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Exploring pathways linking greenspace to health: Theoretical and methodological guidance

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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.

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 and 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 and 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 and 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 and 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, Fig. 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 ex- plain 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 (Fig. 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 et al., 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 et al., 2016; von Lindern et al., 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, Fig. 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.

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 and 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 and Balbus, 2015). Third, larger greenspace characterized by restricted opportunities for surveillance can serve as a place for crime (Kimpton et al., 2016), or simply, a place feared due to the potential for crime, particularly for vulnerable populations (women, children and the elderly; Lee and 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 et al., 2014; Donovan and 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 and 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 and 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 (PM_{10}) and ozone, via deposition (Kroeger et al., 2014), which is widely incorporated into valuation models (Hirabayashi and Nowak, 2016; Nowak et al., 2014). However, empirical research that supports this assumption is limited and inconsistent (Steffens et al., 2012; Grundström and 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 and Oke, 2003). This phenomenon, known as an urban heat island (Voogt and 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 and Hystad, 2014; Luber and McGeehin, 2008; Smargiassi et al., 2009; Zhang et al., 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 and 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 and Oke, 1999; Shashua-Bar et al., 2000; Potchter et al., 2006; Pelta and 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 green- space 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 and Ohrstrom, 2007; Gidlöf-Gunnarsson et al., 2009; Li et al., 2010; Li et al., 2012; Leung et al., 2014; Bodin et al., 2015; Dzhambov and Dimitrova, 2015; van Renterghem and Botteldooren, 2016). The hypothesized mechan- isms include visual shielding of the noise source (Aylor and Marks, 1976), improvement in perceived acoustic quality of the environment because of nature sounds (Kang et al., 2016), combined visual "ex- posure" 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 in- creased sense of control over the acoustic environment (Dzhambov and 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 neighbourhood does not appear to be associated with noise annoyance (van Renterghem and Botteldooren, 2016; Dzhambov and 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 some- times 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; Grigsby-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 and 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 and Talbot, 1983; Kaplan and 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 de- pends. 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 ex- ample, 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., 2003a). 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 out-comes 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 sup- ported by a sense of being away, extent and compatibility in the environmental encounter (Kaplan and 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 re- current activity cycles within a social ecology of stress and restoration (Hartig et al., 2003b). 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 and 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 and 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 greenest 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 et al. (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 and Kearns, 2001; Kuo et al., 1998; Kuo and Sullivan, 2001a, 2001b; Kemperman and Timmermans, 2014; Holtan et al., 2015; Weinstein et al., 2015). Social cohesion needs to be distinguished from social capital (i.e. re- sources 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 and 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 and 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., 2016a; James et al., 2015; Yuan and 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). Fig. 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.

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. Fig. 3 demonstrates that decreasing the spatial resolution from 10 m to 60 m makes it almost im- possible to capture a small urban green space.

Second, as vegetation indices assess the overall level of vegetation only and do not differentiate between structured (e.g. parks) and un- structured (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 (Fig. 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 and 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 and 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 5000 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 Fig. 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.

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. Fig. 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.

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 centers (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 and Fransson, 2009) and to early death (Fransson and 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 path- ways 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 and 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 et al., 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 be- tween 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 re- siding in more deprived neighbourhoods (Dadvand et al., 2012a, 2012c, 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 de- pendent 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 et al., 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 re- siding in a deprived area without greenspace (Mitchell and 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, 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 dis- advantaged neighbourhoods. Effect measure modification by SES could also be context-specific or dependent on the degree of urbanicity (Maas et al., 2006; Mitchell and 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 in- consistent, with some studies providing support (Maas et al., 2009b, 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 ac- knowledged, however, that urbanicity is a very complex concept in it- self, 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 and 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 and Lu, 2012; cf. Hobson, 1994).

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 and 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 and 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 and 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 and 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 and 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 Mowafi et al. (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).

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.

