Summary

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Introduction

The WHO has designated mental health as a public health priority and advocates maintaining and creating healthy cities, which offer a living environment that supports health and healthy behaviour. Of special concern is that the ongoing urbanisation and densification pose a threat to urban green spaces. Moreover, the provision of urban green space is unevenly distributed within cities, with low availability of green space in deprived neighbourhoods. When urban green space becomes scarce, urban residents have fewer opportunities for visiting such spaces and experiencing nature and, therefore, may not take advantage of the potential health benefits of green spaces. Green spaces provide attractive places where urban residents find relief from the demands of urban life and urban stressors, such as noise and crowding. Not only green spaces are often characterized by the absence of urban stressors, but also it is hypothesized that green spaces have a restorative potential (i.e. the potential to reduce stress and mental fatigue) because of contact with nature as such. The availability of green space in the residential environment can also stimulate physical activity and facilitate social contacts.

Previous research has provided indications for an array of possible health benefits of green spaces and contact with nature. Therefore, there is an urgent need for systematically reviewing and synthesizing the level of evidence of health benefits of green spaces. Substantial knowledge gaps exist, especially regarding the underlying mechanisms. Challenges are to identify mediators and modifiers of the associations between green space and health, and to clarify the intermediate role of use of green space. Previous experimental research on the restorative potential of exposure to green space identified a need to further explore the underlying psychophysiological mechanism of mental health benefits, more specifically of stress recovery and buffering effects of viewing green environments.

Aim

The research presented in this thesis aims at addressing these knowledge gaps by using epidemiological as well as experimental methods. The aim of this thesis is threefold:

1. To systematically review and synthesize the evidence for associations between green space in the residential environment and perceived mental health, general health and all-cause mortality;
2. To explore effect modification and underlying mechanisms regarding the association between green space in the residential environment and mental health (three cross-sectional epidemiological studies collecting and using PHENOTYPE data from four European cities);
3. To explore the underlying psychophysiological mechanisms of mental health benefits of green spaces in an experimental study, with a focus on visual exposure.
The research conducted for this thesis is part of the EU Seventh Framework Programme (FP7) project “Positive health effects of the natural outdoor environment in typical populations in different regions in EUROPE (PHENOTYPE)”. The aim of PHENOTYPE is to seek more robust evidence for a relationship between exposure to natural outdoor environments and human health and well-being in different countries/regions across Europe.

**Systematic review**

The systematic review involved an online search using a predetermined search strategy, followed by a selection by eligibility criteria. Three levels of evidence were defined based on the number and quality of the studies, and the consistency of the findings. The search and selection revealed 14 studies on perceived general health, 19 on mental health and 7 on all-cause mortality (Chapter 2). The evidence for a positive association with the availability of green space in the immediate residential environment was found to be strong for perceived mental health and all-cause mortality, and moderate for perceived general health. The evidence for associations with other quantitative measures of green space was inconclusive. There were insufficient studies on the quality of green spaces for an evidence synthesis. A few studies provided indications that associations depend on gender, age and social economic status, but the findings were mixed. Further research should explore whether green space and health relationships differ when using different indicators of green space exposure and for different population subgroups and different countries.

**Epidemiological research**

This thesis presents the results of three epidemiological studies (Chapter 3 to 5). Firstly, the association between time spent on visiting green space and mental health was investigated and whether this association differs between different population (sub)groups. Secondly, the mechanisms explaining the association were explored. Thirdly, it was examined whether time spent visiting green space is, as hypothesized in the analytical framework, an important exposure pathway through which people have contact with green space in the immediate residential environment to explain the green space - mental health link. The specific research questions were the following:

1. How strong is the association between time spent on visiting green spaces and mental health? And do cultural/climatic settings and individual (demographic and motivational) factors modify the association?
2. Do indicators of physical activity and social contacts mediate the association between time spent visiting on green spaces and mental health?
3. Does time spent on purposeful visits to green space mediate the association between the level of residential greenness and mental health?
Many epidemiological studies have found that people living in environments with more green space report better mental health than those with less green space. However, the association between visits to green space and mental health has seldom been studied. Therefore, the first of the three epidemiological studies in this thesis (Chapter 3) explored the associations between total time spent on visiting green spaces in the immediate residential environment as well as further away and two indicators of mental health (perceived mental health and vitality) in four different European cities, and to what extent gender, age, level of education, attitude towards nature and childhood nature experience moderate these associations. Questionnaire data were collected from 3947 residents in 124 neighbourhoods in four European cities: Barcelona (SP), Doetinchem (NL), Kaunas (LT) and Stoke-on-Trent (UK). Multilevel analyses (N = 3748, cases with missing data excluded) showed significant positive associations between time spent visiting green spaces and both mental health indicators in the pooled data, as well as across the four cities. However, the associations were weak, suggesting small mental health benefits associated with additional time spent visiting green space. Significant effect modification was found for level of education and childhood nature experience. The association was stronger for the population group with low level of education, as was expected, but weaker for the subgroup with ample childhood nature experience, which was contrary to the expectation. The findings confirm the hypothesis that more time spent in green space is associated with higher scores on mental health and vitality scales, independent of culture and climate.

