Review

Mohammad Zahirul Islam*, Jessika Johnston and Peter D. Sly

Green space and early childhood development: a systematic review

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Abstract

Background: The urban environment presents significant health challenges for children, such as discouraging physical exercise and increasing exposure to air pollution, excessive noise and higher temperatures. Reducing exposures to these negative environmental factors can have great benefits on a child’s well-being and lower their risk of developing chronic diseases later in life. There is increasing evidence that suggests that the presence of urban green space can offer benefits to human health and well-being. While studies have reported the impact green space exposure has on the individual health outcomes of children, few have paid attention to the link between green space and the child’s development. This review aims to synthesise the evidence of the effect green space exposure has on early childhood development.

Objectives: To explore the relationship between green space and early childhood development.

Methods: An online search was conducted using pre-identified keywords related to green space and early childhood development using search engines such as PubMed, MEDLINE, Web of Science, MeSH and PsycINFO. Peer-reviewed papers published in the past 10 years were included in this review. Papers were selected, extracted, analysed and interpreted based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Results: Fifty-one papers were identified, of which 28 were excluded due to duplications or irrelevance, yielding a total of 23 papers to be reviewed. Articles were categorised based on reported outcomes: perinatal health, physical health, psychological health and respiratory health. An increase in green space during pregnancy was associated with increased birth weight and a decreased risk for low birth weight (LBW). Further, higher greenness exposure during childhood was associated with increased levels of physical activity and a lower risk of obesity and neurodevelopmental issues such as inattentiveness. While green space exposure was negatively associated with wheezing and bronchitis in some cohorts, certain plant species increase asthmatic symptoms during childhood, indicating that plant species type is an important determinant.

Conclusion: The extant literature on green space exposure and early childhood development is small. Regardless, the existing research provides promising insights into the benefits of green space exposure on children’s health and well-being in an ever-increasing urban world. Further research is needed on the causal relationships between both quantity and quality of green space to early childhood development.

Keywords: greenness; neuro-behavioural health; neuro-development; perinatal health; physical activity; respiratory health.

Introduction

Unique to our time, more than half the world’s population live in urban areas – including over 1 billion children (1). The urban environment presents significant health challenges, such as discouraging physical exercise and increasing exposure to air pollution, noise and higher temperatures through urban heat island effects (2). Among those exposed to the adverse effects of the urban environment, children are particularly vulnerable because of their developing organ systems and behavioural interaction with their environment. Further, environmental exposures in early life can increase the lifelong risk of chronic disease (3). There is a growing body of
evidence that suggests that the presence of urban green space offers benefits to human health (4). Green space comprises urban land that is covered in natural vegetation, such as parks, forests, wetlands and other ecosystems, and can facilitate physical activity, social cohesion, relaxation and a buffer from noise and air pollution (5). The importance of urban green spaces is acknowledged in the United Nations Sustainable Development Goals, outlined in goal 11.7.

“By 2030, provide universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities” (6). A number of literature reviews have examined the effects of green space on a broad range of health outcomes, such as mortality risk, obesity and mental health (7); however, there is no systematic review synthesising the evidence of the health effects of green space particularly on early childhood development which encompass physical, socio-emotional, cognitive and motor development. This systematic review aims to identify the updates and compiling the evidence that draws an association between exposure to green space and early childhood development, including the perinatal period, and explores the underlying mechanisms on how green space impacts human health at this stage of life.

Objectives

This systematic review was designed to identify the associations between green space exposure and early childhood development.

Methods

Search strategy

Following Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, potentially relevant articles were identified by searching the medical electronic databases PubMed, MEDLINE, Web of Science, MeSH and PsycINFO. The pre-identified keywords related to green space and early childhood development included ‘green space’ OR ‘greenness’ AND ‘health’ AND ‘maternal’ OR ‘maternity’ OR ‘pregnancy’ OR ‘birth’ AND ‘children’ OR ‘infants’ OR ‘newborn’. Furthermore, additional papers were identified by scanning the reference list of appropriate studies. Results were restricted to peer-reviewed articles and to those published in the last 10 years as an initial thorough scanning of the reference and search indicated to limit till then, resulting in 51 papers.

Selection criteria

Papers must have examined associations between exposure to green space during a child’s early years, including the perinatal period, and health and development outcomes. Resulting papers were screened for eligibility. Of the 51 papers, 28 were excluded due to duplications or irrelevance (Figure 1), resulting in 23 papers deemed eligible for the review. Findings from the literature were separated into categories such as perinatal health, physical exercise, neurodevelopmental health and respiratory health.

