medicine (1982)*, *63*(4), 1011–1022. https://doi.org/10.1016/j.socscimed.2006.03.012

Orsega-Smith, E. M., Payne, L. L., Mowen, A. J., Ho, C.-H., & Godbey, G. C. (2007). The role of social support and self-efficacy in shaping the leisure time physical activity of older adults. *Journal of Leisure Research*, *39*(4), 705–727.

Portegijs, E., Tsai, L.-T., Rantanen, T., & Rantakokko, M. (2015). Moving through life-space areas and objectively measured physical activity of older people. *Plos One*, *10*(8), e0135308. https://doi.org/10.1371/journal.pone.0135308

Robins, L. M., Jansons, P., & Haines, T. (2016). The impact of physical activity interventions on social isolation among community - dwelling older adults: A systematic review. *Research & Reviews: Journal of Nursing and Health Sciences*, *2*(1), 62–71.

Ryan, C. G., Grant, P. M., Tigbe, W. W., & Granat, M. H. (2006). The validity and reliability of a novel activity monitor as a measure of walking. *British Journal of Sports Medicine*, *40*(9), 779–784. https://doi.org/10.1136/bjsm.2006.027276

Saliba, D., Orlando, M., Wenger, N., Hays, R., & Rubenstein, L. (2000). Identifying a short functional disability screen for older persons. *The Journals of Gerontology, Series A: Medical Sciences*, *55*(12), M750–M756. https://doi.org/10.1093/gerona/55.12.M750

Santini, Z. I., Koyanagi, A., Tyrovolas, S., Mason, C., & Maria Haro, J. (2015). The association between social relationships and depression: A systematic review. *Journal of Affective Disorders*, *175*, 53–65. https://doi.org/10.1016/j.jad.2014.12.049

Shankar, A., McMunn, A., Banks, J., & Steptoe, A. (2011). Loneliness, social isolation, and behavioral and biological health indicators in older adults. *Health Psychology: Official Journal of the Division of Health Psychology, American Psychological Association*, *30*(4), 377–385. https://doi.org/10.1037/a0022826

Shimada, K., Yamazaki, S., Nakano, K., Ngoma, A. M., Takahashi, R., & Yasumura, S. (2014). Prevalence of social isolation in community-dwelling elderly by differences in household composition and related factors: From a social network perspective in urban Japan. *Journal of Aging and Health*, *26*(5), 807–823. https://doi.org/10.1177/0898264314531616

Shiovitz-Ezra, S., & Litwin, H. (2012). Social network type and health-related behaviors: Evidence from an American national survey. *Social Science & Medicine*, *75*(5), 901–904. https://doi.org/10.1016/j.socscimed.2012.04.031

Stenholm, S., Koster, A., Valkeinen, H., Patel, K. V., Bandinelli, S., Guralnik, J. M., & Ferrucci, L. (2016). Association of physical activity history with physical function and mortality in old age. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences*, *71*(4), 496–501. https://doi.org/10.1093/gerona/glv111

Steptoe, A., Shankar, A., Demakakos, P., & Wardle, J. (2013). Social isolation, loneliness, and all-cause mortality in older men and women. *Proceedings of the National Academy of Sciences of the United States of America*, *110*(15), 5797–5801. https://doi.org/10.1073/pnas.1219686110

Taber, D. R., Stevens, J., Murray, D. M., Elder, J. P., Webber, L. S., Jobe, J. B., & Lytle, L. A. (2009). The effect of a physical activity intervention on bias in self-reported activity. *Annals of Epidemiology*, *19*(5), 316–322. https://doi.org/10.1016/j.annepidem.2009.01.001

Taraldsen, K., Askim, T., Sletvold, O., Einarsen, E. K., Bjåstad, K. G., Indredavik, B., & Helbostad, J. L. (2011). Evaluation of a body-worn sensor system to measure physical activity in older people with impaired function. *Physical Therapy*, *91*(2), 277–285. https://doi.org/10.2522/ptj.20100159