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Figures and Tables

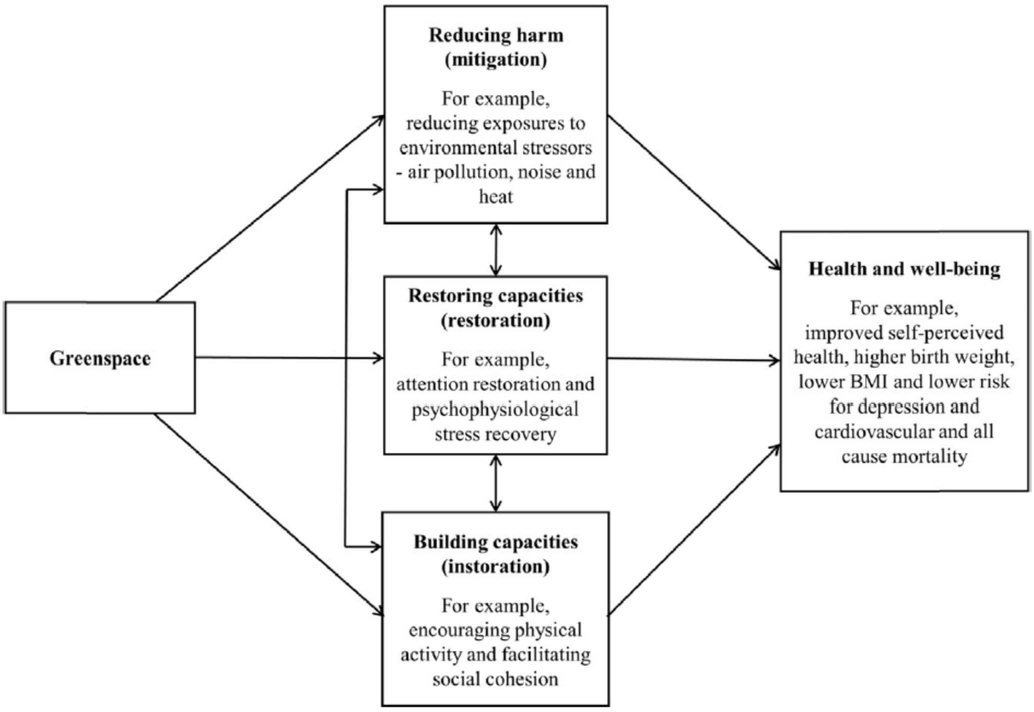


Fig. 1. Three domains of pathways linking greenspace to positive health outcomes. The arrows represent hypothetical patterns of influence, with specific pathways in each domain potentially influencing one or more specific pathways in the other domains.