Figure 1: Flow diagram of the literature search.
Figure 1 shows the flow diagram of the selection of the papers.

Data extraction

The review authors independently scanned the title and abstract of all the relevant literature to determine the outcome of interest of each paper. Papers were then grouped according to their outcomes – perinatal health, physical exercise, neurodevelopmental health and respiratory health – and their methods and findings were summarised (Table 1). Variables such as green space, pregnancy, birth weight, head circumference, socioeconomic status, education, obesity, memory, attentiveness and wheezing were specially extracted for the review.

Results

Perinatal health

Eleven of the studies identified in this review focused on the association between maternal green space exposure and perinatal health. Among these, three are from the USA and one each from Israel, Spain, Lithuania, Canada, Germany, France, Scotland and New Zealand. Study methods generally use birth registries that record birth outcomes, such as birth weight and gestational age, and mothers’ residential address at birth, eliminating the chances of biases. Increases in measures of surrounding greenness were consistently associated with increased birth weight and a decreased risk for low birth weight (LBW) and very low birth weight (VLBW) (8–14), which remained statistically significant after adjusting for confounders. Conversely, Glazer et al. (15) reported that close proximity to green space and the coast was associated with higher birth weight; however, these effects go away when adjusted with confounders [mother’s age, body mass index (BMI), pets, environmental tobacco smoke, education, etc.], an increase in green space within 200 m of residence during pregnancy was associated with a decreased risk of AD [odds ratio (OR): 0.996, 95% CI: 0.993–0.999] at 6 months of age. All the studies included in this review that examined associations between green space exposure and perinatal health involved adjusting for maternal socioeconomic status (12). However, to the best of authors’ knowledge, the French study by Kihal-Talantiki et al. is the only study that investigated the spatial relationship between green space exposure, socioeconomic deprivation level and infant mortality. The study found that spatial variation of deprivation level and greenness index have similar patterns. Further, both variables were correlated with infant mortality rates with the most likely cluster of high infant mortality coinciding with more deprivation and less green space exposure (13).

Furthermore, examining the effects of urban residential distance from city parks on birth outcomes, Grauzuleviciene et al. (10) suggested that living farther from parks has a negative effect on birth outcomes such as the increased risk of preterm birth and decreased gestational age. Based on the normalised difference [normalised difference vegetation index (NDVI)-500 < median] and the distance to city parks (>1000 m), the study found increased risks for LBW (OR: 2.23, 95% CI: 1.20–4.15), term LBW (OR: 2.97, 95% CI: 1.04–8.45) and preterm birth (OR: 1.77, 95% CI: 1.10–2.81) for subjects with low surrounding greenness and farther distance from a city park. Moreover, the study found that the effects do not differ between surrounding greenness levels of 100, 300 and 500 m from...
the maternal residence (10). Greenness is determined by using the NDVI, which is an index providing a measure of vegetation density and condition.

**Physical activity**

Four of the studies in this review examined the associations between green space exposure and childhood physical activity. These studies were conducted in Scotland, the USA and Australia and used anthropometric outcome measurements such as BMI and skinfolds. Considering the nature of studies that seek to investigate physical activity levels, the studies in this review were predominantly retrospective experimental studies, e.g. measuring with physical activity monitors. This means that they were subject to reactivity, in which the participants change their behaviours in response to the experiment, and therefore is a possible threat to the studies’ external validity (17–20). In examining the impacts of the built environment and green space exposure on childhood BMI changes over 2 years, Bell et al. found that participants who lived in closer proximity to green space had significantly lower BMI z-scores. Further, children

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**Table 1: Summary of findings according to categories.**

