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FIFTY SHADES OF GREEN: PATHWAY TO HEALTHY URBAN LIVING

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Abstract

Currently half the world population lives in cities, and this proportion is expected to increase rapidly to 70% over the next years. Over the years we have created large, mostly grey cities with many high-rise buildings and little green space. Disease rates tend to be higher in urban areas than in rural areas. More green space in cities could reduce these rates. Here, we describe the importance of green space for health, and make recommendations for further research.

Green space has been associated with many beneficial health effects, including reduced all-cause and cardiovascular mortality and improved mental health, possibly through mediators such as reduced air pollution, temperature and stress and increased physical activity, social contacts and restoration.

Further studies are needed to strengthen the evidence base and provide further guidelines to transport planners, urban planners and landscape architects. We need more longitudinal studies and intervention studies, further understanding of the contribution of various mechanisms towards health, and more information on susceptible populations and on where, when, how much, and what type of green space is needed. Also needed are standardized methods for green space quality assessments and evaluations of effectiveness of green prescriptions in clinical practice. Many questions are ideally suited for environmental epidemiologists, who should work with other stakeholders to address the right questions and translate knowledge into action.

In conclusion, a growing evidence base supports the hypothesis that greener cities are healthier cities.

Introduction

It is remarkable that when you talk to people about green space they tend to have positive experiences to tell. They remember their childhood climbing a tree, a long hike in the forest, a barbeque with friends in the garden, or some time spent with their beloved in a park (Figure 1). Perhaps this is not so surprising as for tens of thousands of years humans have lived in forests and savannahs surrounded by nature, and only over the past few thousand years have they moved into cities, where nature is often less available. Our bodies and minds may be best adapted to living with nature, a concept EO Wilson [(1)] described with the term biophilia: people´s innate affinity for the natural world.

Currently half the world's population live in cities, and this proportion is expected to increase rapidly to 70% over the next 20 to 30 years.[(2)] This rapid increase is particularly happening in low and medium income countries; 80 to 90% of people already live in cities in high income countries.

Cities have long been known to be society's predominant engine of innovation and wealth creation, yet they are also its main source of crime, pollution, and disease.[(3)] Over the years we have created large, mostly grey cities with many high rise buildings and little green space. (Shenzhen, China; Beirut, Lebanon; Buenos Aires, Argentina; Kuwait City, Kuwait; and Athens, Greece are a few examples.) It is therefore not surprising that only 23% of the residents of Athens are very or rather satisfied with available green space.[(4)] The amount of green space available to people in cities also varies considerably from, for example, 1.9 m^2 per person in Buenos Aires, Argentina to 52.0 m^2 in Curitiba, Brazil.[(5)] Rates of diseases such as mental illnesses tend to be higher

in urban areas compared to rural areas. For example, in a meta-analysis Peen et al [6] found that the risk of mood disorders was 39% higher in urban areas than rural areas.

People value green space and are increasingly willing to pay for it. Donovan et al [7] found that house prices in Portland, Oregon, were on average US$8870 higher if there were street trees and they sold 1.7 days faster. A small 15 meter garden in London sold recently for 1.2 million pound sterling

This topic area is a rapidly evolving field with a substantial number of studies and reviews emerging in the past few years, but a broad overview of the current state-of-research is lacking. We therefore aim to describe the evidence linking green space in cities to health and to make recommendations for further research. We have three main premises. The first is that green cities are healthy cities, but that there generally is lack of sufficient green space in at least parts of many cities. The second is that green space is beneficial for healthy psychophysiological functioning, health, and wellbeing. The third is that there are still many important open questions in terms of when, where, or how much green space is needed and what are the underlying mechanisms of the relation of green space to health.

Methods

This review is not comprehensive; there have been a number of recent extensive reviews on this topic (Table 1).[8-22] Instead, we aim to provide a holistic and narrative overview of the available reviews to highlight the current state of the evidence base, pointing out key reviews, strength of evidence, and influential studies on the importance for healthy green urban living.

