Chapter 6
Green Spaces and Child Health and Development

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Abstract The ongoing urbanisation worldwide has led to an increasing number of children living in urban areas. Urban children, compared to children from rural areas, are generally exposed to higher levels of a number of environmental hazards such as air pollution, noise and heat, and have limited access to natural environments, including green spaces. At the same time, urban lifestyle is predominantly associated with lower levels of physical activity and higher exposure to crime and psychological stress. Contact with green spaces, on the other hand, is thought to have a defining role in human brain development. An accumulating body of evidence has also associated such contact with improved mental and physical health in children. This chapter aims to present a synopsis of the current state-of-the-art of research linking green space and child health and development. Towards this aim, we (1) elaborate on potential mechanisms underlying health effects of green spaces, (2) highlight the importance of prenatal and postnatal periods as windows of vulnerability, and (3) provide an overview of the available evidence on effects of green spaces on (a) pregnancy outcomes, (b) brain development including structural brain development, as well as behavioural and cognitive development, (c) respiratory and allergic conditions, and (d) cardiometabolic risk factors.

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Highlights
- Pre- and postnatal periods are important windows of vulnerability.
- Contact with green spaces is associated with improved pregnancy outcomes.
- Green spaces are beneficial for child brain (cognitive and behavioural) development.
- There is inconsistent evidence on the association with respiratory and allergic conditions.
- There is inconsistent evidence on the association with obesity and physical activity.

6.1 Potential Mechanisms

Mechanisms through which green spaces could exert their health benefits for foetuses and children are yet to be established. However, stress reduction; increase in social contacts and cohesion; enhanced physical activity; mitigation of urban-related environmental hazards such as air pollution, noise and heat; and enrichment of environmental microbiota have been suggested to play a role. The available evidence is still limited. Of the aforementioned mechanisms, mitigation of air pollution has been investigated the most. A study of 52 pregnant women in Barcelona, Spain, reported that higher residential surrounding greenness was associated with lower personal exposure to particulate air pollution, as measured by personal monitors (Dadvand et al. 2012). Another study reported that higher greenness within and surrounding 39 schools in Barcelona, Spain, was associated with lower indoor (e.g. classroom) and outdoor (e.g. yard) levels of traffic-related air pollution in these schools (Dadvand et al. 2015b). A second study of schoolchildren from these schools showed that 20–65% of the associations between school greenness and cognitive development could be explained by lower air pollution levels (Dadvand et al. 2015a). However, other studies did not support a mediatory role of air pollution in the associations between green spaces and foetal growth and blood pressure in children (Dadvand et al. 2012b; Hystad et al. 2014; Markevych et al. 2014a, b).

A study from Finland reported that adolescents living in more natural areas with higher biodiversity had richer skin microbiota, which in turn was associated with lower risk of atopy through improved immunoregulation (Hanski et al. 2012). Similarly, higher surrounding greenness was related to fungi diversity and variation in house dust in Germany (Weikl et al. 2016), which in turn was associated with lower risk of wheezing in children (Tischer et al. 2016). Improved immunoregulation induced by an enriched environmental microbiome in green spaces has not only been suggested to reduce the risk of allergic conditions but has also been postulated to enhance brain development (Rook 2013). Few studies have proposed physical

activity as another potential mechanism underlying the aforementioned associations (Banay et al. 2017). The potential mediatory role of other factors such as stress (Markevych et al. 2014a), noise and heat exposure and social contact are yet to be investigated.

6.2 Pregnancy and Childhood as Important Windows of Vulnerability

An accumulating body of evidence has documented the especial vulnerability of foetuses and infants to the effects of socio-environmental factors (Nieuwenhuijsen et al. 2013). Accordingly, pregnancy and childhood are increasingly recognised as particularly influential for shaping health over the course of life (Hines et al. 2009). The influence of exposures during these periods is not limited to reproductive and childhood outcomes and can extend over a lifetime, as stated by the Developmental Origins of Health and Diseases (DOHaD) concept (Barker 1995; Gluckman and Hanson 2006). DOHaD suggests that environmental exposures during the prenatal and early postnatal periods may permanently alter the body's physiology, metabolism and structure, and that such changes can promote disease long after the environmental exposure has ceased (Hanson et al. 2016). In this context, the ability of green spaces to promote health and development of foetuses and children and to mitigate adverse health effects of urban-related environmental hazards such as air pollution, noise and heat could have lifelong implications.

