**Exploring pathways linking greenspace to health:**

**Theoretical and methodological guidance**

Iana Markevych, PhD1,2\*, Julia Schoierer, PhD1, Terry Hartig, Prof.3, Alexandra Chudnovsky, PhD4, Perry Hystad, PhD5, Angel M. Dzhambov, MD, MSc6, Sjerp de Vries, PhD7, Margarita Triguero-Mas, PhD8,9,10, Michael Brauer, Prof.11, Mark J. Nieuwenhuijsen, Prof. 8,9,10, Gerd Lupp, PhD12, Elizabeth A. Richardson, PhD13, Thomas Astell-Burt, PhD14,15, Donka Dimitrova, PhD16, Xiaoqi Feng, PhD14,15, Maya Sadeh, MSc17, Marie Standl, PhD2, Joachim Heinrich, PhD1,2, Elaine Fuertes, PhD8,9,10

1 Institute for Occupational, Social, and Environmental Medicine, Ludwig-Maximilians-

University of Munich, Munich, Germany

2 Institute of Epidemiology I, Helmholtz Zentrum München - German Research Center for

Environmental Health, Neuherberg, Germany

3 Institute for Housing and Urban Research, Uppsala University, Uppsala, Sweden

4 AIRO Lab, Department of Geography and Human Environment, School of Geosciences, Tel-Aviv University, Tel-Aviv, Israel

5 College of Public Health and Human Sciences, Oregon State University, Corvallis, Oregon, USA

6 Department of Hygiene and Ecomedicine, Faculty of Public Health, Medical University of Plovdiv, Plovdiv, Bulgaria

7 Wageningen University & Research, Environmental Research, Wageningen, The Netherlands

8 ISGlobal, Centre for Research in Environmental Epidemiology (CREAL), Barcelona, Spain

9 Universitat Pompeu Fabra (UPF), Barcelona, Spain

10 CIBER Epidemiología y Salud Pública (CIBERESP), Barcelona, Spain

11 School of Population and Public Health, University of British Columbia, Vancouver, British Columbia, Canada

12 Chair for Strategic Landscape Planning and Management, Technical University of Munich, Munich, Germany

13 Centre for Research on Environment, Society and Health (CRESH), University of Edinburgh, Edinburgh, Scotland, UK

14 Population Wellbeing and Environment Research Lab (PowerLab), Faculty of Social Sciences, University of Wollongong, Wollongong, Australia

15 Early Start, University of Wollongong, Faculty of Social Sciences, University of Wollongong, Wollongong, Australia

16 Department of Health Management and Healthcare Economics, Faculty of Public Health, Medical University of Plovdiv, Plovdiv, Bulgaria

17 School of Public Health, Tel-Aviv University, Tel-Aviv, Israel

**\*Corresponding author**:

Dr. Iana Markevych

Institute for Occupational, Social, and Environmental Medicine,

Ludwig-Maximilians-University of Munich

Ziemssenstraße 1

80336 Munich

Germany

Phone: +4989 31872549

Fax: +4989 31873380

[iana.markevych@helmholtz-muenchen.de](mailto:iana.markevych@helmholtz-muenchen.de)

**Funding**

The Expert Workshop was funded by the European Cooperation in Science and Technology (COST; BM1201 - Developmental Origins of Chronic Lung Disease), the European Union’s Horizon 2020 Research and Innovation programme (ALEC Study, #633212) and the Institute for Occupational, Social, and Environmental Medicine, Ludwig-Maximilians-University of Munich. Elaine Fuertes is supported by a Marie Skłodowska-Curie Individual Fellowship (H2020-MSCA-IF-2015; 704268). ISGlobal is a member of CERCA Programme / Generalitat de Catalunya. Xiaoqi Feng is supported by a National Heart Foundation of Australia postdoctoral fellowship (#100948). Xiaoqi Feng and Thomas Astell-Burt are supported by a National Health and Medical Research Council project grant (#1101065) and a Horticultural Innovation Australia “Green Cities” research grant (#GC15005). The funding sources had no involvement in the writing of the report and the decision to submit the article for publication.

**Acknowledgement**

We would like to thank two anonymous Reviewers for their insightful comments which helped us to improve the manuscript greatly.

**Conflicts of interests**

The authors declare that they have no conflicts of interest.

**Abstract**

**Background.** In a rapidly urbanizing world, many people have little contact with natural environments, which may affect health and well-being. Existing reviews generally conclude that residential greenspace is beneficial to health. However, the processes generating these benefits and how they can be best promoted remain unclear.

**Objectives.** During an Expert Workshop held in September 2016, the evidence linking greenspace and health was reviewed from a transdisciplinary standpoint, with a particular focus on potential underlying biopsychosocial pathways and how these can be explored and organized to support policy-relevant population health research.

**Discussions.** Potential pathways linking greenspace to health are here presented in three domains, which emphasize three general functions of greenspace: reducing harm (e.g. reducing exposure to air pollution, noise and heat), restoring capacities (e.g. attention restoration and physiological stress recovery) and building capacities (e.g. encouraging physical activity and facilitating social cohesion). Interrelations between among the three domains are also noted. Among several recommendations, future studies should: use greenspace and behavioural measures that are relevant to hypothesized pathways; include assessment of presence, access and use of greenspace; use longitudinal, interventional and (quasi)experimental study designs to assess causation; and include low and middle income countries given their absence in the existing literature. Cultural, climatic, geographic and other contextual factors also need further consideration.

**Conclusions.** While the existing evidence affirms beneficial impacts of greenspace on health, much remains to be learned about the specific pathways and functional form of such relationships, and how these may vary by context, population groups and health outcomes. This Report provides guidance for further epidemiological research with the goal of creating new evidence upon which to develop policy recommendations.

**Key words:** greenness, green spaces, greenspace, pathways, mediation analysis.

**1. Introduction**

Overall, 54% of the world's population now lives in urban settings, a term which can encompass relatively small towns of less than 500,000 inhabitants to megacities of more than 10 million inhabitants (United Nations 2014). This percentage is projected to reach 66% by 2050 (United Nations 2014). Urbanization is an important current and future challenge and it entails change in how people interact with the environment (Zenghelis & Stern 2016; Nieuwenhuijsen et al. 2017). This includes quantitatively and qualitatively diminished contact with natural environments. Consequently, the extent to which population exposure to natural environments may be causally related to beneficial health outcomes has become the focus of an emerging field in environmental epidemiology during the past few decades.

The existing reviews and meta-analyses that have considered this question conclude that various measures of exposure to residential greenness (i.e. vegetation level) or green spaces such as parks, gardens and forests (hereon referred to generically only as “greenspace” when both greenness and green spaces are meant; Taylor & Hochuli 2017) are beneficial for multiple measures of health for urban populations in relatively high-income countries (e.g. Hartig et al. 2014; James et al. 2015; van den Berg et al. 2015; Gascon et al. 2015, 2016b; Dzhambov et al. 2014; de Keijzer et al. 2016). In particular, beneficial associations with greenspace have been observed for outcomes such as general health (e.g. Dadvand et al. 2016; Sugiyama et al. 2008), mental health (e.g. de Vries et al. 2013; McEachan et al. 2016), obesity (e.g. Ellaway et al. 2005; Lovasi et al. 2013b), birth weight (e.g. Hystad et al. 2014; Markevych et al. 2014a), childhood behavioural development (e.g. Balseviciene et al. 2014; Amoly et al. 2014) and mortality (e.g. Mitchell & Popham 2008; Villeneuve et al. 2012; Donovan et al. 2013). However, not all studies find evidence of a beneficial association between greenspace and the health outcomes considered (e.g., Flouri et al. 2014; Mowafi et al. 2012; Potestio et al. 2009; Markevych et al. 2016b) and some even report associations opposite to those expected (Cummins & Fagg 2012; Pereira et al. 2012; Prince et al. 2011; Richardson et al. 2012). An interesting example comes from the allergy field, where increasing greenness was positively associated with childhood allergies in one German study area but inversely associated with the same outcomes in a second German study area, despite the use of identical epidemiological methods (Fuertes et al. 2014). This lack of a consistent relationship was replicated in seven birth cohorts from five countries two years later (Fuertes et al. 2016). Similarly, Casey et al. (2016) reported no association between greenness and term birth weight among ~13000 newborns in Pennsylvania, despite the fact that this association is among the most consistent and widely replicated (Dzhambov et al. 2014). More “conflicting” results are likely and therefore, more specific and process-oriented research should be encouraged to improve our understanding of the complexities underlying associations between greenspace and health outcomes.

In September 2016, a workshop entitled “Exploring Potential Pathways Linking Greenness and Green Spaces to Health” took place in Munich-Herrsching, Germany. The attendees included experts from various complementary disciplines, covering environmental and social epidemiology, exposure science, environmental psychology, forestry, geography, remote sensing and city planning. This Report summarizes the discussions that took place, beginning with the primary aim of the Workshop, which was to consider the evidence linking greenspace and health from a transdisciplinary standpoint, while focusing on potential underlying pathways (Section 2, Figure 1). In addition, recommendations for future research, in terms of study designs, exposure assessment and analytical approaches (Section 3, Tables 1 and 2), as well as policy implications (Section 4), were identified. In line with the aims of the Workshop, the objective of this Report is to provide guidance for further research based on the experiences of interdisciplinary researchers interested in greenspace-health relationships. It is not intended to be an exhaustive review of the literature.

**2. Potential pathways linking exposure to greenspace and health outcomes**

**2.1. Summary of the pathways**

**2.1.1. Potentially beneficial influences of greenspace on health**

A variety of biopsychosocial pathways have been proposed to explain the health benefits of greenspace (e.g., Hartig et al. 2014; Kuo 2015). These can be parsimoniously organized into three domains that emphasize different general functions of greenspace (Figure 1).

This organizational approach is novel but not without foundations. Each of the domains maps onto a widely applied perspective on ways to modify the environment in order to support adaptation and promote health (Hartig 2008; Hartig et al. 2008; Von Lindern, Lymeus, & Hartig 2017). Each of these perspectives has distinctive theoretical and practical premises, but these complement rather than contradict one another as a basis for understanding and intervention. Moreover, the three domains encompass the four general pathways (i.e., air quality, physical activity, social contacts and stress) that previous reviewers (e.g., Health Council of the Netherlands 2004; Hartig et al. 2014) have used to organize empirical literature from different disciplines. These four pathways have also been the focus of studies that have tested their relative contributions as mediators of the relationship between greenspace and health (e.g., Dadvand et al. 2016; Triguero-Mas et al. 2015; de Vries et al. 2013; Hystad et al. 2014; Astell-Burt et al. 2013b; James et al. 2016). As discussed during the Workshop, the now conventional organization of the literature into these four pathways is not intrinsic to the subject matter but rather reflects the different concerns of particular research fields. In contrast, our reference here to these three general domains considers how future work might be better organized and suggests possibilities for interdisciplinary exchange, especially as these domains are not mutually exclusive and complex interactions and interrelatedness of processes are likely. For example, environmental epidemiologists and environmental psychologists have long studied effects of noise as well as air pollution, and an understanding of the respective and interactive effects of those stressors can benefit from the consideration of greenspace as both a mitigating influence and a restorative resource (cf. von Lindern, Hartig & Lercher 2016; von Lindern, Lymeus & Hartig 2017). Further, this organizational approach encourages consideration of novel or little studied pathways in the context of other potential influences. For example, it encourages consideration of other forms of capacity building aside from social contacts and physical activity (e.g. improving the functioning of the immune system through increased exposure to microbial biodiversity; Kuo 2015) and other forms of restoration aside from stress recovery and attention restoration (e.g., collective forms of restoration of social resources; Hartig et al. 2013).

For the sake of simplicity and in line with the focus of discussion in the Workshop, Figure 1 represents one direction of influence, from greenspace to health. We acknowledge, however, that feedback from health to greenspace occurs, as residents in an area may sometimes work to preserve and/or enhance nearby greenspace because they value it as a resource for health or related factors (e.g., outdoor recreation).

In Sections 2.2 through 2.4, we overview the existing evidence regarding specific pathways and possible effect modifiers within each of the three general domains. In Sections 3 through 4, we discuss potential challenges and opportunities of greenspace research and provide recommendations for future research efforts.

**H:\Greenspace_workshop\Paper\3_draft\re-submitted\Figure1.tif**

**Figure 1.** Three domains of pathways linking greenspace to positive health outcomes. The arrows represent hypothetical patterns of influence, with specific pathways in each domain potentially influencing one or more specific pathways in the other domains.

**2.1.2. Potentially adverse influences of greenspace on health**

Although this Report focuses on potential mechanisms driving beneficial associations between greenspace and health, some studies have noted possible adverse associations with greenspace that may be context specific. As a summary was recently provided by the World Health Organization (2016), here we only briefly list some of the most important ones. First, in some environments, introducing new or more greenspace may lead to a greater spread and higher concentrations of allergenic pollen by trees and herbaceous species, which could raise allergic disease prevalence (Cariñanos & Casares-Porcel 2011). Second, as greenspace serves as a habitat for disease vectors (in particular, ticks, mosquitos, rats, cats and dogs), more greenspace could increase the rate of infections (Lõhmus & Balbus 2015). Third, larger greenspace characterized by restricted opportunities for surveillance can serve as a place for crime (Kimpton, Corcoran & Wickers 2016), or simply, a place feared due to the potential for crime, particularly for vulnerable populations (women, children and the elderly; Lee & Maheswaran 2011). Finally, in certain situations, urban greening (e.g. building a new park) may lead to increased property rents and taxes in adjacent areas, which could encourage the displacement of populations with lower socioeconomic status (Wolch, Byrne & Newell 2014; Donovan & Butry 2010). These aspects as well as others (such as possible increased risk of skin cancer due to spending more time outdoors in greenspace (Astell-Burt et al. 2014c), increased exposure to pesticides and herbicides (World Health Organization 2016) and physical damage to infrastructures attributable to growing roots and falling trees (McPherson & Peper 1996)) need to be considered when organizing and maintaining greenspace and developing health-related policies.

**2.2. Reducing harm (mitigation)**

**2.2.1. Reducing exposure to air pollution**

There is a general consensus that air pollutant concentrations are lower around greenspace (Nowak et al. 2014; Morani et al. 2011; Hirabayashi & Nowak 2016; David Suzuki Foundation 2015; Planting Healthy Air 2016). One reason for this is that most emissions of primary pollutants are not present in greenspace. For example, levels of traffic-related air pollution are lower in urban green spaces, at least to some extent, because of the lack of traffic in these areas (Su et al. 2011). Residences and schools with higher surrounding greenness have also been observed to have lower traffic-related air pollution exposures (Dadvand et al. 2012b, 2015b). Greenspace variables are even used as predictors in land use regression models of air pollution (Rao et al. 2014).

It is also assumed that vegetation may directly and efficiently remove air pollutants, especially particulate matter of less than 10 µm (PM10) and ozone, via deposition (Kroeger et al. 2014), which is widely incorporated into valuation models (Hirabayashi & Nowak 2016; Nowak et al. 2014). However, empirical research that supports this assumption is limited and inconsistent (Steffens, Wang & Zhang 2012; Grundström & Pleijel 2014). Street trees reduce dispersion of traffic-related pollution and therefore may reduce near-road exposure in a similar manner as solid barriers (Vos et al. 2013; Tong et al. 2015), but they may simultaneously increase on-road concentrations (Pugh et al. 2012; Tong et al. 2015, 2016; Salmond et al. 2013). Further, greenspace has higher concentrations of ozone due to the absence of nitric oxide emissions which serve to quench ozone via atmospheric reactions (Su et al. 2011). Greenspace is also an important source of biogenic volatile organic compounds and secondary organic aerosols (Pacifico et al. 2009). In fact, the overall empirical data do not suggest major impacts of greenspace as means to reduce (i.e. filter) air pollution. On the contrary, it shows that greenspace has the potential to increase concentrations of particular air pollutants.