The second epidemiological study was a multiple mediation study (Chapter 4). Several studies have explored the mechanisms underlying positive associations between residential green space and mental health. There are, however, no studies that explored mediation in the association between visits to green space and mental health. The study in this thesis investigated whether certain indicators of physical activity and social contacts, mediate the association between (total) time spent on visiting green spaces and mental health. The same dataset and indicators of mental health (i.e. perceived mental health and vitality) as in the previous study were used to conduct single and multiple mediation analyses (N= 3748). Single mediation analyses showed that different indicators of physical activity (total, during leisure time and walking during leisure time), social cohesion and feelings of loneliness were mediators in the previous found associations between time spend on visiting green space and mental health. Multiple mediation analyses showed that physical activity during leisure time and loneliness explain about 25% of the association. Other mediators (or mechanism) may thus play a role for example the mental restoration mechanism, or mechanisms related to the possible impact of green space on environmental quality, for example cooling effects and noise abatement.

The third epidemiological study in this thesis explored whether time spent on visiting green space in the immediate residential environment acts as a mediator in the association between level of residential greenness and mental health (Chapter 5). Many epidemiological studies have consistently shown positive associations between availability of green space in the immediate residential environment and mental health, which was judged as strong evidence in the
systematic review in this thesis as being strong (Chapter 2). It is, however, unknown whether people must visit green space to obtain mental health benefits or whether the presence of green space as such in the immediate residential environment is sufficient. Again, PHENOTYPE questionnaire data collected in the four cities were used and matched with data on level of greenness by using satellite images (Normalized Difference Vegetation Index, NDVI). Single mediation analyses were conducted (N = 3765) with the pooled data as well as per city. No significant overall associations were found between the level of residential greenness and mental health, neither in the pooled data, nor in the data of the four cities. However, positive associations were found between level of greenness in the immediate residential environment and time spent visiting green space near home in Barcelona and Doetinchem. The mediation analysis showed that time spent visiting green space near home was a significant, although weak, mediator in the pooled data and in the data for Doetinchem only. The findings provide little support for the hypothesis that people have to visit green space on purpose to obtain mental health benefits from residential greenness. More research is needed to explore other mediators related to different exposure pathways, such as visual exposure, and alternative mechanisms, such as (perceived) safety and quality of green spaces.

Experimental research

In order to explore the underlying psychophysiological mechanisms of mental health benefits of green spaces, with a focus on visual exposure, an experimental study was conducted. A cross-over design was used where participants served as their own control. This laboratory study explored buffering and recovery effects of viewing urban green and built spaces on autonomic nervous system activity (Chapter 6). Forty-six students viewed photos of green and built spaces immediately following, and preceding, acute stress induction. Simultaneously recorded electrocardiogram and impedance cardiogram signals were used to derive respiratory sinus arrhythmia (RSA) and pre-ejection period (PEP), indicators of respectively parasympathetic and sympathetic activity. The findings showed greater recovery after viewing green scenes, as marked by a stronger increase in RSA as a marker of parasympathetic activity. There were no indications for greater recovery after viewing green scenes in PEP as a marker of sympathetic activity, nor were also no indications of greater buffering effects of green space in either RSA or PEP. The findings suggest a predominant role of the parasympathetic nervous system in restorative effects of viewing green space.

Recommendations for research and practice

This thesis was the first to explore cultural differences in the green-space and mental health link, by collecting data in four cities in different regions of Europe. Positive associations were found between time spent visiting green space and mental health in all four cities. However, these associations were weak, which suggests only small mental health benefits from visiting
green space (Chapter 3). In contrast to findings from previous research, no associations were found between the level of residential greenness and mental health. Only in two cities associations between the level of residential greenness and time spent on visiting green space in the immediate residential environment were found (Chapter 5). This suggests cultural differences in, for example, urban planning and motivations to use green space. More research is needed to identify the precise nature of those differences.

As most of the studies included in the systematic review, also the epidemiological studies in this thesis relied on cross-sectional data. Therefore, concerns about unmeasured, residual confounding and reverse causality remain (i.e. people who are healthier spent more time on visiting green space). To strengthen the evidence-base for a causal relationship between green space and mental health, studies with more sophisticated designs, e.g. “natural experiments”, are needed. Further research should unravel which exposure pathways and mechanisms are most important. The experimental study in this thesis (Chapter 6) suggests a direct psychophysiological stress response to short-term exposure to green views, but it is not clear yet what the role of longer exposure times and more intense experiences of being in “real” nature is, with its sounds and smells.

Another interesting research question is whether it is actually the direct restorative effect of greenness as such or the contribution of greenness to the perceived attractiveness of the neighbourhood from an aesthetics and environmental quality point of view. Green space may also lower exposure to noise and air pollution, and can reduce high temperature levels. People who report visits are not necessarily consciously engaged with nature. Green space with its natural features may in that case then function as just an attractive background setting for their leisure activities. But, green space may also provide opportunities for a more intense contact with nature which contribute to more sustained restorative effects and promote personal development. Engagement with nature, as part of urban green space and, thus, of the built environment, may enhance psychological resilience and the ability to cope with everyday demands and life events. Nevertheless, the research on these long-term benefits of engagement with nature as such for people’s well-being (rather than health) is still in its infancy. This raises the question whether greenness or green space provides health benefits in other settings, for example in health care settings, especially those for people with mental health problems.

The study in this thesis that explored the association between the level of residential greenness and mental health in four European cities (Chapter 5) cannot add to the evidence for such an association as presented in the systematic review (Chapter 2). However, the findings do suggest that time spent on visiting green space provides small mental health benefits for the adult population (Chapter 3). However, for certain population groups the mental health benefits may be more substantial, especially for those with low levels of education. Thus, not only providing more green space in residential environments is recommended, but also stimulation people to visit green space by developing special programmes to promote visiting green space for physical activity, social contacts or reducing stress and mental fatigue (restoration) or to strengthen contact and engagement with nature.