6.3 Pregnancy Outcomes and Complications

Among different pregnancy outcomes and complications that have been evaluated in relation to maternal exposure to green spaces, the association with foetal growth was the most consistent (Banay et al. 2017; Dzhambov et al. 2014). Higher greenness surrounding maternal residences has been associated with higher birth weight, higher head circumference, lower risk of low birth weight and lower risk of small-for-gestational age (Banay et al. 2017; Dadvand et al. 2012a, b, 2014b; Dzhambov et al. 2014). Although less consistently shown in the literature, green spaces have been associated with longer gestational age at delivery and lower risk of preterm birth (Banay et al. 2017). A limited body of evidence has associated green spaces with a lower risk of pregnancy complications such as pre-eclampsia, gestational diabetes and peripartum depression (Banay et al. 2017). These associations have been suggested to be stronger among women of lower socio-economic status (Banay et al. 2017). A study from England reported that while for Caucasian British mothers there was a beneficial association between residential green spaces and birth weight, there was no such association for British mothers of Pakistani origin

(Dadvand et al. 2014b). This highlights a potential role of ethnicity in the association between green spaces and foetal growth.

6.4 Brain Development

The Biophilia hypothesis suggests that humans have essential evolutionary bonds to nature (Kellert and Wilson 1993; Wilson 1984). Accordingly, contact with nature, including green spaces, has been postulated to be crucial for brain development in children (Kahn 1997; Kahn and Kellert 2002). The brain develops steadily during the prenatal and early postnatal periods, which are considered to be the most vulnerable windows for environmental influences (Grandjean and Landrigan 2014). Upbringing in urban areas where children often have limited access to green spaces has been associated with a higher risk of neurodevelopmental disorders such as attention deficit hyperactivity disorder (ADHD) (Skounti et al. 2007) and autism spectrum disorders (Williams et al. 2006). Green spaces, in contrast, have been associated with short-term improvements in different brain functions, as well as enhanced development of these functions in the long term.

Earlier studies on the potential effects of contact with green spaces on brain function were mainly experimental studies evaluating short-term 'therapeutic' effects in ADHD children (Kuo and Taylor 2004; Schutte et al. 2017; Taylor and Kuo 2009; Taylor et al. 2001; van den Berg and van den Berg 2011). They mainly compared the effects of playing in indoor environments or urban settings in comparison to green spaces, and showed that the latter could improve attentional function and reduce ADHD symptoms. Later cross-sectional epidemiological studies evaluated the long-term association between green spaces and behavioural and emotional problems among healthy children (Aggio et al. 2015; Amoly et al. 2014; Feng and Astell-Burt 2017; Markevych et al. 2014c; Younan et al. 2017; Zach et al. 2016). They mainly characterised behaviour using the Strengths and Difficulties Questionnaire (SDQ), and associated nearby green spaces or time spent in them to lower risk of behavioural problems such as hyperactivity/inattention, conduct problems, emotional symptoms, peer relationship problems and aggressive behaviour. One cross-sectional study reported improved self-discipline associated with better visual access to green spaces from home (Taylor et al. 2002). A recent ecological study in 543 elementary schools in the USA reported lower prevalence of autism in schools with more green spaces (Wu and Jackson 2017). Another similar ecological study reported that more green spaces at primary schools were associated with better performance of students in math and English exams (Wu et al. 2014). Recently, longitudinal epidemiological studies have prospectively evaluated the association between long-term contact with green spaces and cognitive development (Dadvand et al. 2015a, 2017). They used repeated computerised tests to characterise cognitive function, and reported that more green space surrounding the residential address or at school was associated with improved cognitive functions including working memory and attention. A very recent study utilised magnetic resonance imaging of