In epidemiological studies, air pollution (mostly nitrogen dioxide and particulate matter) has been frequently considered as a possible confounder in greenspace-health associations (e.g. Hystad et al. 2014; Sbihi et al. 2015; Markevych et al. 2014a, 2014b; Dadvand et al. 2012c), although only one study has found evidence of this effect (Thiering et al. 2016). The treatment of air pollution as a confounder rather than a mediator is likely due to the uncertainty regarding whether greenspace has an independent effect on health, rather than simply being an area where pollution levels are lower. One study that has used mediation analysis to test whether air pollution may act as a mediator in the link between greenness and mortality has found support for partial mediation (James et al. 2016). Similarly, Dadvand et al. (2015a) observed partial mediation by reduced air pollution of the association between greenness and cognitive development in children.

**2.2.2. Reducing exposure to heat**

High-rise buildings, dense construction zones, industry and commercial centers, anthropogenic activities as well as opaque surfaces such as asphalt and concrete all contribute to the rise in air temperature of a city compared to its rural surroundings (Parlow 2003; Voogt & Oke 2003). This phenomenon, known as an urban heat island (Voogt & Oke 2003), is largely due to greater absorption and storage of solar energy by these man-made features. It is also associated with reduction of wind speed (Phelan et al. 2015). The rise in air temperature in urban areas correlates with higher air pollution levels and heat stress and can even exacerbate heat related mortality (Brauer & Hystad 2014; Luber & McGeehin 2008; Smargiassi et al. 2009; Zhang, Chen & Begley 2015). In contrast, vegetation absorbs direct solar radiation, changes the albedo of background surfaces and has a cooling effect through evapotranspiration. Numerous publications report a cooling effect of greenspace located within a city on the surrounding areas (e.g. Spronken-Smith & Oke 1999; Bowler et al. 2010a; Saaroni et al. 2000; Morais et al. 2016). Increasing the proportion of greenspace in a city is thus one possible strategy for improving the urban thermal environment (e.g. Spronken-Smith & Oke 1999; Shashua-Bar et al. 2000; Potchter et al. 2006; Pelta & Chudnovsky 2017). Different types of greenspace, vegetation volume and its spatial configuration may exhibit different abilities for temperature moderation and Urban Heat Island mitigation that need to be accounted for in different urban settings located in various climatic zones (Zhou et al. 2011; Potchter et al. 2012; Davis et al. 2016; Sun and Chen 2017).

To our knowledge, no study has investigated whether the beneficial effects of greenspace can be explained by heat mitigation using mediation analysis. However, several studies have tested whether greenspace modifies relationships between heat and mortality, and these studies have found heat-related mortality to be lowest in the greenest areas (e.g. Son et al. 2016; Burkart et al. 2016; Gronlund et al. 2015; Xu et al. 2013).

**2.2.3. Reducing exposure to noise**

Greenspace can buffer the effects of traffic noise through two pathways – acoustic (physical reduction in noise exposure) and psychological (buffering of a stress response to noise). The former has been much more thoroughly researched, with green barriers, green facades and green roofs appearing to reduce noise levels by 5-10 dB through diffraction, absorption or destructive interference of sound waves (van Renterghem et al. 2015). Further, as is the case with air pollution, the simple lack of artificial noise emitting sources in greenspace will lead to lower noise levels. However, in some scenarios such as street canyons, tree crowns may actually reflect the sound waves and increase noise exposure at the level of pedestrians’ ears (Jang et al. 2015).

The psychological effect can provide benefits above those related to acoustic blocking. A handful of field studies that compared the effects of vegetation on noise annoyance under similar acoustic conditions or adjusted for objectively measured noise in their analyses, consistently demonstrated significantly reduced noise annoyance in people who have greenspace near their home (Gidlöf-Gunnarsson & Ohrstrom 2007; Gidlöf-Gunnarsson et al., 2009; Li et al. 2010; Li et al. 2012; Leung et al. 2014; Bodin et al. 2015; Dzhambov & Dimitrova 2015; van Renterghem & Botteldooren 2016). The hypothesized mechanisms include visual shielding of the noise source (Aylor & Marks 1976), improvement in perceived acoustic quality of the environment because of nature sounds (Kang et al. 2016), combined visual “exposure” to both greenspace and water features (as they are both associated with lower noise annoyance and often are seen together; Li et al. 2012; Leung et al. 2014), reduced perceived health risk, and an increased sense of control over the acoustic environment (Dzhambov & Dimitrova 2015). Natural sounds coming from greenspace may also have beneficial psychological effects as they may reduce the effect of non-natural sounds (Annerstedt et al. 2013). Interestingly, the overall perceived greenness of a neighborhood does not appear to be associated with noise annoyance (van Renterghem & Botteldooren 2016; Dzhambov & Dimitrova 2015), possibly because some types of greenspace (wetland parks and garden parks) reduce annoyance to a greater extent than others (grassy hills) (Li et al. 2010). It is possible that the greenness should be visible in order to achieve maximal mitigation of noise annoyance at home, or that more greenspace is sometimes found in sprawling suburban developments which are dependent on noisier transportation (Richardson et al. 2012).

Noise has been associated with several of the same health outcomes as greenspace (e.g., cardiovascular disease, metabolic disorders, adverse pregnancy outcomes, cognitive impairment, mental health; Basner et al. 2014; Christensen et al. 2016; Dzhambov 2015; Gehring et al. 2014). Therefore, noise may lie on the causal pathway between greenspace and health. As one example, it is plausible that noise-related pathways mediate associations between neighbourhood greenspace and sleep duration (Astell-Burt et al. 2013a; Grigby-Toussaint et al. 2015). To date, no study has explicitly tested whether measured or self-reported noise mediates the associations between greenspace and health. As few noise map models consider acoustic shielding by greenspace (Garg & Maji 2014) and land use regression models for noise use only 2D greenspace data to predict noise levels (Ragettli et al. 2016), it is not possible to assume that these greenspace variables are causally related to reduced noise exposure, which violates one assumption of mediation models. Direct measurement of noise at the facade level is one alternative, but this is only possible in small-scale studies. On the contrary, the collection of noise annoyance data via questionnaires is a feasible and useful alternative for testing mediation by noise exposure in epidemiological studies. Future studies exploring how greenspace around people’s home may decrease psychological noise should consider using eye-level panoramic imagery over remotely-sensed imagery if available, as the latter may not correlate sufficiently with perceived greenspace (Jiang et al. 2017).

**2.3. Restoring capacities (restoration)**

Greenspace has received substantial attention as a resource for psychological restoration (Hartig et al. 2014). Over the past few decades, the study of the restorative value of greenspace has been guided by one or both of two theories within environmental psychology, stress reduction theory (SRT; Ulrich 1983; Ulrich et al. 1991) and attention restoration theory (ART; Kaplan & Talbot 1983; Kaplan & Kaplan 1989; Kaplan 1995), each of which specifies an antecedent condition from which a person can need restoration as well as aspects of the environmental experience that can support a particular process of restoration. SRT focuses on psychophysiological stress as the antecedent condition. Building on evolutionary assumptions about biologically prepared patterns of response to environmental features relevant for survival, SRT proposes that viewing vegetation and other natural-appearing environmental features can very rapidly evoke positive emotions that block negative thoughts and emotions, thereby ameliorating or shutting down the stress response. SRT thus encourages study of how an encounter with greenspace brings about a reduction of physiological activation (seen in hormonal, cardiovascular and musculoskeletal parameters) as well as more positive self-reported emotions. In contrast, ART focuses on a depleted capacity to willfully suppress distractions and direct attention as the antecedent condition. As a mean to recover from directed attention fatigue, ART emphasizes the power of vegetation and other natural-appealing environmental features to attract and hold a person’s attention without effort, thereby enabling rest of the neurocognitive mechanism on which effortful directed attention depends. ART thus encourages the study of how an encounter with greenspace can enhance the ability to willfully direct attention and otherwise effectively deploy executive functions, as reflected, for example, in standardized cognitive tests. Whether guided by ART or SRT, research in this area assumes that a person who accesses environments of relatively high restorative quality (e.g., with more greenness) during periods when restoration can occur will cumulatively realize greater health benefits than he or she would do by spending the time in environments of lesser restorative quality (Hartig 2007).

Many experimental studies over the past decades have investigated restorative effects of a single, specific exposure to greenspace or natural features in an environment. For example, one field experiment found that healthy young adults who walked in a peri-urban park after facing taxing demands showed an increase in self-reported positive effects such as cheerfulness and a decrease in negative effects such as anger in comparison to pretest reference values, while those who walked along roads in an area of medium density urban development showed the opposite pattern of change (Hartig et al. 2003). Furthermore, those who walked in the park also showed decline in systolic blood pressure measured with an ambulatory device as well as improved performance in a task requiring directed attention, while those who walked in the urban area again showed the opposed pattern of change. Laboratory experiments have found similar kinds of relatively beneficial changes while viewing some simulated natural setting, as with a forested space or a green roof seen from an office window (e.g. Annerstedt et al. 2013; Brown et al. 2013; Lee et al. 2015). Field and laboratory experiments alike have used diverse affective self-report measures, measures of physiological activity (e.g., cardiovascular, neuroendocrine, musculoskeletal) and standardized cognitive tests to capture outcomes characteristic of physiological stress reduction and/or attention restoration. In recent years, meta-analyses of effect estimates from such experimental studies (Bowler et al. 2010b; Ohly et al. 2016) have yielded evidence both in line and at odds with each theory and with the results of individual studies, raising questions not least about the suitability of the measures used to capture restorative effects. Moreover, some observational studies have found evidence to support the potential role of greenspace in buffering or reducing stress (van den Berg et al. 2010; Roe et al. 2013; Stigsdotter et al. 2010; Ward Thompson et al. 2012). However, the potential mediating effect of recurrent episodes of restoration on associations established between greenspace and health over time has only been examined in three studies (Grazuleviciene et al. 2014; Kuo 2001; de Vries et al. 2013), two of which found indications of mediation (on effectiveness in managing major life issues (Kuo 2001) and general and mental health as well as acute complaints (de Vries et al. 2013)).

Apart from the simple lack of studies exploring this pathway, there are gaps of a more theoretical character to consider. First, research has not adequately addressed the relative contributions of the components of “more restorative encounters” – that is, of the relative importance of such factors as frequency, duration, quality of experience and type of encounter (e.g., incidental viewing of natural surroundings from a window or purposeful entry into greenspace specifically for escaping stressful demands). Moreover, studies have not tested ART or SRT in any complete sense. For example, ART attributes attention restoration to reliance on effortless attention (fascination) as enabled and supported by a sense of being away, extent and compatibility in the environmental encounter (Kaplan & Kaplan 1989). No experiment to date has however addressed the respective contributions of these hypothetical qualities of restorative experience to any restorative outcome as measured with a standardized test. A similar situation holds with respect to research guided by SRT.

Second, applications of ART and SRT need critical consideration with regard to the practical separability of their assumed antecedent conditions (i.e., directed attention fatigue and stress, respectively) when considering the longer timeframes over which an inability to adequately restore would become meaningful for health. As it stands, the kind of cognitive deficits in focus with ART have long been taken to reflect vulnerability to stress (e.g., Broadbent et al. 1982).

Third, greenspace *per se* is of less interest than how people perceive and use greenspace in comparison to other settings. Researchers should take interest in when and from where people move into greenspace considered as behaviour settings, and how their activities in greenspace might serve different restoration needs that arose with activities in other settings occupied prior to visiting greenspace (e.g., as with paid work in an urban office or domestic work in the residence). The restorative experience is thus considered within a broader context. Concomitantly, greenspace is not considered simply as space, distinguished and isolated from other spaces, but rather a place that stands in relation to other places in recurrent activity cycles within a social ecology of stress and restoration (Hartig, Johansson & Kylin 2003). From this perspective, the term “greenspace” is itself somewhat misleading, and “greenplace” would be a more accurate term for the environmental entity of interest.

**2.4. Building capacities (instoration)**

**2.4.1 Encouraging physical activity**

Greenspace is likely to provide a safe, accessible and attractive setting in which to conduct physical activity (Almanza et al. 2012; Mytton et al. 2012; Astell-Burt et al. 2014d). There is even evidence (although inconsistent) that suggests that physical activity performed in greenspace (green physical activity) produces greater psychological and physiological benefits than physical activity done in other settings (Duncan et al. 2014; Mitchell 2013; Pretty et al. 2005; Thompson Coon et al. 2011). However, most studies to date, with only a few exceptions (Kaczynski et al. 2009; Mitchell 2013; Ord et al. 2013; Ou et al. 2016; Schipperijn et al. 2013; de Vries et al. 2013; Almanza et al. 2012), have considered only the amount (duration, intensity) of physical activity conducted, and not whether the activity was performed in a greenspace or another setting. This limitation might at least partially explain the inconsistent existing evidence on the association between greenspace and “overall” physical activity levels (Bancroft et al. 2015; Lachowycz & Jones 2011).

Studies that have used mediation analysis to investigate whether physical activity lies on the causal pathway between greenspace and health have yielded mixed findings: some studies observed an indirect effect (McEachan et al. 2016; Richardson et al. 2013; Sugiyama et al. 2008; de Vries et al. 2013; James et al. 2016), while others did not (Astell-Burt et al. 2013b; Dadvand et al. 2016; Maas et al. 2008; Sturm & Cohen 2014; Triguero-Mas et al. 2015). What appears certain is that the sole presence of greenspace does not necessarily imply its use. In particular, not all greenspace is attractive for physical activity due to characteristics such as size and available facilities. For example, previous work has reported larger green spaces with well-maintained paths are likely to be more attractive to adults for physical activity than smaller “pocket parks”, which may be more attractive for more sedentary forms of recreation (e.g. Giles-Corti et al. 2005). Differences in the greenspace exposure indicators used (Kaczynski et al. 2009), types of greenspace included in the analysis (e.g. agricultural land is not always considered), acknowledgement of limited access to formal entry points for some greenspace (as is the case in many gated parks) or quality of the amenities (Cohen et al. 2006) could be further explanations for the existing inconsistent epidemiological findings.

It should also be noted that the greennest areas might correlate with areas that have fewer everyday destinations (e.g. grocery store, post office and pharmacy) within walking distance, resulting in more car dependency and less active transportation (Richardson et al. 2012; Hartig et al. 2014). This might be especially relevant when examining urban/rural differences. Indeed, Pereira and colleagues (2012) postulate that a balance of green and non-green land uses could have optimal potential for health.

Further studies are thus needed, but these should go beyond exploring physical activity as a mediator in isolation. Rather, they should consider physical activity in combination with other potential mediators. It appears possible that at least some greenspace-health associations are mediated by stress/restoration qualities or social contacts that are fostered by green physical activity (de Vries et al. 2013). Information on physical activity intensities as well as the settings (and their access and quality)where the physical activity is being conducted is needed, and can be (more) easily obtained with the expansion of smartphone ownership.