In the introduction above we set the context, and in the results section we describe a conceptual framework and proposed mechanisms, followed by the description of existing green space indicators, health effects of green space, and the contribution of these mechanisms. Finally we provide recommendations for further research.

In this review we adopt the United States Environmental Protection Agency definition of green spaces as "land that is partly or completely covered with grass, trees, shrubs, or other vegetation," which can include parks, community gardens, and cemeteries.[23] All studies we review here define green space consistently with this definition.

Results

Conceptual framework

We use a modified version of the conceptual framework recently proposal by Hartig et al [11]. In this framework, the relationship between contact with the natural environment and health is mediated through a number of possible mechanisms including air quality, physical activity, social contacts, stress, and restoration. The mechanisms have a number of possible modifiers such as distance to green space, accessibility factors, perceived safety in the green space, societal context, cultural context, gender, age, and socioeconomic status (Figure 2). Improvement in air quality, increase in social contacts, physical activity, and a reduction in stress are all well known to be associated with improved health. Below we briefly describe the possible mechanisms for these associations and give some key examples.

Green space indicators

Before describing possible mechanisms and health effects of green space, we briefly discuss the current methods for assessment of green space indicators in epidemiologic studies. Generally surrounding greenness and/or access to green space are used in epidemiological studies.[14,18] With surrounding greenness (an indicator of general

greenness of living environment), a buffer is built around the home or another location and the percentage of green space or the amount of greenness is estimated within the buffer using satellite-derived indices such as the Normalized Different Vegetation Index. For access to green space, the Euclidean distance to a park, or the network distance to a park based on the closest route using street networks, or the presence of park within a given area around the home is estimated. At times the estimation is not only done for the home, but also for work or school and commuting route. Furthermore, some epidemiologic studies obtain information on the use, perception of, and visual access to green space by questionnaire. Other epidemiologic studies use tracking devices and motion sensors such as GPS, accelerometers, and smartphones with applications for measuring location, ecological momentary assessment, and physical activity.[14] Finally, some epidemiologic studies perform audits to assess the quality of the green space.

Possible Mechanisms

Environmental exposures

Tallis et al [24] found that the tree canopy of the urban forest in the Greater London Area removed between 852 and 2121 tonnes of PM_{10} annually, which equates to between 0.7% and 1.4% PM10 air-quality improvement. Regional plans to increase tree cover from the current 20% to 30% are expected to remove 1.1% to 2.6% of PM_{10} by the year 2050. Dadvand et al [25] found a reduction of around 5 $\mu g/m^3$ in personal exposure to $PM_{2.5}$ and NO_2 in pregnant women in Barcelona per interquartile range of the Normalized Difference Vegetation Index (NDVI). The former study is an example of the possible filtering effect of green space, and the effect is generally fairly small. The latter shows that the combined effects of filtering and replacement of mobile pollution sources by green space can be larger.

Green space also reduces temperature in cities, and therefore reduces the urban heat island effect. In a meta-analysis, Bowler et al [26] found a 1 degree Celsius reduction in temperature when comparing temperatures in parks with urban areas.

Physical activity

More than 50 studies have been conducted aiming to relate access to green space to physical activity levels, but the results have been inconsistent. [8] A recent systematic review of the association of proximity and density of parks and objectively measured physical activity in the United States and found that the associations varied, possibly due to the heterogeneity of exposure measurements. However, there are examples of beneficial associations, such as a recent large Australian study (N=203,883), which found that with an increase in the percentage of green space the odds of moderate to vigorous physical activity increased by up to 30%.[27]

Social contacts and cohesion

The cover of the 20th July 2015 issue of the New Yorker[28] showed people drinking tea under trees. "Sitting together for tea is what friends do" says Jean-Jacques Sempé, the designer of the cover, and he goes on to say that "Time spent with friends is one of the greatest pleasures of my life." Relatively few studies have evaluated the relationship between green space and social contacts. Some of the classic studies in the Robert Taylor Homes, Chicago have shown that apartment greenness and building greenness improve neighborhood social ties.[29]

Biodiversity

The newly promoted biodiversity hypothesis suggests that reduced contact with nature may adversely affect the human commensal microbiota and its immunomodulatory

capacity. Hanski et al [30] found a relationship between generic composition of skin microbiota and land use type around the home. They also found a reduced level of allergic disease, mediated through acinetobacter and gammaproteobacteria. However, very few studies so far have focused on this mechanism.