brain structure to assess whether lifelong exposure to green space surrounding the residential address was associated with beneficial structural changes in the developing brain in 253 urban schoolchildren (Dadvand et al. 2018a). This study detected that such exposure was associated with an increase in grey matter volume in the prefrontal and premotor cortices and an increase in white matter volume in the prefrontal, premotor and cerebellar regions. These structural changes were in turn associated with improved working memory and reduced inattentiveness. These findings provide novel evidence that long-term contact with green spaces is associated with beneficial and potentially lasting changes in brain structure.

6.5 Respiratory and Allergic Conditions

The available evidence on the effects of green spaces on asthma and allergic conditions in children is inconsistent (Lambert et al. 2017). While a number of studies have reported a higher risk of allergic conditions and exacerbation of asthma in children in relation to green spaces (Dadvand et al. 2014a; DellaValle et al. 2012; Fuertes et al. 2016; Lovasi et al. 2013), others have shown no or even protective associations (Dadvand et al. 2014a; Fuertes et al. 2016; Hanski et al. 2012; Lovasi et al. 2008; Müller-Rompa et al. 2018; Pilat et al. 2012; Tischer et al. 2017, 2018). These inconsistencies reflect the potential conflicting functions of green spaces in relation to these health outcomes. For example, green spaces can increase the risk of asthma and allergic conditions through releasing allergic pollens (DellaValle et al. 2012; Lovasi et al. 2013) and fungal spores (Bartra et al. 2009; De Linares et al. 2010), or through pesticides or fertilisers used for green space maintenance (Corsini et al. 2012; see also Damialis et al. Chap. 3, this volume). On the other hand, green spaces can prevent these conditions through enriching environmental biodiversity, mitigating exposure to air pollution and, to a lesser extent, encouraging physical activity and reducing the risk of obesity (Hanski et al. 2012; Lovasi et al. 2008; Pilat et al. 2012). The heterogeneity in the available literature could also have been, in part, due to the poor metrics that did not take into account the differential allergenicity of different vegetation species or seasonal variation in their allergenic properties. Different types of green spaces (e.g. parks vs. forests) and different climates/settings could also be contributing factors to such a heterogeneity. For example, a study from Spain reported that residing close to urban parks was associated with a higher risk of concurrent asthma and allergic rhinoconjunctivitis, while residing close to natural green spaces (e.g. forests) was not (Dadvand et al. 2014a). Another study that evaluated the impacts of green spaces on respiratory outcomes reported different impacts across two bio-geographic regions in Spain (Tischer et al. 2017). In the Euro-Siberian region, characterised by a humid climate with water availability throughout the year, cold winters and maximum vegetation during summer months (Alcaraz-Segura et al. 2009), green spaces were negatively associated with wheezing. In the Mediterranean region, characterised by an arid climate with hot and dry summers, mild and rainy winters, and maximum vegetation between

autumn and spring (Alcaraz-Segura et al. 2009), living closer to green spaces was associated with a reduced risk of bronchitis. Similarly, a study including seven birth cohorts from across Europe, Australia and Canada has reported heterogeneous associations for different regions (Fuertes et al. 2016). While the association between green spaces and allergic rhinitis was positive in Sweden and Southern Germany, it was negative in Northern Germany and the Netherlands. For the Australian and two Canadian cohorts, no associations were observed. A similar pattern was observed for aeroallergen sensitisation (Fuertes et al. 2016). Further research with more refined green space assessment is warranted in this field.