**2.4.2 Facilitating social cohesion**

Greenspace provides settings for contacts with neighbours, which are likely to increase social cohesion within a neighbourhood: the feeling that the people in the neighbourhood know and respect each other, pose no danger and may help if needed (Forrest & Kearns 2001; Kuo et al. 1998; Kuo & Sullivan 2001a & 2001b; Kemperman & Timmermans 2014; Holtan et al. 2015; Weinstein et al. 2015). Social cohesion needs to be distinguished from social capital (i.e. resources available to an individual through his/her social connections, which may be activated in times of need) as the former is expected to be more susceptible to the physical layout of the residential environment (Hartig et al. 2014). Social cohesion within the neighbourhood is related to human health and well-being (Rios et al. 2012; Fone et al. 2014) and is hypothesized to account for a considerable extent of the relationship between greenspace and health, especially mental and general health (de Vries et al. 2013; Dadvand et al. 2016; Maas et al. 2009a). However, a mediating effect has not been observed in all studies (Triguero-Mas et al. 2015), which may be attributable to the selection of the social cohesion indicator (Maas et al. 2009a).

Not all greenspace might be equally suitable for positive social contacts, and thus more refined greenspace measures are required. Moreover, social contacts might not be equally important for different population groups. For example, greenspace suitable for social development and outdoor play by young children is not necessarily the same as that for the elderly. Current research suggests that neighbourhood social cohesion is especially important for the elderly (Elliott et al. 2014), but this may partly be due to the fact that other segments of the population have not yet been adequately investigated. Social contacts among children during outdoor play may positively affect socio-emotional development and help to establish social cohesion, which may also extend to the parents (Bar-Haim & Bart 2006). Data on actual contacts with neighbourhood members (frequency and type of contact) and social function-oriented greenspace assessments will help to assess to what extent social cohesion is responsible for the link between greenspace and health in different population groups. Relatively new methods, such as the use of big data (e.g., smartphone data) and/or GPS-tracking, may aid a finer-grained assessment of social contacts in green environments (Donaire-Gonzalez et al. 2016), as an alternative to questionnaires.

**3. Challenges and opportunities**

**3.1. Study designs**

Cross-sectional designs are commonly used and help to identify potential greenspace-health associations. However, their methodological limitations are well recognized, in particular, their inability to establish causality and their vulnerability to residential self-selection (e.g. healthier people will tend to choose to live in greener places (Toftager et al. 2011)). Instead, longitudinal, intervention and (quasi)experimental research designs should be employed whenever possible. Longitudinal cohort studies – in which participants can be traced through greener and less green residential neighbourhoods – have already shown that moves to greener or more natural places are associated with improved mental health and wellbeing (Alcock et al. 2015; van den Bosch et al. 2015; White et al. 2013). The addition of new spatial exposure measures and/or key questions on greenspace and behaviour involving greeenspace (e.g., “green” view from a window at home/work; amount of time spent outdoors in nearby greenspace conducting physical activity, socializing; ownership of a private garden; weekend and holiday travel to distant greenspace/leisure home; perceptions of restorative qualities of residential greenspace) to the many ongoing longitudinal studies is a realistic and cost-effective method of utilizing already existing resources for data collection. Researchers should also take advantage of natural experiments to capture the impact of a change in the quantity and quality of greenspace on health and the hypothesized pathways (e.g. Donovan et al. 2013; Giles-Corti et al. 2013; Astell-Burt, Feng & Kolt 2016). Finally, small-scale experiments are still needed to advance the understanding of the affective, cognitive, physiological and social processes engaged in discrete encounters with greenspace which may over time lead to associations with different health outcomes.

**3.2 Greenspace exposure assessment**

**3.2.1 Current exposure metrics**

In nearly all epidemiological studies, “greenspace exposure” generally implies the presence of greenspace near the home, although no standardized definition for even this “simple” exposure proxy exists. A number of methods have been used to assess the presence of greenspace, including satellite-based indices and GIS-based land use variables.

A common greenspace exposure method used in population-based studies is the Normalized Difference Vegetation Index (NDVI; Tucker 1979). The NDVI is easy to retrieve across different study areas and has been shown to be a valid and practical metric to study associations between greenspace and health outcomes (Rhew et al. 2011; Gascon et al. 2016b; James et al. 2015; Yuan & Bauer 2007). However, there are numerous other vegetation indices that might better be able to capture vegetation signals across different climates and built-up areas, such as the Green Ratio Vegetation Index (GRVI) (Sripada et al. 2006), Soil-Adjusted Vegetation Index (SAVI) (Huete 1988) and Enhanced Vegetation Index (EVI) (Huete et al. 2002). A detailed description of the available vegetation indices is beyond the scope of this Report, but can be found elsewhere (Jensen 2007; Harris Geospatial Solutions 2017). Importantly, vegetation indices can be customized for particular applications (Lugassi et al. 2015). Figure 2 shows the upper quartile of vegetation pixels (highlighted by red colour) based on three different Landsat-derived vegetation indexes - NDVI, GRVI and SAVI. Although the spatial pattern looks quite similar, there is spatial variability over the same location as well as number of selected pixels for the same location. No doubt that future studies should shed a light on whether associations with health are sensitive to the use of different indices with buffers of different sizes around locations of interest.

C:\Users\Niavka\AppData\Local\Microsoft\Windows\INetCacheContent.Word\Iana_75percent.tif

**Figure 2.** Spatial pattern of vegetation for the urban site of Tel-Aviv and suburbs based on upper quartile of Landsat-derived NDVI, GRVI and SAVI.

All aforementioned vegetation indices share the same set of limitations. First, these indices are limited by the spatial and temporal availability of the satellite images used in their calculation. Numerous epidemiological studies are based on NDVI calculated from 30 m pixel size Landsat images (http://earthexplorer.usgs.gov/) taken during a single summer day (e.g. Dadvand et al. 2014b, 2012a; Markevych et al. 2014a; Agay-Shay et al. 2014; Grazuleviciene et al. 2015). Only occasionally NDVI is averaged over several images taken during different seasons over several years (e.g. Hystad et al. 2014). The main reason for this is the low temporal resolution of the Landsat images: there are only two acquisitions per month, and these are not always done under cloud-free conditions. This is especially challenging if a study area is large and several Landsat images are needed to cover it completely (Markevych et al. 2014a; Fuertes et al. 2016; Laurent et al. 2013). MODIS, another satellite instrument provides a better temporal resolution, images that are pre-processed and includes pre-calculated NDVI and EVI products (<http://daacmodis.ornl.gov/cgi-bin/MODIS/GLBVIZ_1_Glb/modis_subset_order_global_col5.pl>). These data are increasingly being used in epidemiological studies (e.g. Cusack et al. 2016; Casey et al. 2016; James et al. 2016). However, it should be noted that MODIS imagery has a spatial resolution of 0.25-1 km and is therefore limited in its ability to capture within-city greenspace variation. Figure 3 demonstrates that decreasing the spatial resolution from 10 m to 60 m makes it almost impossible to capture a small urban green space.

C:\Users\Niavka\AppData\Local\Microsoft\Windows\INetCacheContent.Word\Figure3_cor.tif**Figure 3.** Spatial resolution: decreasing the spatial resolution impacts the accuracy of NDVI. “True color” means “human-like (i.e. vegetation is shown in green), whereas “false color”, highlight vegetation in red.

Second, as vegetation indices assess the overall level of vegetation only and do not differentiate between structured (e.g. parks) and unstructured (e.g. street trees, backyards) vegetation, they are unable to assess the quality of greenspace. For example, an inaccessible abandoned lot overgrown with vegetation may give the same value as a widely used city park. Spatial/texture classification algorithms could help to solve this problem (Shoshany 2002; Shoshany et al. 2012) but their use requires expert knowledge. Vegetation indices on their own are also poor at identifying vegetation types (trees, grass and shrubs), but various machine learning algorithms and spectral and object classification approaches are emerging to solve this problem (Fan 2013; Rodriguez-Galiano et al. 2012). The recent launch of the Sentinel-2 Multi-Spectral Instrument (MSI), which has improved spectral and spatial resolution (Figure 3), will also allow different vegetation types to be quantified (Thenkabail et al. 2016). There are also very high spectral resolution sensors (e.g. hyperspectral) that enable the identification of vegetation species (Asner et al. 2015; Roth et al. 2015), but these data are spatially restricted and the data pre-processing and analyses require special training. Two satellites of this type are scheduled to launch: EnMAP (in 2018) and HyspIRI (in 2023).

A third issue related to the use of these indices is that water surfaces (lakes, rivers, seas) receive a negative score (Weier & Herring 2000). In practice, these negative values are often recoded to zero (e.g. Fuertes et al. 2016) or set to missing (e.g. Markevych et al. 2016b; Pereira et al. 2012) before further analyses are conducted, so that the effects of water surfaces do not negate the presence of greenspace. It is however probable that water surfaces have independent beneficial effects on health (e.g. Nutsford et al. 2016) or compensate for a lack of greenspace (de Vries et al. 2016). Studies are currently underway to explore this further, such as the European BlueHealth initiative (http://www.ecehh.org/research-projects/bluehealth/). If the research emphasis is only on greenspace, we recommend the removal of negative values, especially in areas with large blue spaces, for which the greenspace exposure assignment will otherwise be substantially affected (i.e. artificially reduced; Ekkel & de Vries 2017). In studies researching joint effects of greenspace and bluespace, negative values could be modified (e.g., set to the highest value of vegetation in the specific study area), under the assumption that bluespace may provide similar benefits as parks and forests with respect to physical activity, social interactions and restoration with viewing of scenery.

A number of other measures not related to satellite-derived vegetation indices have been used in epidemiological studies, such as land use- and land cover-derived metrics of distance, presence, amount and type of greenspace. For example, among the most widely used sources of data in the European Union is the Coordination of Information on the Environment (CORINE) database (<http://www.eea.europa.eu/data-and-maps/data/clc-2006-vector-data-version>). However, CORINE data does not capture small green spaces and includes only areas that are at least 25 ha (the minimum mapping unit), rending its use inappropriate in urban areas (Annerstedt et al. 2012; Mitchell et al. 2011). The more detailed European Urban Atlas (http://www.eea.europa.eu/data-and-maps/data/urban-atlas) is a useful alternative and includes small green spaces. However, these data are available only for urban areas with more than 100 000 inhabitants. In the United States of America, the EnviroAtlas (<https://www.epa.gov/enviroatlas>) currently provides data on land use, vegetation types, and measures of ecosystem services for 16 US cities (goal is 50 cities by 2019). Other detailed land use or vegetation databases and Light Detection and Ranging (LiDAR) data are often developed by local authorities and can be used to estimate very detailed greenspace exposures (e.g., Ulmer et al. 2016; Lovasi et al. 2013a), although comparability and quality across study areas may become issues.

Regardless of the use of the selected greenspace measure, it is important to highlight the difficulty in defining an individual’s neighbourhood. A large number of buffer distances have been applied in epidemiological studies, ranging from 30 m to 5,000 m. There is also variability in how the buffers are calculated (circular buffers, as the “crow flies”, and more sophisticated measures that take into account distances along road networks). Furthermore, although buffers of certain sizes are often highly correlated (e.g., 100 m and 300 m), it is unknown what buffer sizes (and shapes, which are better able to take into account road networks and accessibility (Higgs et al. 2012)) are best suited for representing the different pathways within the mitigation, restoration and instoration domains. Conceivably, the relevant spatial scale might differ according to the specific pathway and health outcome within any of the domains. For greenspace reductions of traffic air pollution and noise, the relevant buffer size would be small (<100 m), representing physical vegetation buffers (e.g. trees) along the roadways near residential locations. Similarly, for “viewsheds” around homes, small buffer distances might better represent restorative influences. Alternatively, larger buffers might better reflect potential influences of greenspace on recreational physical activity. It is also likely that the optimal buffer size may differ by population group as small children and senior citizens are more limited in their residential mobility than adults. Finally, in line with the uncertain geographic context problem, epidemiological findings could be affected by how the neighbourhood size and shape was defined before abstracting greenspace information (Kwan 2012a, 2012b). As there is now nearly no available information on how to optimally define neighbourhoods for different outcomes, pathways and population groups, several buffer sizes and shapes should be tested, whenever possible.

**3.2.2 Ways forward in greenspace exposure assessment**

Table 1 summarizes individual and spatial exposure metrics for different pathways contained within the three domains from Figure 1. For the mitigation (harm reduction) domain, where the simple presence of greenspace may be sufficient to realize benefits, individual-level behavioural/perceptual measures may be of little value. That is not to say that individual behaviours do not modify resulting exposures (e.g. use of air conditioning and different time-activity patterns will change exposure levels) but that individual-level behaviours will not change the mitigating impact of greenspace on other environmental exposures. In contrast, restoring capacities (restoration) and building capacities (instoration) have important individual behavioural components; people deliberately engage with greenspace, whether briefly and in passing (e.g., a few minutes spent looking out one’s window; Kaplan 2001) or in the context of recreational outings of longer duration (e.g. Lupp et al. 2016b). In these cases, data on time-activity patterns as well as access to and use of greenspace, which have been rarely considered thus far (James et al. 2015), are needed. Smartphone GPS technologies, which are increasingly feasible in large population-based epidemiological studies, may help fill this gap by identifying if, when, how regularly and for how long people visit greenspace (Lachowycz et al. 2012; Nieuwenhuijsen et al. 2014a, 2014b; Donaire-Gonzalez et al. 2016). However, high privacy standards and restrictions in certain countries have to be observed when collecting and using data that can be assigned to individual persons (Lupp et al. 2016a). Personal experiences within greenspace also need to be captured, either by questionnaires (paper or electronically (e.g. smartphones)) or qualitative research approaches.

**Table 1.** Summary of individual behavioural/perceptual and spatial measures relevant to each pathway domain.

|  |  |  |
| --- | --- | --- |
| **Domain/ Pathway** | **Individual behavioural/perceptual measures (mediators or moderators)** | **Spatial measures** |
| **Reducing harm (mitigation)** | | |
| Air pollution | * NN | * Tree cover * Greenness * Area covered by greenspace * Eye-level panoramic imagery of greenspace |
| Noise | * NN | * Tree cover * Greenness * Eye-level panoramic imagery of greenspace |
| Heat | * NN | * Tree cover * Greenness * Area covered by greenspace |
| **Restoring capacities (restoration)** | | |
| Attention restoration and physiological stress recovery | * „Green“ view from a window * Perceived greenness * Perceived access and attractiveness of greenspace * Perceived restorative quality of greenspace (psychological distance, positive engagement) * Amount of time spent in greenspace | * Greenness * Tree cover * Eye-level panoramic imagery of greenspace * Type, size, facilities, maintenance and other qualities of greenspace |
| **Building capacities (instoration)** | | |
| Encouraging physical activity | * Amount of time spent in greenspace conducting physical activity * Perceived access and attractiveness of greenspace for physical activity * Perceived safety of greenspace | * Greenness * Distance to green spaces * Type, size, physical activity facilities, maintenance and other qualities of greenspace |
| Improving social cohesion | * Amount of time spent in greenspace in social activities * Perceived social cohesion in greenspace * Perceived safety of greenspace | * Greeness * Distance to green spaces * Type, size, social facilities (e.g. benches), maintenance and other qualities of greenspace |

NN stands for “not necessary”.

Looking forward, researchers should work towards developing new composite measures of greenspace to further our understanding of how greenspace may influence a wide range of health outcomes in different settings and populations through multiple pathways. The different satellite vegetation metrics highlighted previously could be a first step. The difficulty with working with large Landsat or Sentinel datasets, especially for large geographic and long-term studies, can now be overcome, for example, with the emergence of the Google Earth Engine (https://earthengine.google.com/) which contains all Landsat and Sentinel satellite images globally. Open source scripts could easily be made available to researchers to help standardize satellite-based greenspace metrics and develop new metrics for epidemiological studies. Expanded measures could also capture the spatial arrangement of greenspace, including other measures such as species richness and abundance, as well as species and land cover diversity. These measures could be adapted from studies that assessed urban ecosystem services (Haase et al. 2014; Dobbs et al. 2014).