Thompson Coon, J., Boddy, K., Stein, K., Whear, R., Barton, J., & Depledge, M. H. (2011). Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. *Environmental Science & Technology*, *45*(5), 1761–1772. https://doi.org/10.1021/es102947t

Watson, K. B., Dai, S., Paul, P., Carlson, S. A., Carroll, D. D., & Fulton, J. (2016). The attributable proportion of specific leisure-time physical activities to total leisure activity volume among US adults, National Health and Nutrition Examination Survey 1999-2006. *Journal of Physical Activity & Health*. https://doi.org/10.1123/jpah.2015-0695

World Health Organization. (2003). *Health and development through physical activity and sport*. Geneva: World Health Organization.

Table 1
Sample characteristics of respondents (N = 1162)

	Mean ± SD / Percentage (%)
Main study variables	
Indoor physical activity[a] (minutes / day)	55.0 ± 21.8
Outdoor physical activity[a] (minutes / day)	53.7 ± 30.1
Outdoor activities (minutes / day)	
walking	11.1 ± 15.5
shopping	10.6 ± 8.5
social contact	7.4 ± 9.3
gardening	6.2 ± 10.1
sports	6.0 ± 13.5
work	4.4 ± 11.6
services[b]	2.8 ± 4.4
cultural events	2.3 ± 5.0
Social isolation	
LSNS overall	
0 - 11	18.4 %
12 - 30	81.6 %
LSNS family subscale	
0 - 5	13.3 %
6 - 15	86.7 %
LSNS Neighbor/friend subscale	
0 - 5	28.0 %
6 - 15	72.0 %
Control Variables	
Male	57.2 %
Age [c] (years)	
65 - 69	24.5 %
70 - 79	47.2 %
80 - 90	28.3 %
School education	
low (<=9 years)	59.3 %
middle (10 years)	20.1 %
high (>10 years)	20.6 %
Multimorbididy (0-16)	2.2 ± 1.5
Depression score (HADS-D) (0-21)	3.7 ± 2.8
Body mass index	27.5 ± 3.9
Disability (0-20)	1.0 ± 2.1
Average temperature	12.4 ± 9.3
Living status	
Alone	24.5 %
Living with a partner	69.1 %
Living with children	11.4 %

Notes. LSNS - 6 = 6-item Lubben social network scale; HADS-D = Depression subscore of Hospitality and Anxiety Score; FCI = Functional Comorbidity Index (Groll et al. 2005); Possible ranges in brackets; [a] Based on accelerometer measurement; [b] Hair dresser, consulting, etc.; [c] Age was stratified in three groups

Table 2

Multivariate linear regression analysis predicting physical activity with social isolation as main independent variable (n = 1162)

	Main predictor model			Complete model		
	B	*SE*	β	*B*	*SE*	β
Intercept	110.1 ***	1.2		184.0 ***	7.6	
Social isolation[a] (LSNS < 12) [a]	-7.8 **	2.9	-.08	-3.4	2.5	-.03
Male				1.5	2.0	.02
Age						
65 - 69				Ref.		
70 - 79				-8.4 **	2.5	-.11
80 - 90				-27.8 ***	2.9	-.33
School education						
low (<=9 years)				Ref.		
middle (10 years)				-4.3	2.5	-.05
high (>10 years)				-9.8 ***	2.6	-.10
Multimorbidity (FCI) [b]				-1.6 *	0.8	-.06
Depression score (HADS-D) [c]				-0.5	0.4	-.03
Body mass index (BMI) [d]				-2.3 ***	0.3	-.23
Disability [e]				-2.7 ***	0.5	-.15
Average temperature [f]				0.7 ***	0.1	.17
adj. R^2			.006			.226

Notes. Notes. B = unstandardized beta coefficients; SE = standard error; β = standardized beta coefficients; Ref. = reference category for categorical predictors; FCI = Functional Comorbidity Index; [a] LSNS = 6-item Lubben Social Network Scale; [b] Possible ranges from 0 to 16;[c] HADS-D = Depression subscore of Hospitality and Anxiety Score (HADS-D) with a possible range from 0 to 21;[d] BMI that ranges from 16.4 to 48.0; [e] Activities of daily living (ADL) with possible ranges from 0 to 20; [f] Average temperature during activity monitoring; *p< .05, **p< .01, ***p< .001