Biogenics hypothesis

Moore et al [31] recently suggested the "biogenics" hypothesis, suggesting that regular exposure to low concentrations of mixtures of natural compounds and toxins in natural environments confers pleiotropic health benefits by inhibiting the activities of interconnected cell signaling systems, particularly PI3K/Akt/mTORC1. When overactive, Akt and mTOR (mTORC1) can lead to pathological processes resulting in cancers, diabetes, inflammation, immunosuppression, and neurodegenerative diseases. Future evaluation of this mechanism is required.

Restoration and stress reduction

The more consistent and promising pathways are stress reduction and restoration. The Stress Reduction Theory suggests natural environments promote recovery from stress and help to lessen states of arousal and negative thoughts through psycho-physiological pathways. Natural elements with characteristics such as a level of ground surface, spatial openness, curving sightlines, and the presence of water may induce recovery from any form of stress, even mild short-term stress, via an unconscious and innate response.[32] The Attention Restoration Theory suggests that nature can replenish directed attention fatigue. Natural environments abound with "soft fascinations" that a person can reflect upon in "effortless attention", such as clouds moving across the sky, leaves rustling in a breeze or water bubbling over rocks in a stream.[33] For example, Ulrich [32] found that patients who underwent a gall bladder operation and had a view from a window with trees recovered faster and used fewer potent analgesics than

patients with a view of a brick building wall. Ulrich et al[34] also found that subjects recovered from stress faster, measured in terms of skin conductance and pulse transit time, when they viewed photos from nature compared to traffic and pedestrian malls. In subjects who initially underwent a stressful interview, Jiang et al[35] found that the percentage of tree cover in videos (ranging from 2% to 61%) was directly related in an exposure response fashion with stress recovery. The Japanese have developed a practice called ´´Shinrin Yoku´´ or forest bathing to relieve stress.[36]

The more recent use of technology such as electroencephalography, in which electroencephalography signals are translated and classified in different emotional states, showed different responses for volunteers walking around in different neighborhoods (urban shopping streets, green space, and busy commercial districts).[37] Volunteers showed lower frustration, engagement, and arousal, and higher meditation when moving into the green space zones. Bratman et al.[38] showed that after a walk in nature subjects showed reduced rumination, as measured by questionnaire and reduced blood perfusion in the subgenual prefrontal cortex compared to a walk in an urban area. Reduced activity in the subgenual prefrontal cortex has been associated with improved symptoms in people with depression and regulation of cortisol levels, which is related to reduced stress.

Health effects

Mental health and cognitive function

A recent systematic review found limited evidence for a causal relationship between surrounding greenness and mental health status in adults, but little or no relationship with access to green space.[18] Although the review found many associations, the main limitation was the cross-sectional nature of most of the studies. For example, a recent cross-sectional study by Triguero-Mas et al[39] found a 10% to 20% reduction in

perceived risk of poor mental health, perceived depression and/or anxiety, and intake of tranquilizers or sedatives, antidepressants, and sleeping medications per interquartile range increase in average Normalized Difference Vegetation Index around the homes, suggesting that substantial health benefits are possible. Alcock et al[40] used a longitudinal design by following up the mental health status of people moving house. They found an improvement of mental health scores for those moving to greener areas, with effects lasting at least 3 years, and deterioration in mental scores for those moving to less green areas. Green space may reduce health inequalities emanating from differences in socioeconomic status. Mitchell et al[41] found a 20% difference in mental well being when comparing the most and least financially strained among those who had great difficulty with access to green space, while the difference was only 11.9% for those with very easy access to green space. Finally, Dadvand et al[42] measured the cognitive development of children 7 to 10 years old using repeated computer tests over a year and found a 6% better development of the working memory and superior working memory among those in the highest tertiles of greenness in school compared to those in the lowest tertile of greenness.