Another promising avenue to refine greenspace exposure is to calculate new greenspace measures from street view and other geo-tagged images. These street level exposures likely better reflect actual greenspace exposure, especially for the restoration and instoration domains that require viewing or engaging with greenspace. A method has already been developed to assess street-level urban greenery using Google Street View and a green view index (Li et al. 2015), which due to the availability of these types of georeferenced images, could be applied to most existing epidemiological studies. Figure 4 illustrates an example of a Google Street View panorama and automatically extracted greenspace. Such images could be further classified using deep learning algorithms to quantify specific exposure pathways, such as the restorative potential of streetscapes, physical activity opportunities, opportunities for social interactions, and more.



**Figure 4.** Example of extracting green areas from Google Street View images to assess street level exposures.

Finally, an important challenge that researchers face is to try and understand the gap between measuring greenspace around an individual’s residential address and an individual’s actual exposure to greenspace. Almost all population-based studies have used residential addresses and only a small number have also included workplaces and education centres (Dadvand et al. 2015a; Amoly et al. 2014). Further, few studies have considered spatial and temporal human mobility patterns (Dadvand et al. 2015a; James et al. 2016). A related issue is the use of strategies to compensate for a lack of greenspace near an urban residence, such as hotel stays in ex-urban settings during leisure time (Sijtsma et al. 2012) and ownership of a leisure home in a natural area, which longitudinal studies have found to be related to early retirement for health reasons (Hartig & Fransson 2009) and to early death (Fransson & Hartig 2010). The contribution of residential greenspace exposure to total exposure (including work, school and other locations with time-activity patterns at different temporal scales) is unknown, but is likely to vary greatly by age group and context. As we know that individuals spend only a minority of their time outdoors at their homes (e.g. Jenkins et al. 1992), more data on engagement with greenspace elsewhere (including indoors) is needed.

**3.3. Analytic approaches**

**3.3.1. Pathway exploration**

Although pathways are nearly always discussed as single entities for simplicity, it is more than likely that they intertwine (Hartig et al. 2014). For example, conducting physical activity in greenspace could bring psychophysiological restoration and reduce a person’s exposure to traffic-related air pollution. As another example, residing in a greener neighbourhood might be associated with both lower air pollution and noise perception, which implies both lower stressor exposure and preservation of restorative quality in periods and activities dedicated to restoration (e.g., nighttime sleep).

Choices made by researchers, funding agencies and institutions may make it difficult to shift or expand the focus to encompass multiple pathways in epidemiological studies. Nonetheless, we see a need for attention to the ways in which multiple pathways can work simultaneously in the generation of health benefits. Widely disseminated analytic tools are currently available for assessing the relative contributions of multiple mediators using standard regression approaches. For example, Baron and Kenny's (1986) causal steps approach could be criticized on multiple grounds. Notably, contradicting their approach, more recent scholarship indicates that a direct effect of greenspace on a studied health indicator is not required as a logical prerequisite for establishing an indirect effect of any mediator, as multiple, competitive pathways can conceal a direct effect (Hayes 2009; Zhao et al. 2010). Bias-corrected bootstrapping estimation of mediation paths and conditional process modelling can be used as alternatives as they allow for simultaneous comparison of the hypothesized mediators, disentanglement of the mediation paths and assessment of moderation or effect modification (Fritz & MacKinnon 2007; Hayes 2009, 2013; Dalton et al. 2016). Structural equation modelling (SEM) is more flexible than ordinal least squares (OLS) regression and can fit complex conceptual models while also modelling error in the measurement of latent constructs. Researchers are also advised to consider the theoretical plausibility of alternative models that treat multiple mediators as working in serial rather that in parallel (e.g., von Lindern, Hartig & Lercher 2016; Shepherd et al. 2016). All of this said, the validity of tests of mediation, whether with a single candidate mediator or multiple ones, will fundamentally depend on the data used, particularly with regard to the representation of the time needed for the presumed causal process to generate effects. Mediation analyses are commonly performed with cross-sectional data, but estimates obtained with such analyses are prone to bias. Maxwell et al. (2011) illustrated how cross-sectional estimates of the indirect path between an independent and dependent variable through a single mediator could be substantial even when the coefficient for the indirect path was known to be zero in a longitudinal design. Maxwell et al.’s demonstration was done under particular assumptions and does not necessarily rule out the validity of all mediation tests based on cross-sectional data, but it does stand as a warning. Researchers who want to use available cross-sectional data to shed light on the underlying causal processes should proceed with caution, with support from relevant theory and previous empirical findings on components of the assumed process in question as well as attention to the way in which the measures used represent time (e.g., as with self-reports regarding a period of residence in relation to the period covered by a self-report of stress, such as the last four weeks).

**3.3.2. Effect measure modification**

The strength and direction of the links in pathways between greenspace and health, as well as the relative contribution to health of different pathways, can depend on several factors, such as socioeconomic status (SES), gender, ethnicity or contextual characteristics. Several studies have demonstrated that the beneficial associations between greenspace and health are strongest for those with low individual-level SES and those residing in more deprived neighborhoods (Dadvand et al. 2012a; Dadvand et al. 2012c; Dadvand et al. 2014b; de Vries et al. 2003; Maas et al. 2009b; McEachan et al. 2016; van den Berg et al. 2016). One explanation for these variations is that those with low SES generally have a worse health status and live in more polluted areas, which makes them more likely to benefit from a health promotion intervention (Bolte et al. 2010; de Vries et al. 2003; Su et al. 2011). A second explanation is that those with low SES are less mobile and consequently, spend more time near their home, which makes them more dependent on their immediate greenspace (Maas 2008; Schwanen et al. 2002). The opposite appears true for people with high SES (Bell et al. 2010; Greenspace Scotland 2008). Greenspace offers opportunities that may disrupt the usual pathway by which socioeconomic disadvantage is converted to health disadvantage. For instance, people in deprived areas might have higher levels of chronic stress due to poverty, safety and pollution concerns, which, in turn could increase their risk of cardiovascular disease (Langraauw, Kuiper & Bot 2015). Given that greenspace has stress-reduction potential, people living in one deprived area with greenspace could be at lower risk for heart disease compared to their equal counterparts residing in a deprived area without greenspace (Mithell & Popham 2008).

Despite these possible explanations, some studies report no effect measure modification of greenspace-health relationships by SES (Astell-Burt et al. 2014b; Dadvand et al. 2015a; Dadvand et al. 2014a; Triguero-Mas et al. 2015). One reason for this may be that the poor quality or safety concerns of some greenspace hinder their use in socioeconomically disadvantaged neighbourhoods. Effect measure modification by SES could also be context-specific or dependant on the degree of urbanicity (Maas et al. 2006; Mitchell & Popham 2007). Hence, in some settings, no effect measure modification by SES may be present. The evidence supporting urbanicity in-itself as an effect modifier is limited and inconsistent, with some studies providing support (Maas et al. 2009b; Maas et al. 2006; Casey et al. 2016) and others not (de Vries et al. 2003; Markevych et al. 2014c; Triguero-Mas et al. 2015). It should be acknowledged, however, that urbanicity is a very complex concept in itself, and reflects not only the types of greenspace that may be present (e.g. urban green spaces are more prevalent in an inner city while forests are more common in rural areas), but also the levels of walkability as well as air and noise pollution.

Gender, age and ethnicity are other factors that may also modify greenspace-health relationships, possibly by affecting the frequency of use of greenspace and the activities conducted there. The evidence for gender is mixed. Some studies have found stronger effects for women (Astell-Burt et al. 2014a; Bjork et al. 2008; Reklaitiene et al. 2014; Markevych et al. 2016a), others for men (Richardson & Mitchell 2010; Markevych et al. 2014c) and others find no differences (van den Berg et al. 2016). This same inconsistency exists for age groups in adults (van den Berg et al. 2016; Bjork et al. 2008; Dadvand et al. 2016; Maas et al. 2009b; de Vries et al. 2003). One longitudinal study described gender differences in a greenspace-mental health association, which were further contingent on age (Astell-Burt et al 2014e). In this study, greenspace was most beneficial for males in early adulthood, while for females, greenspace was (non-linearly) protective only from 40 years onwards. Very few studies have considered ethnicity explicitly (Dadvand et al. 2014b, McEachan et al. 2016), but some environmental preferences and design practices reflecting traditions of particular cultural groups plausibly have implications for health via pathways discussed here (e.g. as with the Chinese principles of feng shui; Wu, Yau & Lu 2012; cf. Hobson 2004).

Further research which includes the use of more comprehensive and potentially multi-dimensional metrics is warranted. Such metrics could include deprivation indices for area-level SES (Fairburn, Maier & Braubach 2016), education, occupation and income domains for individual-level SES (Galobardes et al. 2006), population density and degree of sealed soil for defining urban/semi-urban/rural areas (van Dijk & van der Valk 2007), public transport availability, and finally, age categorizations according to potential differential uses of greenspace.

**3.3.3. Residual confounding**

Residual confounding is always a concern in epidemiological studies. For example, if imperfect metrics for individual- and area-level SES are used for model adjustment, or if one or both of these metrics is unavailable, residual confounding could bias findings and lead to inflated or deflated effect sizes. Since area-level SES may be related to greenspace (Astell-Burt et al. 2014f), observed positive associations with greenspace will reflect benefits from residing in both a greener and more prosperous neighbourhood if SES is not completely accounted for in the analysis.

A number of solutions exist to assess the impact of unmeasured confounding, such as using sensitivity analyses to test assumptions made about unmeasured confounders (Greenland 1996), conducting a small validation study (Faries et al. 2013; Stürmer et al. 2005), incorporating negative control outcomes in which no associations are expected (e.g. infectious diseases of the intestinal canal (Maas et al. 2009b) or accidental mortality (James et al. 2016)) for purposes of falsification testing, as well as replicating studies in populations with different confounding structures. It is reassuring that the likely impact of unmeasured confounders is often small and would only substantially bias the results if it was not correlated with other measured confounders (Fewell et al. 2007). Therefore, researchers should continue to focus on improving the assessment of the main exposure of interest (in this case, greenspace) rather than on collecting a large amount of information on possible confounders. The use of different study designs, particularly (quasi)experimental studies, will also help address concerns of confounding.

**4. Policy implications and recommendations for future epidemiological research**

**4.1. Policy implications**

Actors outside of academia may question the need for research on greenspace and health, as it can be viewed as “common sense”. One could argue that we should simply green our cities and the health improvements will follow. But city planners, politicians and other practitioners involved in urban greening often rightfully require hard evidence demonstrating the public health benefits of different quantity, quality and accessibility scenarios. Indeed, without acknowledging the many likely nuances, the full benefits of greening our cities may not be realized. Or worse, new policies aimed at improving health may have unintended negative consequences and/or lead to ill-spent public health resources. For example, if allocations of new greenspace are concentrated predominantly within more socially advantaged neighbourhoods where local communities are potentially more vocal or more strongly linked to local political decision-making than their counterparts in disadvantaged areas, this could lead to the widening of health inequities. Similarly, planting trees that emit allergenic pollen could increase the prevalence of allergic disease (Cariñanos & Casares-Porcel 2011). These and other adverse effects of urban greening should be taken into account to achieve maximum health benefits.

Besides health benefits, greenspace also provides different ecosystem services, in particular, regulating services (e.g., flood protection, air pollution control), supporting services (e.g., maintenance of biodiversity) and numerous cultural services (e.g., aesthetic enjoyment). Greenspace also provides benefits for the sustainable development of urban areas, including the mitigation of climate change effects through the lowering of air temperature (Gill et al. 2007, Fryd et al. 2011). With these multiple beneficial roles of greenspace in mind, it is important to conduct cost-benefit analyses to demonstrate the sustainability and investment associated with changes in greenspace (van den Bosch & Nieuwenhuijsen 2016). Although limited, a few cost-benefit analyses do exist, and generally report a favourable return on investment (Kardan et al. 2015; Branas et al. 2016).

More information is also required with respect to, for example, the experiences afforded by different types of greenspace; the kinds of benefits realized with visits of differing duration, in different activities in different greenspaces; how benefits realized with individual visits or episodes of viewing greenspace might aggregate over time; and how these factors may change throughout a life-course (Astell-Burt et al. 2014e; Pearce et al. 2016). Also poorly understood is how and to what degree different spatial configurations promote health in a community (e.g., whether one large park is better serving restoration needs than many smaller green spaces) and if this varies by context, across population groups and with different park designs (e.g., Nordh et al. 2009). These missing links weaken the potential for this evidence to have an impact on decision-makers and the creation of greenspace policies that could have a positive benefit on health and help narrow health inequalities.

The use of green infrastructure and multifunctional greenspace (based on the concept of ecosystem services; Pauleit et al. 2011, Hansen and Pauleit 2014) is a current trend in urban greenspace planning and is promoted by the European Union (EC 2013). Among the most important goals of green infrastructure planning is the promotion of human health and well-being, as indicated by a recent survey of 20 European cities (Davies et al. 2015). However, this goal is formulated on a very general level and is rarely elaborated on with regard to epidemiological evidence. The existing guidelines (e.g. Natural England 2003) are based on indirect indicators and rather vague suggestions for planning and management of greenspace. There is a clear need for better and simple indicators. This is a knowledge gap that researchers should work to address. In particular, how much, how big, and how accessible greenspace needs to be in order to achieve maximal health benefits needs to be defined. For that, scientific findings need to be published in an understandable and accessible format for actors at the local level so that these findings can fit within the social, environmental, political and administrative reality of a city (Hansen et al. 2016). Additionally, the benefits provided need to be translated into monetary values, as this appears to efficiently raise awareness among decision makers (Hansen et al. 2016). Finally, better monitoring of implemented changes is necessary, for instance, on the number of people using greenspace for recreation (Lupp et al. 2016a).

Importantly, epidemiological research should be designed to provide the evidence needed for this type of policy formation. This will require studies to use exposure measures and/or measures of mediators specific to pathways, rather than only an overall NDVI measure, to determine what types of greenspace are more/less important for health. In addition, drawing on the air pollution and noise fields, high quality greenspace epidemiological studies could be pooled together using meta-analysis to estimate dose-response relationships between different greenspace indicators and health and to look for threshold effects to inform policy-makers. To facilitate the meta-analysis, these studies need to be sufficiently standardized in terms of design, exposure and outcome assessment, confounders, and type of effect reported. Even with the NDVI (which is a comparable metric), studies have used various buffer sizes, satellites, time periods, averaging techniques and filtering methods. The commonly used random effects model underestimates the statistical error and produces overconfident conclusions (Doi et al. 2015). The quality effects model is an alternative method for meta-analysis that is increasingly being used (e.g. Dzhambov et al. 2014; Dzhambov & Dimitrova 2017). It allows the inclusion of information on the methodological quality of primary studies into the estimation of meta-analysis weights using a quality index, and also supports the variance-based weighting schemes in a similar manner as the random effects model (Doi et al. 2015).

**4.2. Recommendations for future epidemiological research**

Despite the boom in greenspace research over the last few decades, major gaps in knowledge remain. In many areas of the world (Asia, Africa, less affluent European countries and South America) no or very few studies have been undertaken. It is somewhat naïve to assume that associations will be similar across the globe given the vast differences in climatic, vegetative and cultural factors, as well as differences in progress along the stages of the epidemiological and demographic transitions. As an example, the absence of a link between greenspace and obesity in Cairo, Egypt, led Mofawi and colleagues (2012) to question whether increasing greenspace will be as beneficial for health in developing countries as it appears to be in many Western contexts. Such issues highlight the need to address this geographical imbalance of study settings for future studies and to develop international collaborative efforts.