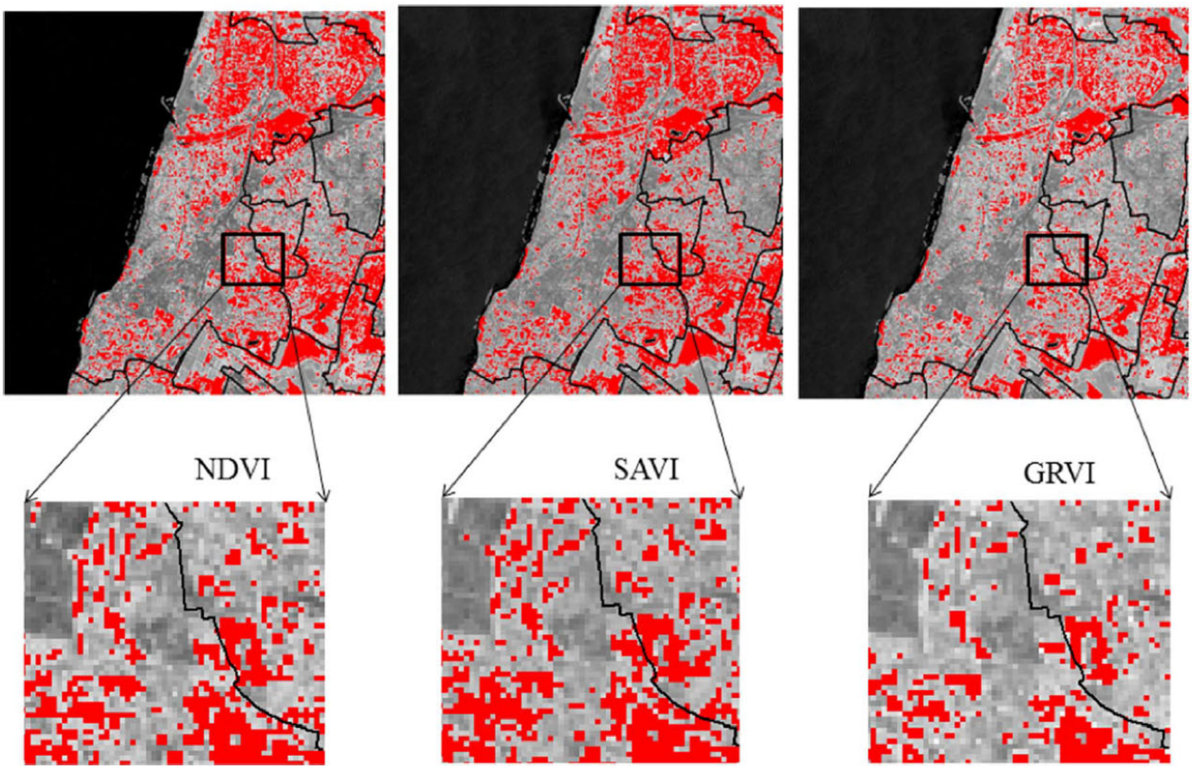


Fig. 2. Spatial pattern of vegetation for the urban site of Tel-Aviv and suburbs based on upper quartile of Landsat-derived NDVI, GRVI and SAVI.