Mortality

A seminal study on the relationship between green space and all-cause mortality in the United Kingdom found that all-cause mortality was around 6% lower in the highest quintile of green space compared to the lowest quintile.[43] Furthermore, the difference in all-cause and circulatory disease mortality between different socioeconomic classes was much smaller among those in the highest quintile of green space compared to the lowest quintile, further suggesting that green space may reduce health inequalities. A natural experiment reported by Donovan et al[44], in which they evaluated the effect of the loss of 100 million trees to the emerald ash borer, an invasive forest pest on

mortality, found that the presence of the borer was associated with 6.8 additional deaths per 100,000 adults and 16.7 additional cardiovascular deaths per 100,000 adults. In meta-analyses of green space and mortality, Gascon et al[18] found an 8% reduction in all-cause mortality and a 4% reduction in cardiovascular mortality when comparing the highest with the lowest exposure group of green space.

Other outcomes

Other beneficial impacts of access to green space have been reported, such as a reduction in crime[22] and obesity [8, 17] and an increase in birth weight.[12] But there are also risks with green space such as physical risks when trees fall on people or property, the spread of Lyme disease, and an increase in skin cancer, allergies, and asthma.[11,21]

Contribution of mechanisms

Very few studies have evaluated the contribution of the different mediators between green space and morbidity and mortality. De Vries et al[45] estimated the contribution of different potential mediators of green space on health (stress, social cohesion, and green physical activity) to general health, acute complaints, and mental health and found that stress and social cohesion contributed the most to the outcomes (around 20% to 40%) while green physical activity contributed less than 10%.

Discussion

The recent surge in studies of green space and health has strengthened the evidence base considerably. Many of these new and emerging studies have shown evidence of beneficial associations with health outcomes, but some concerns has been raised about potential residual confounding by socio-economic status. Green space is valued by people and they are willing to pay more for having greener residences. There is also some evidence showing differential access to green spaces among racial and ethnic

minorities.[46] There may therefore be a relationship between green space and socioeconomic position [47] making socioeconomic position a potential confounder; however, the impact of the socioeconomic position on the findings of studies of the health effects of green spaces depends on local context and the type of health outcome and can vary from minimal to moderate.[48,49] Furthermore, people with poorer mental health may be more inclined to move to greener areas, but there is little evidence this happens so far.[40]

Even though it appears that green space is associated with benefits to mental health, mortality, and other outcomes, questions remain in terms of where, when, how much, and what type of green space is required –if causal -- for those benefits, the contribution of various mechanisms, and the effectiveness of green prescriptions. The epidemiologic studies so far have used fairly crude green space indicators, which may not be enough to guide transport and urban planners, landscape architects and policy makers to start planning or refitting our cities and investing more in green infrastructure. For example, can we get our ´´dose´´ of green space when we visit a large natural area outside the city once in a while, or can we get it when commuting to work in our car, or do we need local parks and trees in our streets? Is blue space as important? So what more is needed, particularly in urban environments?

Agenda for improved research designs

To date, most epidemiologic studies have been cross-sectional in design and we need more longitudinal studies and Intervention studies to ensure that access to green space, or the lack of it, precedes the measured health outcomes. For cost effectiveness, green space exposure indicators could be assigned to subjects in existing cohort studies that have good data on individual and area level or individual socioeconomic status

information and other covariates [14]. Pooled analyses that exploit the wealth of data available within existing cohorts also provide opportunities to strengthen the evidence base. These pooled cohorts have been used to investigate other exposures such as air pollution at larger scales than would have been possible if only relying on the individual cohorts[54]Information on potential mediators would be desirable.

Although easily obtained green space measures such as Normalized Difference Vegetation Index or percentage green space are attractive, researchers should go beyond these measures and include more information on type and quality of the green space. This type of information is critical for urban planning, so must be provided to translate research results into interventions. Although exposure estimates are traditionally assigned to the home of study participants, it may be important to assign green space estimates to commuting routes, as there is evidence to show that only short duration of green space exposure –such as that obtained during a commute -- may be needed to obtain beneficial effects. Assigning green space indicators to work or school is also important as these places are attended during daylight hours and subjects can see green space. People within a cohort or cohorts who change residence may be an interesting subgroup to study as their exposure to green space may change, allowing estimates of longitudinal effects.