Several other recommendations that can be implemented now were discussed during the Workshop and are summarized in Table 2. We hope these recommendations can guide future studies, but acknowledge that this list is far from complete. For example, each of the three domains of pathways that we have discussed here (mitigation, restoration and instoration) comprise more specific mechanisms, either known, hypothesized or as yet unrecognized; these warrant more attention (cf. Hartig et al. 2013; Kuo 2015).

**Table 2.** Recommendations for future epidemiological research in the field of greenspace and health

|  |  |
| --- | --- |
| **Study designs** | Longitudinal, intervention and (quasi)experimental studies are needed to establish causality and reduce selection bias.  Sibling studies or studies of movers (from more/less green neighbourhoods) will be informative. |
| **Exposure assessment** | Specific greenspace exposure measures should be conceptualized for each specific pathway of interest as these likely vary in terms of vegetation types, spatial and temporal characteristics and behavioural components that ultimately determine exposure. These will also be most informative for policy formation.  While NDVI is informative as a surrogate for overall greenspace exposure, other more detailed satellite-derived vegetation indices should be considered. The choice of the best vegetation index will depend on the climatic and built-up characteristics of a study area. Spatial resolution needs to be considered in all cases.  As it is possible to derive information on vegetation types from Sentinel satellite images, their use should be encouraged.  Detailed spatial datasets that can quantify and qualify specific greenspace exposures (e.g. amount of birch trees, ornamental flowers, park trails etc.) are increasingly becoming available from regional authorities and should be used.  Street-level greenspace exposure assessment using geotagged images, such as Google Street View images, may better capture greenspace exposures that require contact and activities.  Researchers should go beyond simply assessing the presence of greenspace and begin collecting information on quality, access and use. GPS and smartphone technologies that apply extensive spatiotemporal population mobility patterns and estimates can be used in smaller-scale studies. In large cohorts, questionnaires currently remain the best viable option, although more advanced technologies (GPS and smartphones) are likely to increase in use. |
| **Analysis methods** | Correcting models for individual-level SES (and often, also for area-level SES) is essential.  Effect modification (by SES, degree of urbanicity and gender (also, if applicable, age and ethnicity) should be examined and effect estimates reported for different strata.  Mediation analysis is an appropriate method to assess the potential contributions of hypothesized pathways in greenspace-health relationships, and should be pursued whenever possible/appropriate. Due to residential selection and residual confounding concerns, studies should be conducted in various locations and populations that have different confounding structures to evaluate the consistency of associations. |
| **Study areas** | Most research has been conducted in high-income countries in Europe, North America and Australia. Asia, Africa, and South America as well as less affluent European countries remain under-researched settings where little evidence has been accumulated on greenspace-health relationships.  Large international collaborations would allow inter-country comparisons to be conducted, so that a better understanding of the impact of climate and culture on greenspace-health associations can be developed and used to inform city planning. |

**5. Conclusion**

In this Report, we provide a framework in which the many potential pathways by which greenspace can benefit health are organized into three domains that emphasize three general functions of greenspace: reducing harm, restoring capacities and building capacities.

This Report also provides guidance for further epidemiological research, upon which policy recommendations can be developed. As the percentage of people living in urban environments continues to rise, there is an urgent need to better understand and exploit the various potential beneficial impacts of urban greenspace on a large range of health factors.

**References**

Agay-Shay K, Peled A, Crespo AV, Peretz C, Amitai Y, Linn S, Friger M, Nieuwenhuijsen MJ. Green spaces and adverse pregnancy outcomes. Occup Environ Med 2014;71(8):562-569.

Alcock I, White MP, Lovell R, Higgins SL, Osborne NJ, Husk K, et al. 2015. What accounts for “England’s green and pleasant land’? A panel data analysis of mental health and land cover types in rural England. Landsc Urban Plan 2015;142:38–46.

Almanza E, Jerrett M, Dunton G, Seto E, Pentz MA. A study of community design, greenness, and physical activity in children using satellite, GPS and accelerometer data. Health & Place 2012;18(1):46-54.

Amoly E, Dadvand P, Forns J, López-Vicente M, Basagaña X, Julvez J, Alvarez-Pedrerol M, Nieuwenhuijsen MJ, Sunyer J. Green and blue spaces and behavioral development in Barcelona schoolchildren: the BREATHE project. Environ Health Perspect 2014;122(12):1351-1358.

Annerstedt M, Jönsson P, Wallergård M, Johansson G, Karlson B, Grahn P, Hansen AM, Währborg P. Inducing physiological stress recovery with sounds of nature in a virtual reality forest--results from a pilot study. Physiol Behav 2013;118:240-250.

Annerstedt M, Ostergren PO, Björk J, Grahn P, Skärbäck E, Währborg P. Green qualities in the neighbourhood and mental health–results from a longitudinal cohort study in Southern Sweden. BMC Public Health 2012;12(1):337.

Asner GP, Martin RE, Anderson CB, Knapp DE. Quantifying forest canopy traits: Imaging spectroscopy versus field survey. Remote Sensing of Environment 2015;158:15-27.

Astell-Burt T, Feng X, Kolt GS. Does access to neighbourhood green space promote a healthy duration of sleep? Novel findings from a cross-sectional study of 259 319 Australians. BMJ Open 2013a;3(8):e003094.

Astell-Burt T, Feng X, Kolt GS. Greener neighborhoods, slimmer people? Evidence from 246,920 Australians. Int J Obes 2014a;38:156–159.

Astell-Burt T, Feng X, Kolt GS. Is neighborhood green space associated with a lower risk of type 2 diabetes? Evidence from 267,072 Australians. Diabetes Care 2014b;37(1):197-201.

Astell-Burt T, Feng X, Kolt GS. Large-scale investment in green space as an intervention for physical activity, mental and cardiometabolic health: study protocol for a quasi-experimental evaluation of a natural experiment. BMJ Open 2016;6(4):e009803.

Astell-Burt T, Feng X, Kolt GS. Mental health benefits of neighbourhood green space are stronger among physically active adults in middle-to-older age: evidence from 260,061 Australians. Preventive Medicine 2013b;57:601-606.

Astell-Burt T, Feng X, Kolt GS. Neighbourhood green space and the odds of having skin cancer: multilevel evidence of survey data from 267 072 Australians. J Epidemiol Community Health 2014c;68:370-374.

Astell-Burt T, Feng X, Kolt GS. Neighbourhood green space is associated with more frequent walking and moderate to vigorous physical activity (MVPA) in middle-to-older aged adults. Findings from 203,883 Australians in The 45 and Up Study. British Journal of Sports Medicine 2014d;48:404-406.

Astell-Burt T, Mitchell R, Hartig T. The association between green space and mental health varies across the lifecourse. A longitudinal study. J Epidemiol Community Health 2014e;68:578-583.

Astell-Burt T, Feng X, Mavoa S, Badland HM, Giles-Corti B. Do low-income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. BMC Public Health 2014f;14;292

Aylor DE, Marks LE. Perception of noise transmitted through barriers. J Acoust Soc Am 1976;59(2):397-400.

Balseviciene B, Sinkariova L, Grazuleviciene R, Andrusaityte S, Uzdanaviciute I, Dedele A, Nieuwenhuijsen MJ.Impact of residential greenness on preschool children’s emotional and behavioral problems. Int J Environ Res Public Health 2014,11:6757–6770.

Bancroft C, Joshi S, Rundle A, Hutson M, Chong C, Weiss CC, et al. Association of proximity and density of parks and objectively measured physical activity in the United States: A systematic review. Soc Sci Med 2015;138:22–30.

Bar‐Haim Y, Bart O. Motor function and social participation in kindergarten children. Social Development 2006;15(2):296-310.

Baron RM, Kenny DA. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. J Pers Soc Psychol 1986;51(6):1173-1182.

Basner M, Babisch W, Davis A, Brink M, Clark C, Janssen S, Stansfeld S. Auditory and non-auditory effects of noise on health. Lancet 2014;383(9925):1325-1332.

Bell ML, Belanger K, Ebisu K, Gent JF, Lee HJ, Koutrakis P, et al. Prenatal exposure to fine particulate matter and birth weight: variations by particulate constituents and sources. Epidemiology 2010;21(6):884-891.

Bjork J, Albin M, Grahn P, Jacobsson H, Ardo J, Wadbro J, Ostergren PO, Skarback E. Recreational values of the natural environment in relation to neighbourhood satisfaction, physical activity, obesity and wellbeing. J Epidemiol Community Health 2008;62:e2.

Bodin T, Björk J, Ardö J, Albin M. Annoyance, sleep and concentration problems due to combined traffic noise and the benefit of quiet side. Int J Environ Res Public Health 2015;12(2):1612-1628.

Bolte G, Tamburlini G, Kohlhuber M. Environmental inequalities among children in Europe--evaluation of scientific evidence and policy implications. Eur J Public Health 2010;20(1):14-20.

Bowler DE, Buyung-Ali L, Knight TM, Pullin AS. Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landsc Urban Plan 2010a;97:147–155

Bowler DE, Buyung-Ali LM, Knight TM, Pullin AS. A systematic review of evidence for the added benefits to health of exposure to natural environments. BMC Public Health 2010b;10:456.

Branas CC, Kondo MC, Murphy SM, South EC, Polsky D, MacDonald JM. Urban blight remediation as a cost-beneficial solution to firearm violence. American Journal of Public Health 2016;106(12):2158-2164.

Brauer M, Hystad P. Commentary: Cities and Health…Let Me Count the Ways. Epidemiology 2014;25(4):526-527.

Broadbent DE, Cooper PF, FitzGerald P, Parkes KR. The Cognitive Failures Questionnaire (CFQ) and its correlates. British Journal of Clinical Psychology 1982;21:1-16.

Brown DK, Barton JL, Gladwell VF. Viewing nature scenes positively affects recovery of autonomic function following acute-mental stress. Environ Sci Technol 2013;47:5562–5569.

Burkart K, Meier F, Schneider A, Breitner S, Canário P, Alcoforado MJ, Scherer D, Endlicher W. Modification of heat-related mortality in an elderly urban population by vegetation (urban green) and Proximity to Water (Urban Blue): Evidence from Lisbon, Portugal. Environ Health Perspect 2016;124(7):927-34.

Cariñanos P, Casares-Porcel M. Urban green zones and related pollen allergy: a review. Some guidelines for designing spaces with low allergy impact. Landscape and Urban Planning 2011;101(3):205-214.

Casey JA, James P, Rudolph KE, Wu CD, Schwartz BS. Greenness and birth outcomes in a range of Pennsylvania communities. Int J Environ Res Public Health 2016;13(3):311.

Cohen DA, Ashwood JS, Scott MM, Overton A, Evenson KR, Staten LK, et al. Public parks and physical activity among adolescent girls. Pediatrics 2006;118(5):e1381–1389.

Christensen JS, Hjortebjerg D, Raaschou-Nielsen O, Ketzel M, Sørensen TI, Sørensen M. Pregnancy and childhood exposure to residential traffic noise and overweight at 7 years of age. Environ Int 2016;94:170-176.

Cummins S, Fagg J. Does greener mean thinner? Associations between neighbourhood greenspace and weight status among adults in England. Int J Obes 2012;36:1108–1113.

Cusack L, Larkin A, Carozza S, Hystad P. Associations between residential greenness and birth outcomes across Texas. Environ Res 2016;152:88-95.

Dadvand P, Bartoll X, Basagaña X, Dalmau-Bueno A, Martinez D, Ambros A, et al. Green spaces and general health: Roles of mental health status, social support, and physical activity. Environ Int 2016;91:161–167.

Dadvand P, de Nazelle A, Figueras F, Basagaña X, Sue J, Amoly E, et al. 2012a. Green space, health inequality and pregnancy. Environ Int 2012a.;40:110-115.

Dadvand P, de Nazelle A, Triguero-Mas M, Schembari A, Cirach M, Amoly E, Figueras F, Basagaña X, Ostro B, Nieuwenhuijsen M. Surrounding greenness and exposure to air pollution during pregnancy: an analysis of personal monitoring data. Environ Health Perspect 2012b;120(9):1286–1290.

Dadvand P, Nieuwenhuijsen MJ, Esnaola M, Forns J, Basagaña X, Alvarez-Pedrerol M, et al. Green spaces and cognitive development in primary schoolchildren. Proc Natl Acad Sci U S A 2015a;112(26):7937-7942.

Dadvand P, Rivas I, Basagaña X, Alvarez-Pedrerol M, Su J, De Castro Pascual M, Amato F, Jerret M, Querol X, Sunyer J, Nieuwenhuijsen MJ. The association between greenness and traffic-related air pollution at schools. Sci Total Environ 2015b;523:59-63.

Dadvand P, Sunyer J, Basagaña X, Ballester F, Lertxundi A, Fernández-Somoano A, Estarlich M, García-Esteban R, Mendez MA, Nieuwenhuijsen MJ. Surrounding greenness and pregnancy outcomes in four Spanish birth cohorts. Environ Health Perspect 2012c;120(10):1481-1487.

Dadvand P, Villanueva CM, Font-Ribera L, Martinez D, Basagaña X, Belmonte J, et al. Risks and benefits of green spaces for children: A cross-sectional study of associations with sedentary behavior, obesity, asthma, and allergy. Environ Health Perspect 2014a;122(12):1329-1325.

Dadvand P, Wright J, Martinez D, Basagaña X, McEachan RRC, Cirach M, et al. Inequality, green spaces, and pregnant women: Roles of ethnicity and individual and neighbourhood socioeconomic status. Environ Int 2014b;71:101-108.

Dalton AM, Wareham N, Griffin S, Jones AP. Neighbourhood green space is associated with a slower decline in physical activity in older adults: A prospective cohort study. SSM - Population health 2016;2:683-691.

David Suzuki Foundation. The Impact of Green Space on Heat and Air Pollution in Urban Communities | Publications | David Suzuki Foundation. 2015. Available: <http://www.davidsuzuki.org/publications/reports/2015/the-impact-of-green-space-on-heat-and-air-pollution-in-urban-communities/> (accessed 14.10.16).

Davis AY, Jung J, Pijanowski BC, Minor ES. Combined vegetation volume and "greenness" affect urban air temperature. Applied Geography 2016;71:106-114.

Davies C, Hansen R, Rall E, Pauleit S, Lafortezza R, De Bellis Y, Santos A, Tosics I. The status of European green space planning and implementation based on an analysis of selected European city-regions. EU FP7 project GREEN SURGE, Deliverable D5.1, 2015. Available: [www.greensurge.eu](http://www.greensurge.eu/) (accessed 19.03.16).

de Keijzer C, Gascon M, Nieuwenhuijsen MJ, Dadvand P. Long-Term Green Space Exposure and Cognition Across the Life Course: a Systematic Review. Curr Environ Health Rep 2016 [Epub ahead of print]

de Vries S, ten Have M, van Dorsselaer S, van Wezep M, Hermans T, de Graaf R. Local availability of green and blue space and prevalence of common mental disorders in the Netherlands. British Journal of Psychiatry Open 2016;2(6):366-372.

de Vries S, van Dillen SME, Groenewegen PP, Spreeuwenberg P. Streetscape greenery and health: Stress, social cohesion and physical activity as mediators. Soc Sci Med 2013;94:26–33.

de Vries S, Verheij RA, Groenewegen PP, Spreeuwenberg P. Natural environments-healthy environments? An exploratory analysis of the relationship between greenspace and health. Environ Plan A 2003;35(10):1717-1732.