6.6 Cardiometabolic Risk Factors

Living in a green neighbourhood or close to green spaces has been postulated to increase physical activity or, in other terms, reduce sedentary behaviour (see Cook et al. Chap. 11, this volume). However, the available evidence is not conclusive and there are inconsistencies in the reported direction and strength of associations (Lachowycz and Jones 2011; Markevych et al. 2017; McGrath et al. 2015). The main reason for this inconsistency could be the fact that the majority of these studies have only focused on the mere presence of green spaces without taking into account their quality aspects. Aesthetics, walkability, biodiversity, availability of sport/play facilities, organised social events and perceived safety have all been suggested to affect the use of green spaces for physical activity (McCormack et al. 2010). For children and their parents, the perceived safety and crime rate in the neighborhood are main determinants of their outdoor physical activity (Sullivan et al. 2017). Moreover, most studies have relied on the mere presence of green spaces without taking into account whether they are actually accessible. Some green spaces are not open to the public at all or have restricted access. The methods with which physical activity was measured can be another source of the observed heterogeneity. While some studies have applied objective measures of physical activity (e.g. personal monitors), others have relied on questionnaires to obtain data on physical activity. Each of these methods has strengths and limitations.

In addition to the association between residential green spaces and physical activity, studies have also evaluated how active children were while in green spaces (McCrorie et al. 2014). These studies mainly relied on Global Positioning Systems and accelerometers to objectively characterise time-activity patterns and the locations. They revealed that children are more likely to engage in moderate-to-vigorous physical activity while they are in green spaces, and such an activity accounts for a notable part of the total moderate-to-vigorous physical activity that a child might perform (McCrorie et al. 2014).

Similar to physical activity, the available evidence on the association between green spaces and obesity is not conclusive yet (Gascon et al. 2016). For other cardiometabolic risk factors, the available evidence for a potential influence of

green spaces is very scarce (Markevych et al. 2014b, 2016; Thiering et al. 2016). A cross-sectional study of 10-year-old children in Germany reported higher blood pressure in children living in less green areas (Markevych et al. 2014b). A longitudinal study following the same cohort of children for 5 years did not find any association between residential green spaces and blood lipids (Markevych et al. 2016). Very recently, a study of a population-based sample of around 4,000 school children in Iran found a beneficial association between time spent in green spaces and fasting blood glucose levels (Dadvand et al. 2018b). These findings were in line with those of an earlier German study that reported an inverse association between residential green spaces and insulin resistance (Thiering et al. 2016). Further studies are required to investigate the effects of green spaces on cardiometabolic risk factors such as sedentary behaviour, obesity, dyslipidemia, hyperglycaemia and hypertension.

6.7 Final Remarks

Currently, about half of the world's population lives in cities (UN Department of Economic and Social Affairs 2015). By 2050, almost two-thirds of the global population are projected to live in urban areas (UN Department of Economic and Social Affairs 2015). Urban dwellers often have higher exposure to environmental hazards, limited access to green spaces, and a more sedentary and stressful lifestyle. Not surprisingly, urban children have been reported to be more likely to suffer from neurodevelopmental problems such as ADHD and autism spectrum disorders than rural children (Skounti et al. 2007; Williams et al. 2006). An accumulating body of evidence supports the potential of green spaces for mitigating and buffering the adverse impacts of urban living on child health and development. So far, green spaces have been consistently associated with brain development and foetal growth. The available evidence for preterm birth, obesity, respiratory and allergic conditions has remained relatively inconsistent. Similarly, while there is heterogeneity in the reported associations between access to green spaces and physical activity, available studies suggest higher levels of physical activity while the children are in green spaces. Few studies exist for other outcomes such as dyslipidemia, hyperglycaemia, hypertension and pregnancy complications (e.g. pre-eclampsia or diabetes). Moreover, to date, the vast majority of the studies on the effects of green spaces on child health and development have been conducted in high-income countries. As ethnicity, climate and lifestyle might modify such effects, the generalisability of studies from these countries to the rest of the world could be limited. There is a need for more studies in low- and middle-income countries. Although further research is needed, all in all, the body of evidence on the effects of green spaces on child health and development highlights the importance of providing children with a natural and biodiverse environment, enabling them to better grow and thrive in our rapidly urbanising world.

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