Also, cohort studies may provide the opportunity to look at the relation between green space and health for multiple and new outcomes and to examine the underlying biological pathways by using -omics technologies that these studies often already apply.[50] Various studies have shown that green space may be able to reduce health inequalities and this needs replication and confirmation. Setting up a new cohort for green space and health research only may be prohibitively expensive, but if new cohorts are set up for other purposes, green space should be considered as a potential exposure

of interest from the early stages of design and planning so that the required data will be available.

In general it appears that there are health benefits associated with an increase in green space, especially around the home, and even short-term exposure to green space may offer improvement in acute psychophysiological parameters[14]. However, it is still unclear how much, where, when and what type of green space is needed to improve and/or sustain long term health benefits. For example, is green space needed around the home, or around work, or is exposure to green space during commuting sufficient? Is there an exposure–response relationship, and if so what is the shape and is there some minimum level? Further work is needed on these questions, using appropriate study designs in order to inform transport and urban planners, landscape architects and policy makers.

Quality assessments in future epidemiologic studies are therefore also essential to better address these questions. Quality characteristics of green spaces such as aesthetics, biodiversity, walkability, sport and play facilities, safety, and organized social events have been suggested to affect the use of green spaces for physical activity.[53] Badly maintained and unsafe parks with few attractions may be a deterrent to park visits. This deterrence may partly explain the inconsistent evidence for the association of green space with physical activity as generally the quality aspect of green spaces has not been considered. Having highly allergenic trees in the street may lead to an increase in allergies and asthma. A number of GIS-based studies have started to include quality or perception measures in the research. These have not been widely used in epidemiologic studies, but are likely to be important. Future studies should include audits to assess the quality of green space or subjects' satisfaction with green space.

Agenda for research topics

Many cities have recently started to introduce or improve green space or green space programs; such efforts lend themselves to evaluation of effects on health and other indicators.[51,52] Changes to the urban environment—such as introducing new parks or upgrading existing ones, greening of vacant lots, and introducing green corridors, urban gardens or green exercise programs—provide opportunities for evaluation of effects on health. The main challenges are to find good populations to study before and after the changes and to find a valid control group as cities change continuously. Improvements to the urban environment often lead to gentrification with a large influx of wealthier residents and outgoing of the traditional residents, which makes it difficult to have valid before and after comparisons. Furthermore, these types of studies lend themselves to both quantitative and qualitative approaches to evaluation. Collaboration with social scientists is essential.

Furthermore, there are very few studies on the magnitude of the contribution of various mechanisms of the benefits of green space (e.g. air quality, physical activity, social contacts and cohesion, stress and restoration) to health[45] and some of these mechanisms have been very poorly studied. Foremost among the understudied mechanisms is the importance of biogenics and biodiversity. More studies on the contribution of these mechanisms are needed to plan effective interventions in cities. The problem is often that, in existing epidemiologic studies, either some information on the mechanisms or on health outcomes exists, but rarely, if ever, information on both. Therefore, studies on the health benefits of green space rarely comprise complete information to answer research questions. Some attempts are made with specially designed studies to evaluate the contribution of the various mechanisms.[14] In the foreseeable future it is most likely that we can only estimate the contribution of some

mediators, unless new cohort studies are set up in which they can be incorporated from the beginning, but as mentioned above, these are expensive.

There is some indication in the literature that some groups of the population may benefit more than others, such as people with lower social economic positions and women, including pregnant women, and these results need further confirmation[43, 46, 49]. A group of particular interest may be racial or ethnic minorities moving into cities, for whom there is little data.

In addition to their ability to improve mental and physical health, green spaces have also been suggested to have "therapeutic effects" on a range of health problems for people with diseases such as mental health problems, pulmonary diseases, and Alzheimer's disease. Evaluations of these green prescriptions are generally small in size or lacking entirely. Further work is needed in this area as it is a promising aspect of clinical practice, but a good evidence base is needed.