Dobbs C, Nitschke CR, Kendal D. Global drivers and tradeoffs of three urban vegetation ecosystem services. PLoS One 2014 17;9(11):e113000.

Doi SA, Barendregt JJ, Khan S, Thalib L, Williams GM. Simulation comparison of the quality effects and random effects methods of meta-analysis. Epidemiology 2015;26:e42–e44.

Donaire-Gonzalez D, Valentín A, de Nazelle A, Ambros A, Carrasco-G, Seto E, Jerrett M, Nieuwenhuijsen MJ. Benefits of Mobile Phone Technology for Personal Environmental Monitoring. JMIR Mhealth Uhealth 2016;4(4):e126.

Donovan GH, Butry DT, Michael YL, Prestemon JP, Liebhold AM, Gatziolis D, Mao MY. The relationship between trees and human health: evidence from the spread of the emerald ash borer. Am J Prev Med 2013;44(2):139-45.

Donovan GH, Butry DT. Trees in the city: Valuing street trees in Portland, Oregon. Landscape and Urban Planning 2010;94(2):77-83.

Duncan MJ, Clarke ND, Birch SL, Tallis J, Hankey J, Bryant E, et al. The effect of green exercise on blood pressure, heart rate and mood state in primary school children. Int J Environ Res Public Health 2014;11:3678–3688.

Dzhambov A, Dimitrova D, Dimitrakova ED. Association between residential greenness and birth weight: Systematic review and meta-analysis. Urban Forestry & Urban Greening 2014;13(4):621-629.

Dzhambov AM, Dimitrova DD. Children's blood pressure and its association with road traffic noise exposure - A systematic review with meta-analysis. Environ Res 2017;152:244-255.

Dzhambov AM, Dimitrova DD. Green spaces and environmental noise perception. Urban Forestry & Urban Greening 2015a;14:1000–1008.

Dzhambov AM. Long-term noise exposure and the risk for type 2 diabetes: a meta-analysis. Noise Health 2015;17(74):23-33.

EC (European Commission) Green Infrastructure (GI) — Enhancing Europe’s Natural Capital. Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and The Committee of the Regions. Brussels: Com, 2013.

Ekkel AD, de Vries S. Nearby green space and human health: Evaluating accessibility metrics. Landscape and Urban Planning 2017;157:214-220.

Ellaway A, Macintyre S, Bonnefoy X. Graffiti, greenery, and obesity in adults: secondary analysis of European cross sectional survey. Br Med J 2005;331:611–612.

Elliott J, Gale C R, Parsons S, Kuh D, HALCyon Study Team. Neighbourhood cohesion and mental wellbeing among older adults: a mixed methods approach. Soc Sci Med 2014;107:44-51.

Fairburn J, Maier W, Braubach M. Incorporating Environmental Justice into Second Generation Indices of Multiple Deprivation: Lessons from the UK and Progress Internationally. Int J Environ Res Public Health 2016;13(8):750.

Fan H. Land-cover mapping in the Nujiang Grand Canyon: Integrating spectral, textural, and topographic data in a random forest classifier. International Journal of Remote Sensing 2013;34(21):7545-7567.

Faries D, Peng X, Pawaskar M, Price K, Stamey JD, Seaman JW Jr. Evaluating the impact of unmeasured confounding with internal validation data: an example cost evaluation in type 2 diabetes. Value Health 2013;16(2):259-66.

Fewell Z, Davey Smith G, Sterne JA. The impact of residual and unmeasured confounding in epidemiologic studies: a simulation study. Am J Epidemiol 2007;166(6):646-55.

Flouri E, Midouhas E, Joshi H. The role of urban neighbourhood green space in children’s emotional and behavioural resilience. J Environ Psychol 2014;40:179–186.

Fone D, White J, Farewell D, Kelly M, John G, Lloyd K, et al. Effect of neighbourhood deprivation and social cohesion on mental health inequality: a multilevel population-based longitudinal study. Psychological medicine 2014;44(11):2449-2460.

Forrest R, Kearns A. Social cohesion, social capital and the neighbourhood. Urban studies 2001;38(12):2125-2143.

Fransson U, Hartig T. Leisure home ownership and early death: A longitudinal study in Sweden. Health & Place 2010;16:71-78.

Fritz MS, MacKinnon DP. Required sample size to detect the mediated effect. Psychol Sci 2007;18(3):233-239.

Fryd O, Pauleit S, Bühler O. The role of urban green space and trees in relation to climate change. CAB Rev Perspect Agric Vet Sci Nutr Nat Resour 2011;6:1–18.

Fuertes E, Markevych I, Bowatte G, Gruzieva O, Gehring U, Becker A, Berdel D, von Berg A, Bergström A, Brauer M, Brunekreef B, Brüske I, Carlsten C, Chan-Yeung M, Dharmage SC, Hoffmann B, Klümper C, Koppelman GH, Kozyrskyj A, Korek M, Kull I, Lodge C, Lowe A, MacIntyre E, Pershagen G, Standl M, Sugiri D, Wijga A, Heinrich J. Residential greenness is differentially associated with childhood allergic rhinitis and aeroallergen sensitization in seven birth cohorts. Allergy 2016;71(10):1461-1471.

Fuertes E, Markevych I, von Berg A, Bauer CP, Berdel D, Koletzko S, Sugiri D, Heinrich J: Greenness and allergies: Evidence of differential associations in two areas in Germany. J Epidemiol Community Health 2014;68(8):787-790.

Galobardes B, Shaw M, Lawlor DA, and Lynch JW, Smith GD. Indicators of socioeconomic position (part 1). J Epidemiol Community Health 2006;60(1):7–12.

Garg N, Maji S. A critical review of principal traffic noise models: Strategies and implications. Environmental Impact Assessment Review 2014;46:68–81.

Gascon M, Cirach M, Martínez D, Dadvand P, Valentín A, Plasència A, Nieuwenhuijsen MJ Normalized difference vegetation index (NDVI) as a marker of surrounding greenness in epidemiological studies: The case of Barcelona city. Urban Forestry & Urban Greening 2016a;19:88-94.

Gascon M, Triguero-Mas M, Martínez D, Dadvand P, Forns J, Plasència A, Nieuwenhuijsen MJ. Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. Int J Environ Res Public Health. 2015;12(4):4354-4379.

Gascon M, Triguero-Mas M, Martínez D, Dadvand P, Rojas-Rueda D, Plasència A, Nieuwenhuijsen MJ. Residential green spaces and mortality: A systematic review. Environ Int 2016b;86:60-67.

Gehring U, Tamburic L, Sbihi H, Davies HW, Brauer M. Impact of noise and air pollution on pregnancy outcomes. Epidemiology 2014;25(3):351-358.

Gidlöf-Gunnarsson A, Öhrström E, Ögren M, Jerson T. Good sound environment in green areas modify road-traffic noise annoyance at home. In: 8th European Conference on Noise Control 2009 (EURONOISE 2009). Curran Associates, Inc., 2009:1579-1587.

Gidlöf-Gunnarsson A, Öhrström E. Noise and well-being in urban residential environments: The potential role of perceived availability to nearby green areas. Landscape and Urban Planning 2007;8(2-3):115–126.

Giles-Corti B, Broomhall MH, Knuiman M, Collins C, Douglas K, Ng K, Lange A, Donovan RJ. Increasing walking: How important is distance to, attractiveness, and size of public open space? American Journal of Prev Med 2005;28:169-176.

Giles-Corti B, Bull F, Knuiman M, McCormack G, Van Niel K, Timperio A, Christian H, Foster S, Divitini M, Middleton N, Boruff B. The influence of urban design on neighbourhood walking following residential relocation: longitudinal results from the RESIDE study. Soc Sci Med 2013;77:20-30.

Gill S, Handley JF, Ennos AR, Pauleit S. Adapting Cities for Climate Change: The Role of the Green Infrastructure. Built Environment 2007;33(1):115-133

Grazuleviciene R, Danileviciute A, Dedele A, Vencloviene J, Andrusaityte S, Uždanaviciute I, Nieuwenhuijsen MJ. Surrounding greenness, proximity to city parks and pregnancy outcomes in Kaunas cohort study. Int J Hyg Environ Health 2015;218(3):358-365.

Grazuleviciene R, Dedele A, Danileviciute A, Vencloviene J, Grazulevicius T, Andrusaityte S, Uzdanaviciute I, Nieuwenhuijsen MJ. The influence of proximity to city parks on blood pressure in early pregnancy. Int J Environ Res Public Health 2014;11(3):2958-2972.

Greenland S. Basic methods for sensitivity analysis of biases. Int J Epidemiol 1996;25(6):1107-16.

Greenspace Scotland. Health Impact Assessment of greenspace. A Guide. (Eilidh Johnston). Stirling, Scotland: Greenspace Scotland, 2008.

Grigsby-Toussaint DS, Turi KN, Krupa M, Williams NJ, Pandi-Perumal SR, Jean-Louis G. Sleep insufficiency and the natural environment: Results from the US Behavioral Risk Factor Surveillance System survey. Preventive medicine 2015;78:78-84.

Gronlund CJ, Berrocal VJ, White-Newsome JL, Conlon KC, O'Neill MS. Vulnerability to extreme heat by socio-demographic characteristics and area green space among the elderly in Michigan, 1990-2007. Environ Res 2015;136:449-461.

Grundström M, Pleijel H. Limited effect of urban tree vegetation on NO2 and O3 concentrations near a traffic route. Environ Pollut 2014;189:73-76.

Haase D, Larondelle N, Andersson E, Artmann M, Borgström S, Breuste J, Gomez-Baggethun E, Gren Å, Hamstead Z, Hansen R, Kabisch N, Kremer P, Langemeyer J, Rall EL, McPhearson T, Pauleit S, Qureshi S, Schwarz N, Voigt A, Wurster D, Elmqvist T. A quantitative review of urban ecosystem service assessments: concepts, models, and implementation. Ambio 2014;43(4):413-33. Hansen R, Pauleit S. From multifunctionality to multiple ecosystem services? A conceptual framework for multifunctionality in green infrastructure planning for urban areas. AMBIO 2014;43(4):516-529.

Hansen R, Rolf W, Rall E, Pauleit S, Erlwein S, Fohlmeister S, Santos A, Luz AC, Branquinho C, Santos-Reis M, Gerőházi E, Száraz L, Tosics I, Davies C, DeBellis Y;, Lafortezza R, Vierikko K, van der Jagt A, Cvejić R, Železnikar S, Nastran M, Pintar M, Hjorth Caspersen O, Stahl Olafsson A, Gentin S, Andersson E, Kronenberg J, Delshammar T, Mattijssen T, Otten R. Advanced Urban Green Infrastructure Planning and Implementation - Innovative Approaches and Strategies from European Cities. GREEN SURGE Deliverable 5.2 Technical Report. 2016. Available: <http://greensurge.eu/working-packages/wp5/files/D5_2_Hansen_et_al_2016_Advanced_UGI_Planning_and_Implementation_v3.pdf> (assessed 24.04.2017).

Harris Geospatial Solutions. Broadband Greenness. Available: <http://www.harrisgeospatial.com/docs/BroadbandGreenness.html#Infrared> (accessed 14.10.2016).

Hartig T. Three steps to understanding restorative environments as health resources. In: Thompson CW, Travlou P (Eds.). Open space: People space. London: Taylor & Francis, 2007: 163-179.

Hartig T, Bringslimark T, Grindal Patil G. Restorative environmental design: What, when, where, and for whom? In: Kellert SR, Heerwagen J, Mador M (Eds.). Bringing buildings to life: The theory and practice of biophilic building design. New York: Wiley, 2008: 133-151.

Hartig T, Catalano R, Ong M, Syme SL. Vacation, collective restoration, and mental health in a population. Society and Mental Health 2013;3:221-236.

Hartig T, Evans GW, Jamner LD, Davis DS, Gärling T. Tracking restoration in natural and urban field settings. Journal of Environmental Psychology 2003;23:109-123.

Hartig T, Fransson U. Leisure home ownership, access to nature, and health: A longitudinal study of urban residents in Sweden. Environment & Planning A 2009;41:82-96.

Hartig T, Johansson G, Kylin C. Residence in the social ecology of stress and restoration. Hartig T, Mang M, Evans GW. Restorative effects of natural environment experiences. Environment & Behavior 1991;23:3-26. Journal of Social Issues 2003;59:611-636.

Hartig T, Mitchell R, de Vries S, Frumkin H. Nature and Health. Annu Rev Public Health 2014;35(1):207–28.

Hartig T. Green space, psychological restoration, and health inequality. Lancet 2008;372:1614-1615.

Hayes AF. Beyond Baron and Kenny: Statistical Mediation Analysis in the New Millennium. Communication Monographs 2009;76(4):408‐420.

Hayes AF. Introduction to Mediation, Moderation, and Conditional Process Analysis. A Regression-Based Approach. New York: Guilford Press, 2013.

Health Council of the Netherlands. Nature and Health: The Influence of Nature on Social, Psychological and Physical Well-Being. The Hague: Health Council of the Netherlands and RMNO, 2004.

Higgs G, Fry R, Langford M. Investigating the implications of using alternative GIS-based techniques to measure accessibility to green space. Environment and Planning B: Planning and Design 2012;39(2):326-343.

Hirabayashi S, Nowak DJ. Comprehensive national database of tree effects on air quality and human health in the United States. Environ Pollut 2016;215:48–57.

Hobson JSP. Feng Shui: Its Impacts on the Asian Hospitality Industry. International Journal of Contemporary Hospitality Management 1994;6(6):21-26.

Holtan MT, Dieterlen SL, Sullivan WC. Social life under cover tree canopy and social capital in Baltimore, Maryland. Environment and behavior 2015;47(5):502-525.

Huete A. A Soil-Adjusted Vegetation Index (SAVI). Remote Sens Environ 1988;25:295-309.

Huete AR, Didan K, Miura T, Rodriguez EP, Gao X, Ferreira LG. Overview of the radiometric and biophysical performance of the MODIS vegetation indices. Remote Sens Environ 2002;83:195–213.

Hystad P, Davies HW, Frank L, Van Loon J, Gehring U, Tamburic L, Brauer M. Residential greenness and birth outcomes: evaluating the influence of spatially correlated built-environment factors. Environ Health Perspect 2014;122(10):1095-1102.

James P, Banay RF, Hart JE, Laden F. A review of the health benefits of greenness. Curr Epidemiol Rep 2015;2(29):131–142.

James P, Hart JE, Banay RF, Laden F. Exposure to Greenness and Mortality in a Nationwide Prospective Cohort Study of Women. Environ Health Perspect 2016;124(9):1344-1352.

Jang HS, Lee SC, Jeon JY, Kang J. Evaluation of road traffic noise abatement by vegetation treatment in a 1:10 urban scale model. J Acoust Soc Am 2015;138(6):3884-3895.

Jenkins PL, Phillips TJ, Mulberg JM, Hui SP. Activity patterns of Californians: use of and proximity to indoor pollutant sources. Atmospheric Environment 1992;26A:2141-2148.

Jensen JR. Remote sensing of vegetation. In: Remote Sensing of the Environment: An Earth Resource Perspective. New York; Prentice Hall Upper Saddle River, 2007: 355–408.

Jiang B, Deal B, Pan H, Larsen L, Hsieh C-H, Chang C-Y, Sullivan WC. Remotely-sensed imagery vs. eye-level photography: Evaluating associations among measurements of tree cover density. Landscape and Urban Planning 2017;157:270–281.