Table 3

Multivariate linear regression analyses: Indoor and outdoor physical activity by social isolation (n = 1162)

	Indoor physical activity						Outdoor physical activity					
	Main predictors model			Complete model			Main predictors model			Complete model		
	B	*SE*	β	*B*	*SE*	β	*B*	*SE*	β	*B*	*SE*	β
Intercept	55.7 ***	0.8		80.2 ***	4.8		55.8 ***	1.1		103.6 ***	6.1	
Social isolation from friends (LSNS < 6) [a]	-0.8	1.4	-.02	0.5	1.4	.01	-8.7 ***	2.0	-.13	-4.5 *	1.8	-.07
Social isolation from family (LSNS < 6) [a]	-3.8 *	1.9	-.06	-4.5 *	1.8	-.07	2.6	2.6	.03	4.5	2.3	.05
Male				-8.9 ***	1.3	-.20				10.3 ***	1.6	.17
Age												
65 - 69				Ref.						Ref.		
70 - 79				1.2	1.5	.03				-9.4 ***	2.0	-.15
80 - 90				-4.2 *	1.8	-.08				-23.2 ***	2.3	-.35
School education												
low (<=9 years)				Ref.						Ref.		
middle (10 years)				0.2	1.6	.00				-4.5 *	2.0	-.06
high (>10 years)				-3.8 *	1.6	-.07				-6.0 **	2.0	-.08
Multimorbidity (FCI) [b]				-0.7	0.5	-.05				-0.9	0.6	-.04
Depression score (HADS-D) [c]				0.4	0.2	.05				-0.8 *	0.3	-.07
Body mass index (BMI) [d]				-0.7 ***	0.2	-.13				-1.5 ***	0.2	-.20
Disability [e]				-1.0 **	0.3	-.09				-1.7 ***	0.4	-.12
Average temperature [f]				0.2 *	0.1	.07				0.5 ***	0.1	.17
adj. R^2			.002			.096			.015			.228

Notes. B = unstandardized beta coefficients; SE = standard error; β = standardized beta coefficients; Ref. = reference category for categorical predictors; FCI = Functional Comorbidity Index; [a] LSNS = 6-item Lubben Social Network Scale; [b] Possible ranges from 0 to 16; [c] HADS-D = Depression subscore of Hospitality and Anxiety Score (HADS) with a possible range from 0 to 21;[d] BMI ranges from 16.4 to 48.0; [e] Activities of daily living (ADL) with possible ranges from 0 to 20; [f] average temperature during activity monitoring; *p< .05, **p< .01, ***p< .001

Table 4

Comparison of outdoor physical activity levels between socially isolated and non-isolated (from friends/ neighbors) older adults by different purposes (minutes/day)

	Non-isolated [a] (*n*= 837)		isolated [a] (*n*= 325)			
	M	*SE*	*M*	*SE*	*F*	*p*
social contact	7.9	0.3	6.1	0.5	9.3	.003
gardening	6.7	0.3	5.0	0.5	6.8	.010
cultural events	2.5	0.2	1.9	0.3	4.1	.043
services [b]	2.6	0.2	3.1	0.3	3.0	.083
shopping	10.3	0.3	11.1	0.5	2.2	.135
walk	11.5	0.5	10.2	0.9	1.7	.200
sports	6.2	0.5	5.3	0.7	0.3	.607
work	4.4	0.4	4.2	0.6	0.1	.745

Notes. M = adjusted mean; SE = standard error; Tests of significance are based on ANCOVAs (analysis of covariance); Adjusted for education, age, multimorbidity, disability, depression, sex, body mass index and temperature; N = 1162; [a] Social isolation from friends and neighbors; [b] Hair dresser, consulting, etc.