Conclusions

Cities can be healthier for people, not by painting trees on walls, but by having a nearby park, planting trees in the streets, and introducing urban gardens. Urban gardens may have additional benefits in terms of local food production and economy and, if done at a sufficiently large scale, can contribute to the sustainability and self-sufficiency of cities. Many cities need more parks, which can also become part of the identity and attraction of cities. Think, for example, of the iconic Central Park in New York. Finally, green roofs may transform the city, not only in terms of resilience but also in terms of visual attractiveness. More research is needed to tease out the important aspects, but in general to strengthen the evidence that more green space leads to better health.

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Figure 1 Parks and trees in streets are essential for human health and well being

Figure 2 Conceptual framework of green space, mechanisms, health effects and current status of evidence

Table 1 Summary of recent reviews relevant to studying the relationship between green space and health.

Study	Type of Review	Exposures and outcomes	Key results and conclusions
Lachowycz K, Jones AP 2011 (8)	Systematic review	Physical activity and weight status	The majority (68%) of papers found a positive or weak association between greenspace and obesity-related health indicators, but findings were inconsistent and mixed across studies.
Thornton et al 2011 (9)	Review, glossary	GIS terminology	Key concepts
Lee AC, Maheswaran 2011 (10)	Review	A range of health outcomes, including physical and mental health	There is weak evidence for the links between physical health, mental health and well-being, and urban green space.
Hartig et al 2014 (11)	Review, systematic search for reviews	A range of different health outcomes	A conceptual framework
Dzhambov et al 2014 (12)	Systematic review and meta-analysis	Birth weight	Neighbourhood greenness within 100-m buffer was weakly and positively associated with birth weight.
Bancroft et al 2015 (12)	Systematic review	Parks and objectively measured physical activity in the US	The association between access to parks and physical activity varied between studies, possibly due to heterogeneity of exposure measurement.
Nieuwenhuijsen et al 2014 (13)	Review and Study protocol	A range of different health outcomes	Positive associations with health of green space have been observed on longevity,

			cardiovascular diseases, people's self-reported general health, mental health, sleep patterns, recovery from illness, social health aspects, and birth outcomes.
Kuo 2015 (14)	Review and compilation of possible pathways	A range of possible pathways	21 pathways of health effects of green spaces were identified
Coutts C, Hahn M 2015 (15)	Survey of the literature	Health outcomes including physical activity and mental health in the light of ecosystems services	(Co) benefits of ecosystems services on various health outcomes
James et al 2015 (16)	Review	Mental health outcomes, cardiovascular disease, physical activity, weight, and mortality and birth weight	Greenness is protective against adverse mental health outcomes, cardiovascular disease, and mortality. Intermediate evidence for physical activity and weight. Consistent evidence that greenness exposure during pregnancy is positively associated with birth weight, though findings for other birth outcomes are less conclusive.
Gascon et al 2015 (17)	Systematic review	Objectively measured green space and mental health	Limited evidence for a causal relationship between surrounding greenness and mental

			health in adults, whereas the evidence was inadequate in children.
Gascon et al 2015 (18)	Systematic review and meta-analysis	All-cause mortality, cardiovascular mortality and lung cancer	The majority of studies show lower risk of cardiovascular disease mortality in areas with higher residential greenness. Evidence of lower all-cause mortality is more limited, and no beneficial association of residential greenness with lung cancer mortality are observed.
van den Berg et al 2015 (19)	Systematic reviews	A number of health outcomes including mental health, perceived health, and mortality	Strong evidence for positive associations between the quantity of green space (objectively measured around the residence) and perceived mental health and all-cause mortality, and moderate evidence for an association with perceived general health
Lohmus and Balbus 2015 (21)	Review	Harmful effects of green space on health	Possible increased risk for infectious disease and allergies
Bogar S and Beyer KM 2015 (22)	Systematic review	Crime and violence	Evidence supports the positive associations of green space with violence and crime, indicating great potential for green space to shape health-

			promoting environments.

Figure 1.

Figure 2.

Figures paper 2