Kaczynski AT, Potwarka LR, Smale BJA, Havitz ME. Association of parkland proximity with neighborhood and park-based physical activity: Variations by gender and age. Leis Sci 2009;31(2):174–191.

Kang J, Aletta F, Gjestland TT, Brown LA, Botteldooren D, Schulte-Fortkamp B, Lercher P, van Kamp I, Genuit K, Fiebig A, Luis Bento Coelho J, Maffei L, Lavia L. Ten questions on the soundscapes of the built environment. Building and Environment 2016;108:284–294.

Kaplan R, Kaplan S. The experience of nature: y psychological perspective. New York: Cambridge University Press, 1989.

Kaplan S, Talbot JF. Psychological benefits of a wilderness experience. In: Altman I & Wohlwill JF (Eds.) Behavior and the natural environment. New York: Plenum, 1983: 163-203.

Kaplan S. The restorative benefits of nature: Towards an integrative framework. Journal of Environmental Psychology 1995;15:169-182.

Kardan O, Gozdyra P, Misic B, Moola F, Palmer LJ, Paus T, Berman MG. (2015). Neighborhood greenspace and health in a large urban center. Scientific reports 2015;5:11610.

Kemperman A, Timmermans H. Green spaces in the direct living environment and social contacts of the aging population. Landscape and Urban Planning 2014;129:44-54.

Kimpton A, Corcoran J, Wickers R. Greenspace and Crime. An Analysis of Greenspace Types, Neighboring Composition, and the Temporal Dimensions of Crime. Journal of Research in Crime and Delinquency 2016. Available: <http://jrc.sagepub.com/content/early/2016/08/31/0022427816666309.abstract> (assessed 25.11.16).

Kroeger T, Escobedo FJ, Hernandez JL, Varela S, Delphin S, Fisher JR, Waldron J. Reforestation as a novel abatement and compliance measure for ground-level ozone. Proc Natl Acad Sci U S A 2014;111(40):E4204-4213.

Kuo FE, Sullivan WC, Coley RL, Brunson L. Fertile ground for community: Inner-city neighborhood common spaces. American Journal of Community Psychology 1998;26(6): 823-851.

Kuo FE, Sullivan WC. Aggression and violence in the inner city. Effects of environment via mental fatigue. Environment and behavior 2001a;33(4):543-571.

Kuo FE, Sullivan WC. Environment and crime in the inner city. Does vegetation reduce crime? Environment and behavior 2001b;33(3):343-367.

Kuo FE. Coping with poverty. Impacts of environment and attention in the inner city. Environment and Behavior 2001;33(1):5-34.

Kuo M. How might contact with nature promote human health? Promising mechanisms and a possible central pathway. Front Psychol 2015;6:1093.

Kwan MP. How GIS can help address the uncertain geographic context problem in social science research. Annals of GIS 2012a;18(4):245-255.

Kwan MP. The uncertain geographic context problem. Annals of the Association of American Geographers 2012b;102(5):958-968.Lachowycz K, Jones AP, Page AS, Wheeler BW, Cooper AR. What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? Health Place 2012;18(3):586-594.

Lachowycz K, Jones AP. Greenspace and obesity: a systematic review of the evidence: Greenspace and obesity review. Obes Rev 2011;12(5):e183–189.

Langraauw HM, Kuiper J, Bot I. Acute and chronic psychological stress as risk factors for cardiovascular disease: Insights gained from epidemiological, clinical and experimental studies. Brain Beha Immun 2015;50:18–30.

Laurent O, Wu J, Li L, Milesi C. Green spaces and pregnancy outcomes in Southern California. Health Place 2013;24:190-195.

Lee AC, Maheswaran R. The health benefits of urban green spaces: a review of the evidence. J Public Health (Oxf). 2011;33(2):212-22.

Lee KE, Williams KJH, Sargent LD, Williams NSG, Johnson KA. 40-second green roof views sustain attention: the role of micro-breaks in attention restoration. Journal of Environmental Psychology 2015;42:182-189.

Leung TM, Chau CK, Tang SK, Pun LSC. On the study of effects of views to water spaces on noise annoyance perceptions at home. Melbourne: Internoise, 2014.

Li HN, Chau CK, Tang SK. Can surrounding greenery reduce noise annoyance at home? Sci Total Environ 2010; 408:4376–4384

Li HN, Chau CK, Tse MS, Tang SK. On the study of the effects of sea views, greenery views and personal characteristics on noise annoyance perception at homes. J Acoust Soc Am 2012;131(3):2131-2140.

Li X, Zhang Z, Li W, Ricard R, Meng O, Zhang W. Assessing street-level urban greenery using Google Street View and a modified green view index. Urban Forestry & Urban Greening 2015;14(3):675-685.

Lõhmus M, Balbus J. Making green infrastructure healthier infrastructure. Infection Ecology & Epidemiology 2015;5. Available: <http://www.infectionecologyandepidemiology.net/index.php/iee/article/view/30082> (accessed 09.11.16).

Lovasi GS, O'Neil-Dunne JP, Lu JW, Sheehan D, Perzanowski MS, Macfaden SW, King KL, Matte T, Miller RL, Hoepner LA, Perera FP, Rundle A. Urban tree canopy and asthma, wheeze, rhinitis, and allergic sensitization to tree pollen in a New York City birth cohort. Environ Health Perspect 2013a;121(4):494-500.

Lovasi GS, Schwartz-Soicher O, Quinn JW, Berger DK, Neckerman KM, Jaslow R, Lee KK, Rundle A. Neighborhood safety and green space as predictors of obesity among preschool children from low-income families in New York City. Prev Med (Baltim) 2013b;57:189–93.

Luber G, McGeehin M. Climate Change and Extreme Heat Events. American Journal of Preventive Medicine 2008;35(5):429–435.

Lugassi R, Chudnovsky A, Zaady E, Dvash L, Goldshleger N. Estimating Pasture Quality of Fresh Vegetation Based on Spectral Slope of Mixed Data of Dry and Fresh Vegetation—Method Development. Remote Sens 2015;7(6):8045-8066.

Lupp G, Förster B, Kantelberg V, Markmann T, Naumann J, Honert C, Koch M, Pauleit S. Assessing the Recreation Value of Urban Woodland Using the Ecosystem Service Approach in Two Forests in the Munich Metropolitan Region. Sustainability 2016a;8(1156):1-14.Lupp G, Melber M, Hirschbeck T, Ritter A, Brockard M, Kantelberg V, Pauleit S. Outdoor recreation in urban forests - user patterns and impacts. In: Francis RA, Millington J, Chadwick MA (Eds). Urban Landscape Ecology, Science, Policy and Practice. Routledge, 2016b: 209-228.

Maas J, van Dillen SM, Verheij RA, Groenewegen PP. Social contacts as a possible mechanism behind the relation between green space and health. Health Place 2009a;15(2):586-595.

Maas J, Verheij RA, de Vries S, Spreeuwenberg P, Schellevis FG, Groenewegen PP. Morbidity is related to a green living environment. J Epidemiol Community Health 2009b;63(12):967-973.

Maas J, Verheij RA, Groenewegen PP, De Vries S, Spreeuwenberg P. Green space, urbanity, and health: how strong is the relation? J Epidemiol Community Health 2006;60(7):587-592.

Maas J, Verheij RA, Spreeuwenberg P, Groenewegen PP. Physical activity as a possible mechanism behind the relationship between green space and health: A multilevel analysis. BMC Public Health 2008;8(1):206.

Maas J. Vitamin G: Green environments-Healthy environments. Utrecht: Nivel, 2008.

Markevych I, Fuertes E, Tiesler CMT, Birk M, Bauer CP, Koletzko S, von Berg A, Berdel D, Heinrich J. Surrounding greenness and birth weight: Results from the GINIplus and LISAplus birth cohorts in Munich. Health Place 2014a;26:39-46.

Markevych I, Smith MP, Jochner S, Standl M, Brüske I, von Berg A, Bauer CP, Fuks K, Koletzko S, Berdel D, Heinrich J, Schulz H. Neighbourhood and physical activity in German adolescents: GINIplus and LISAplus. Environ Res 2016a;147:284-293.

Markevych I, Standl M, Sugiri D, Harris C, Maier W, Berdel D, Heinrich J. Residential greenness and blood lipids in children: a longitudinal analysis in GINIplus and LISAplus. Environ Res 2016b;151:168-173.

Markevych I, Thiering E, Fuertes E, Sugiri D, Berdel D, Koletzko S, von Berg A, Bauer CP, Heinrich J. A cross-sectional analysis of the effects of residential greenness on blood pressure in 10-year old children: Results from the GINIplus and LISAplus studies. BMC Public Health 2014b;14:477.

Markevych I, Tiesler CMT, Fuertes E, Romanos M, Dadvand P, Nieuwenhuijsen MJ, Berdel D, Koletzko S, Heinrich J. Access to urban green spaces and behavioural problems in children: Results from the GINIplus and LISAplus studies. Environ Int 2014c;71:29-35.

Maxwell SE, Cole DA, Mitchell MA. Bias in Cross-Sectional Analyses of Longitudinal Mediation: Partial and Complete Mediation Under an Autoregressive Model. Multivariate Behav Res. 2011;46(5):816-41. McEachan RRC, Prady SL, Smith G, Fairley L, Cabieses B, Gidlow C, et al. The association between green space and depressive symptoms in pregnant women: moderating roles of socioeconomic status and physical activity. J Epidemiol Community Health 2016;70(3):253–259.

McPherson EG, Peper P. Costs of street tree damage to infrastructure. Arboricultural Journal. The International Journal of Urban Forestry 1996;20(2):143-160.

Mitchell R, Astell-Burt T, Richardson EA. A comparison of green space indicators for epidemiological research. Journal of epidemiology and community health 2011; doi:10.1136/jech.2010.119172.

Mitchell R, Popham F. Effect of exposure to natural environment on health inequalities: an observational population study. Lancet 2008;372(9650):1655-1660.

Mitchell R, Popham F. Greenspace, urbanity and health: relationships in England. J Epidemiol Community Health 2007;61(8):681-683.

Mitchell R. Is physical activity in natural environments better for mental health than physical activity in other environments? Soc Sci Med 2013;91:130-134.

Morais MVB, Freitas ED, Urbina Guerrero VV, Martins LD. A modeling analysis of urban canopy parameterization representing the vegetation effects in the megacity of São Paulo. Urban Climate 2016;17:102-115.

Morani A, Nowak DJ, Hirabayashi S, Calfapietra C. How to select the best tree planting locations to enhance air pollution removal in the Million Trees NYC Initiative. Environ Pollut 2011;159(5):1040–47.

Mowafi M, Khadr Z, Bennett G, Hill A, Kawachi I, Subramanian SV. Is access to neighborhood green space associated with BMI among Egyptians? A multilevel study of Cairo neighborhoods. Health Place 2012;18:385–390.

Mytton OT, Townsend N, Rutter H, Foster, C. Green space and physical activity: an observational study using health survey for England data. Health & Place, 2012;18(5):1034-1041.

Natural England. Accessible Natural Green Space Standards in Towns and Cities: A Review and Toolkit for their Implementation. English Nature Research Reports, 2003. Available: <http://publications.naturalengland.org.uk/publication/65021> (accessed 14.10.16).

Nieuwenhuijsen MJ, Donaire-Gonzalez D, Foraster M, Martinez D, Cisneros A. Using personal sensors to assess the exposome and acute health effects. Int J Environ Res Public Health. 2014a;11(8):7805-7819.

Nieuwenhuijsen MJ, Khreis H, Triguero-Mas M, Gascon M, Dadvand P. Fifty Shades of Green: Pathway to Healthy Urban Living. Epidemiology 2017;28(1):63-71.

Nieuwenhuijsen MJ, Kruize H, Gidlow C, Andrusaityte S, Antó JM, Basagaña X, Cirach M, Dadvand P, Danileviciute A, Donaire-Gonzalez D, Garcia J, Jerrett M, Jones M, Julvez J, van Kempen E, van Kamp I, Maas J, Seto E, Smith G, Triguero M, Wendel-Vos W, Wright J, Zufferey J, van den Hazel PJ, Lawrence R, Grazuleviciene R. Positive health effects of the natural outdoor environment in typical populations in different regions in Europe (PHENOTYPE): a study programme protocol. BMJ Open 2014b;4(4):e004951.

Nordh H, Hartig T, Hagerhall C, Fry G. Components of small urban parks that predict the possibility for restoration. Urban Forestry and Urban Greening 2009;8:225-235.

Nowak DJ, Hirabayashi S, Bodine A, Greenfield E. Tree and forest effects on air quality and human health in the United States. Environ Pollut 2014;193:119–129.

Nutsford D, Pearson AL, Kingham S, Reitsma F. Residential exposure to visible blue space (but not green space) associated with lower psychological distress in a capital city. Health Place 2016;39:70-78.

Ohly H, White MP, Wheeler BW, Bethel A, Ukoumunne OC, Nikolaou V, Garside R. Attention Restoration Theory: A systematic review of the attention restoration potential of exposure to natural environments. J Toxicol Environ Health B Crit Rev 2016;19(7):305-343.

Ord K, Mitchcell R, Pearce J. Is level of neighbourhood green space associated with physical activity in green space? Int J Behav Nutr Phys Act 2013;10:127.

Ou J, Levy J, Peters J, Bongiovanni R, Garcia-Soto J, Medina R, et al. A walk in the park: the influence of urban parks and community violence on physical activity in Chelsea, MA. Int J Environ Res Public Health 2016;13(1):97.

Pacifico F, Harrison SP, Jones SD, Sitch S. Isoprene Emissions and Climate. Atmos Environ 2009;43(39):6121–6135.

Parlow E. The urban heat budget derived from satellite data. Geographica Helvetica 2003;58(2):99–111.

Pauleit S, Liu L, Ahern J, Kazmierczak A. Multifunctional green infrastructure planning to promote ecological services in the city. In: Niemelä J (Ed). Handbook of Urban Ecology. Oxford: Oxford University Press, 2011: 272-285.

Pearce J, Shortt N, Rind E, Mitchell R. Life course, green space and health: incorporating place into life course epidemiology. Int J Environ Res Public Health 2016;13(3):331.

Pelta R, Chudnovsky A. Spatiotemporal Estimation of Air Temperature Patterns at the Street Level Using High Resolution Satellite Imagery. Science of the Total Environment 2017; 579: 675-684.

Pereira G, Foster S, Martin K, Christian H, Boruff BJ, Knuiman M, et al. The association between neighborhood greenness and cardiovascular disease: an observational study. BMC Public Health 2012;12:466.

Phelan PE, Kaloush K, Miner M, Golden J, Phelan B, Silva H, Taylor RA. Urban Heat Island: Mechanisms, Implications, and Possible Remedies. Annual review of Environment and Resources 2015;40:285-307.

Planting Healthy Air. A global analysis of the role of urban trees in addressing particulate matter pollution and extreme heat. 2016. Available: <https://thought-leadership-production.s3.amazonaws.com/2016/11/07/14/13/22/685dccba-cc70-43a8-a6a7-e3133c07f095/20160825_PHA_Report_Final.pdf> (assessed 14.11.16).

Potchter O, Cohen P, Bitan A. Climatic behavior of various urban parks during hot and humid summer in the mediterranean city of Tel-Aviv, Israel. International Journal Of Climatology 2006;26:1695–1711.

Potchter O, Goldman D, Iluz D, Kadish D. The climatic effect of a manmade oasis during winter season in a hyper arid zone: The case of Southern Israel. Journal of Arid Environments 2012;87:231-242.