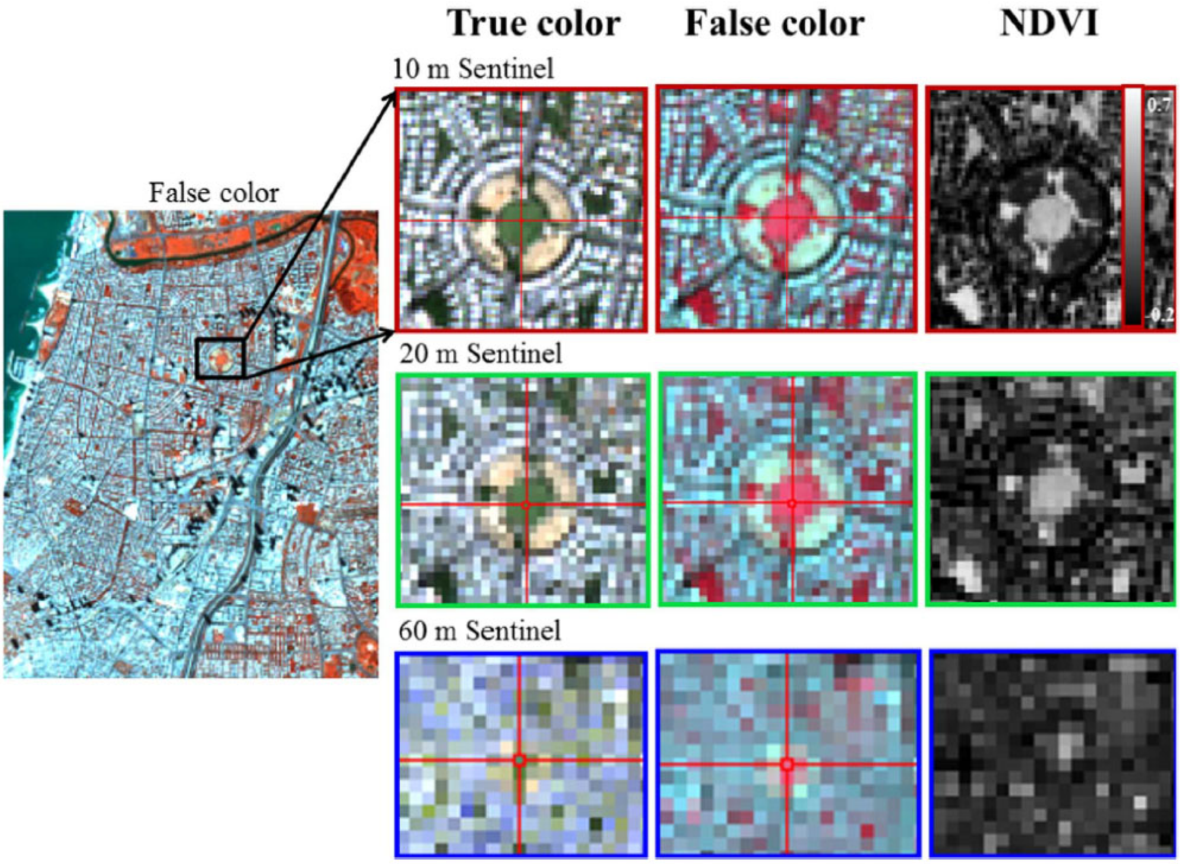
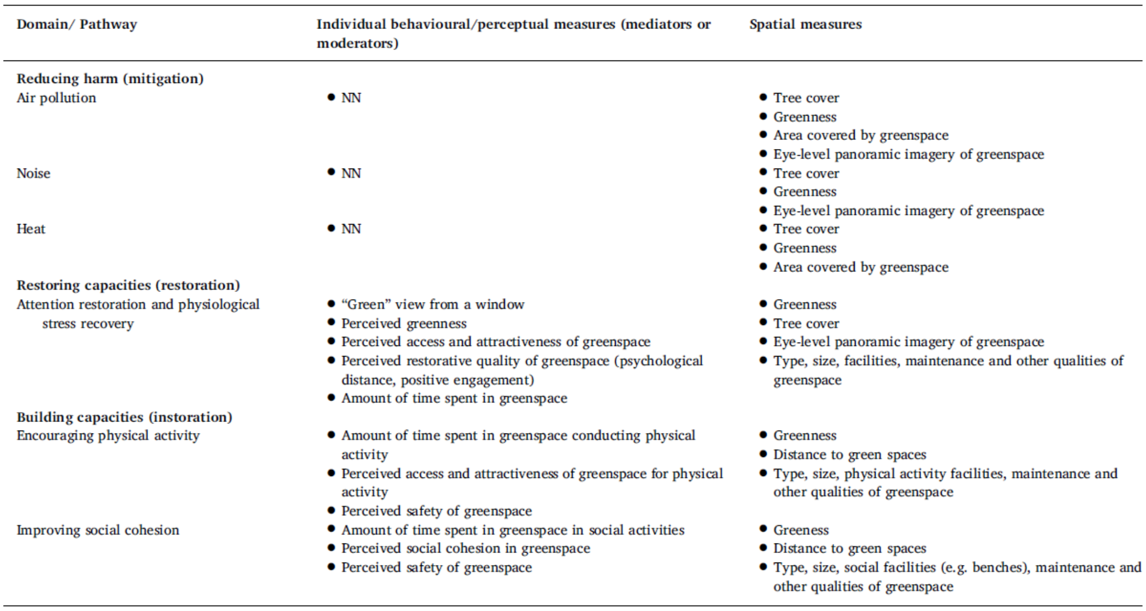


Fig. 3. Spatial resolution: decreasing the spatial resolution impacts the accuracy of NDVI. “True color” means “human-like (i.e. vegetation is shown in green), whereas “false color”,highlight vegetation in red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).

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



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

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

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.