Potestio M, Patel A, Powell C, McNeil D, Jacobson RD, McLaren L. Is there an association between spatial access to parks/green space and childhood overweight/obesity in Calgary, Canada? Int J Behav Nutr Phys Act 2009;6:77.

Pretty J, Peacock J, Sellens M, Griffin M. The mental and physical health outcomes of green exercise. Int J Environ Health Res 2005;15:319–337.

Prince SA, Kristjansson EA, Russell K, Billette J-M, Sawada M, Ali A, et al. A multilevel analysis of neighbourhood built and social environments and adult self-reported physical activity and body mass index in Ottawa, Canada. Int J Environ Res Public Health 2011;8:3953–3978.

Pugh TA, Mackenzie AR, Whyatt JD, Hewitt CN. Effectiveness of green infrastructure for improvement of air quality in urban street canyons. Environ Sci Technol 2012 J;46(14):7692-7699.

Ragettli MS, Goudreau S, Plante C, Fournier M, Hatzopoulou M, Perron S, Smargiassi A. Statistical modeling of the spatial variability of environmental noise levels in Montreal, Canada, using noise measurements and land use characteristics. J Expo Sci Environ Epidemiol 2016;26(6):597-605.

Rao M, George LA, Rosenstiel TN, Shandas V, Dinno A. Assessing the relationship among urban trees, nitrogen dioxide, and respiratory health. Environ Pollut 2014;194: 96–104.

Reklaitiene R, Grazuleviciene R, Dedele A, Virviciute D, Vensloviene J, Tamosiunas A, Baceviciene M, Luksiene D, Sapranaviciute-Zabazlajeva L, Radisauskas R, Bernotiene G, Bobak M, Nieuwenhuijsen MJ. The relationship of green space, depressive symptoms and perceived general health in urban population. Scand J Public Health 2014;42(7):669-676.

Rhew IC, Vander Stoep A, Kearney A, Smith NL, Dunbar MD. Validation of the Normalized Difference Vegetation Index as a measure of neighborhood greenness. Ann Epidemiol 2011; 21(12):946–952.

Richardson EA, Mitchell R. Gender differences in relationships between urban green space and health in the United Kingdom. Soc Sci Med. 2010;71(3):568-75.

Richardson EA, Mitchell RJ, De Vries S, Hartig T, Astell-Burt T. Green cities and health: a question of scale? J Epidemiol Community Heal 2012; 66:160–165.

Richardson EA, Pearce J, Mitchell R, Kingham S. Role of physical activity in the relationship between urban green space and health. Public Health 2013;127(4):318–324.

Rios R, Aiken LS, Zautra AJ. Neighborhood contexts and the mediating role of neighborhood social cohesion on health and psychological distress among Hispanic and non-Hispanic residents. Annals of Behavioral Medicine 2012;43(1):50-61.

Roe JJ, Ward Thompson C, Aspinall PA, Brewer MJ, Duff EI, Miller D, Mitchell R, Clow A. Green space and stress: evidence from cortisol measures in deprived urban communities. Int J Environ Res Public Health 2013;10:4086–4103.

Rodriguez-Galiano VF, Chica-Olmo M, Abarca-Hernandez F, Atkinson PM, Jeganathan C. Random Forest classification of Mediterranean land cover using multi-seasonal imagery and multi-seasonal texture. Remote Sensing of Environment 2012;121:93-107.

Roth KL, Roberts DA, Dennison PE, Peterson SH, Alonzo M. The impact of spatial resolution on the classification of plant species and functional types within imaging spectrometer data. Remote Sens Environ 2015;171:45–57.Saaroni H, Ben-Dor E, Bitan A, Potchter O. Spatial distribution and microscale characteristics of the urban heat island in Tel-Aviv, Israel. Landscape and Urban Planning 2000;48(1):1–18.

Sallis JF, Cerin E, Conway TL, Adams MA, Frank LD, Pratt M, Salvo D, Schipperijn J, Smith G, Cain KL, et al. Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. The Lancet 2016; 387:2207–2217.

Salmond JA, Williams DE, Laing G, Kingham S, Dirks K, Longley I, Henshaw GS. The influence of vegetation on the horizontal and vertical distribution of pollutants in a street canyon. Sci Total Environ 2013;443:287-298.

Sbihi H, Tamburic L, Koehoorn M, Brauer M. Greenness and Incident Childhood Asthma: A 10-Year Follow-up in a Population-based Birth Cohort. Am J Respir Crit Care Med 2015;192(9):1131-1133.

Schipperijn J, Bentsen P, Troelsen J, Toftager M, Stigsdotter UK. Associations between physical activity and characteristics of urban green space. Urban For Urban Green 2013;12(1):109–116.

Schwanen T, Dijst M, Dieleman FM. A microlevel analysis of residential context and travel time. Environ Plan A 2002;34(8):1487-1508.

Shashua-Bar L, Hoffman M. Vegetation as a climatic component in the design of an urban street. An empirical model for predicting the cooling effect of urban green areas with trees. Energy and Buildings 2000;31(3):221-235.

Shepherd D, Dirks K, Welch D, McBride D, Landon J. The Covariance between Air Pollution Annoyance and Noise Annoyance, and Its Relationship with Health-Related Quality of Life. Int J Environ Res Public Health 2016;13(8).

Sijtsma FJ, de Vries S, van Hinsberg A, Diederiks J. Does ‘grey’ urban living lead to more ‘green’ holiday nights? A Netherlands case study. Landscape and Urban Planning 2012;105:250-257.

Shoshany M. Landscape fragmentation and soil cover changes on south- and north-facing slopes during ecosystems recovery: an analysis from multi-date air photographs. Geomorphology 2002;45(1–2):3-20.

Shoshany M. The rational model of shrubland biomass, pattern and precipitation relationships along semi-arid climatic gradients. Journal of Arid Environments 2012;78:179-182.

Smargiassi A, Goldberg MS, Plante C, Fournier M, Baudouin Y, Kosatsky T. Variation of daily warm season mortality as a function of micro-urban heat islands. Journal of Epidemiology and Community Health 2009;63(8):659–664.

Son JY, Lane KJ, Lee JT, Bell ML. Urban vegetation and heat-related mortality in Seoul, Korea. Environ Res 2016;151:728-733.

Spronken-Smith RA, Oke TR. Scale modelling of nocturnal cooling in urban parks. Boundary-Layer Meteorol 1999;93:287–312.

Sripada RP, Heiniger RW, White JG, Meijer AD. Aerial color infrared photography for determining early in-season nitrogen requirements in corn. Agronomy Journal 2006;98:968-977.

Steffens JT, Wang YJ, Zhang KM. Exploration of effects of a vegetation barrier on particle size distributions in a near-road environment. Atmos Environ 2012;50:120–28.

Stigsdotter UK, Ekholm O, Schipperijn J, Toftager M, Kamper-Jørgansen F, Randrup TB. Health promoting outdoor environments – associations between green space, and health, health-related quality of life and stress based on a Danish national representative survey. Scand J Public Health 2010;38(4):411–417.

Sturm R, Cohen D. Proximity to urban parks and mental health. J Ment Health Policy Econ 2014;17(1):19.

Stürmer T, Schneeweiss S, Avorn J, Glynn RJ. Adjusting effect estimates for unmeasured confounding with validation data using propensity score calibration. Am J Epidemiol 2005;162(3):279-89.

Su JG, Jerrett M, de Nazelle A, Wolch J. Does exposure to air pollution in urban parks have socioeconomic, racial or ethnic gradients? Environ Res 2011;111(3):319-328.

Sugiyama T, Leslie E, Giles-Corti B, Owen N. Associations of neighbourhood greenness with physical and mental health: do walking, social coherence and local social interaction explain the relationships? J Epidemiol Community Health 2008;62(5):e9.

Sun R, Chen L. Effects of green space dynamics on urban heat islands: Mitigation and diversification. Ecosystem Services 2017;23:38-46.

Teylor L, Hochuli DF. Defining greenspace: Multiple uses across multiple disciplines. Landscape and Urban Planning 2017;158:25-38.

Thenkabail PS, Lyon JG, Huete A (Eds.). Hyperspectral remote sensing of vegetation. CRC Press, 2016.

Thiering E, Markevych I, Brüske I, Fuertes E, Kratzsch J, Sugiri D, Hoffmann B, von Berg A, Bauer CP, Koletzko S, Berdel D, Heinrich J. Associations of residential long-term air pollution exposures and satellite-derived greenness with insulin resistance in German adolescents. Environ Health Perspect 2016;124(8):1291-1298.

Thompson Coon J, Boddy K, Stein K, Whear R, Barton J, Depledge MH. 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. Environ Sci Technol 2011;45:1761–1772.

Toftager M, Ekholm O, Schipperijn J, Stigsdotter U, Bentsen P, Grønbæk M, Randrup TB, Kamper-Jørgensen F. Distance to green space and physical activity: a Danish national representative survey. J Phys Act Health 2011;8(6):741-9.

Tong Z, Baldauf RW, Isakov V, Deshmukh P, Zhang KM. Roadside vegetation barrier designs to mitigate near-road air pollution impacts. Sci Total Environ 2016;541:920-927.

Tong Z, Whitlow TH, MacRae PF, Landers AJ, Harada Y. Quantifying the effect of vegetation on near-road air quality using brief campaigns. Environ Pollut 2015;201:141-149.

Triguero-Mas M, Dadvand P, Cirach M, Martínez D, Medina A, Mompart A, et al. Natural outdoor environments and mental and physical health: Relationships and mechanisms. Environ Int 2015;77:35–41.

Tucker CJ. Red and Photographic Infrared Linear Combinations for Monitoring Vegetation. Remote Sensing of Environment 1979;8(2):127-150.

Ulmer JM, Wolf KL, Backman DR, Tretheway RL, Blain CJ, O'Neil-Dunne JP, Frank LD. Multiple health benefits of urban tree canopy: The mounting evidence for a green prescription. Health Place 2016;42:54-62.

Ulrich RS, Simon RF, Losito BD, Fiorito E, Miles MA, Zelson M. Stress recovery during exposure to natural and urban environments. J Environ Psychol 1991;11:201-230.

Ulrich RS. Aesthetic and affective response to natural environment. In: Altman I & Wohlwill JF (Eds.). Human behavior and environment: Vol. 6. Behavior and the natural environment. New York: Plenum, 1983: 85-125.

United Nations, Department of Economic and Social Affairs, Population Division. World Urbanization Prospects: The 2014 Revision, Highlights (ST/ESA/SER.A/352). 2014. Available: <https://esa.un.org/unpd/wup/Publications/Files/WUP2014-Highlights.pdf> (accessed 08.10.16).

van den Berg AE, Maas J, Verheij RA, Groenewegen PP. Green space as a buffer between stressful life events and health. Soc Sci Med 2010;70(8):1203-1210.

van den Berg M, van Poppel M, van Kamp I, Andrusaityte S, Balseviciene B, Cirach M, et al. Visiting green space is associated with mental health and vitality: A cross-sectional study in four European cities. Health Place 2016;38:8-15.

van den Berg M, Wendel-Vos W, van Poppel M, Kemper H, van Mechelen W, Maas J. Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. Urban Forestry & Urban Greening 2015;14(4):806-816.

van den Bosch M, Nieuwenhuijsen M. No time to lose - Green the cities now. Environ Int. 2016. doi: 10.1016/j.envint.2016.11.025. [Epub ahead of print]

van den Bosch M, Östergren P-O, Grahn P, Skärbäck E, Währborg P. Moving to serene nature may prevent poor mental health—Results from a Swedish Longitudinal Cohort Study. Int J Environ Res Public Health 2015;12:7974–7989.

Van Dijk T, van der Valk A. Shades of urbanity: diverging statistical definitions. 2007. Available from: <https://www.researchgate.net/publication/40103012_Shades_of_urbanity_diverging_statistical_definitions> (assessed 11.11.16).

van Renterghem T, Botteldooren D. View on outdoor vegetation reduces noise annoyance for dwellers near busy roads. Landscape and Urban Planning 2016;148:203–215.

van Renterghem T, Forssén J, Attenborough K, Jean P, Defrance J, Hornikx M, Kang J. Using natural means to reduce surface transport noise during propagation outdoors. Applied Acoustics 2015;92:86–101.

Villeneuve PJ, Jerrett M, G. Su J, Burnett RT, Chen H, Wheeler AJ, Goldberg MS. A cohort study relating urban green space with mortality in Ontario, Canada. Environ Res 2012. 115:51–58.

von Lindern E, Hartig T, Lercher P. Traffic-related exposures, constrained restoration, and health in the residential context. Health & Place 2016;39:92-100.

von Lindern E, Lymeus F, Hartig T. The restorative environment: A complementary concept for salutogenesis studies. In: Mittelmark MB et al. (Eds.). Handbook of Salutogenesis. New York: Springer, 2017: 181-195.

Voogt J, Oke T. Thermal remote sensing of urban climates. Remote Sensing of Environment 2003;86:370–384.

Vos PE, Maiheu B, Vankerkom J, Janssen S. Improving local air quality in cities: to tree or not to tree? Environ Pollut 2013;183:113-122.

Ward Thompson C, Roe J, Aspinall P, Mitchell R, Clowd A, Miller D. More green space is linked to less stress in deprived communities: Evidence from salivary cortisol patterns. Landscape and Urban Planning 2012;105(3):221–229.

Weier J, Herring D. Measuring vegetation (NDVI&EVI). 2000. Available: <http://earthobservatory.nasa.gov/Features/MeasuringVegetation/> (assessed 24.11.16).

Weinstein N, Balmford A, DeHaan CR, Gladwell V, Bradbury RB, Amano T. Seeing community for the trees: the links among contact with natural environments, community cohesion, and crime. BioScience 2015;65(12):1141-1153.

White MP, Alcock I, Wheeler BW, Depledge MH. Would you be happier living in a greener urban area? A fixed-effects analysis of panel data. Psychol Sci 2013;24:920–928.

Wolch JR, Byrne J, Newell JP. Urban green space, public health, and environmental justice: The challenge of making cities “just green enough”. Landscape and Urban Planning 2014;125:234-244.

World Health Organization. Urban green spaces and health - a review of evidence. 2016. Available: <http://www.euro.who.int/en/health-topics/environment-and-health/urban-health/publications/2016/urban-green-spaces-and-health-a-review-of-evidence-2016> (accessed 08.11.16).

Wu WY, Yau OHM, Lu HY. Feng shui principles in residential housing selection. Psychology & Marketing 2012;29:502-518.

Xu Y, Dadvand P, Barrera-Gómez J, Sartini C, Marí-Dell'Olmo M, Borrell C, Medina-Ramón M, Sunyer J, Basagaña X. Differences on the effect of heat waves on mortality by sociodemographic and urban landscape characteristics. J Epidemiol Community Health 2013;67(6):519-525.

Yuan F, Bauer ME. Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. Remote Sens Environ 2007;106:375–386.

Zenghelis D, Stern N. This is humankind’s “great urbanisation”. We must do it right, or the planet will pay. The Guardian 2016; 8November.

Zhang K, Begley C, Chen TH. Impact of the 2011 heat wave on mortality and emergency department visits in Houston, Texas. Environmental Health 2015;14(1):11.

Zhao X, Lynch JG, Chen Q. Reconsidering Baron and Kenny: Myths and truths about mediation analysis. Journal of consumer research 2010;37(2):197-206.

Zhou W, Huang G, Cadenasso M. Does spatial configuration matter? Understanding the effects of land cover pattern on land surface temperature in urban landscapes. Landscape Urban Planning 2011;102:54–63.