| Outcomes               | Number of studies | Study designs                | Findings                                                                                                                                                                                                 |
|------------------------|-------------------|------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Perinatal health       | 11                | 3 Prospective cohorts (n=2393; 3292; 659) 8 Cross-sectional (birth records) (n=39,132; 16,913; 3,026,603; 61,640; 64,705; 3203; 5091; one study did not mention any specific number) | - Increased maternal exposure to green space associated with increased birth weight and head circumference  
- Maternal exposure to green space in urban environments associated with a decreased odds of preterm and small-for-gestational age births and decreased risk of infant atopic dermatitis  
- No association observed with additional green space exposure and perinatal health in communities with higher absolute levels of green space  
- Beneficial associations generally stronger among mothers of lower socioeconomic status and lower education attainment level  
- No association between maternal residential distance from green space and physical exercise during pregnancy  
- Confounding variables include maternal socioeconomic status, ethnicity and education attainment levels |
| Physical exercise      | 4                 | Retrospective (n = 3831) Prospective (n = 3586; 4423) Cross-sectional (n = 428) | - Increased childhood exposure to neighbourhood green space associated with higher levels of physical activity, a lower risk of overweight and obesity and less television time  
- Positive associations between increased exposure to green space and increased physical activity levels stronger for boys compared to girls  
- Associations are not constant across childhood but becomes evident as age increases |
| Neuro-behavioural health | 5                | Prospective cohort (n = 1875; 2954) Cross-sectional (n = 1668; 253); one study did not mention any specific number | - Childhood exposure to green space positively associated with better physiological health including memory, attentiveness and emotional well-being  
- Green space exposure positively associated with brain volume development in areas related to better working memory and reduced inattentiveness  
- Differing results observed among children of mothers with low education levels compared to those of mothers with high education levels, demonstrating that green space may only be beneficial to the former |
| Respiratory health      | 3                 | Prospective cohort (n = 466; 65,000; 2472) | - Exposure to certain pollens produced from green space can increase the risk of asthmatic symptoms during childhood  
- Exposure to residential green space in urban environment associated with less wheezing and other respiratory conditions depending on the green space type and quality |
who lived closer to natural vegetation had a lower odds of increasing BMI over the 2 years (OR: 0.87, 95% CI: 0.79–0.97) (18).

Lovasi et al. (19) investigated the environmental correlates of physical activity with socioeconomically disadvantaged children and found that measures of green space had statistically significant associations with more physical activity (19). In addition, disadvantaged children who lived in areas with a higher street tree density had lower BMI z-scores (95% CI: −0.04, −0.19 to 0.11) and lower skinfold thickness (95% CI: −0.6, −1.4 to 0.2) and children living in areas with more access to city parks had smaller skinfolds [a decrease of 1.0 mm for each standard deviation (SD) increase in park access] (8, 19). Using data collected in the Longitudinal Study of Australian Children, Sanders et al. concluded that exposure to higher levels of green space may be a protective factor against childhood overweight and obesity. After adjusting for family socioeconomic status, they found an association between green space exposure and children’s BMI scores that were statistically significant for boys (p = 0.009) but the effect is weaker in girls (p = 0.048). This finding suggests that sex is a modifying factor. Further, while there was an apparent inverse relationship between neighbourhood green space and high child BMI scores, associations are not constant across childhood but become evident in older children (20).

Aggio et al. (17) conducted a study in Scotland to determine the associations between mothers’ perception of residential distance from green space and their child’s TV viewing time, which can be an impeding factor on children’s physical activity levels. The study found that TV viewing time was significantly higher among children who lived more than 20 min of walking distance from green space compared to those in the less than 5-min walking distance category. Further, those who lived further from green space had worse mental health scores [mean Strengths and Difficulties Questionnaire (SDQ) score ± SD, 7.0 ± 4.6 vs. 8.7 ± 6.2], worst general health ratings (% fair-poor, 4.6 vs. 8.6) and were taken to parks/playgrounds less often, which possibly resulted in less engagement in physical activity (17).

**Neuro-behavioural health**

Five of the studies identified in this review examined the association between green space exposure and psychological health among children. Studies were conducted in Lithuania, Spain (three studies) and the UK.

Balseviciene et al. (21) assessed the effects of residential proximity to city parks and surrounding greenness on children’s emotional and behavioural problems (21). The study found that living farther from city parks and residential green space levels was positively associated with higher levels of children’s mental health problems. Regression models found strong associations between the variables (p < 0.0001). Low levels of maternal education were found to be a strongly associated covariate as a positive relationship between proximity to parks and children’s mental health problems was observed. However, among the higher maternal education group, more residential greenness was associated with more emotional and behavioural problems and less prosocial behaviour. Conversely, no significant association between hyperactivity and residential greenness was found with this maternal education group (21).

Dadvand et al. (22) conducted a study in Spain and examined whether long-term exposure to green space was associated with differences in brain development in primary school children. Using data from the Brain Development and Air Pollution Ultrafine Particle in School Children (BREATHE) project, the authors examined the association between average NDVI surrounding the participant’s residence, commuting route from home to school and greenness surrounding school and their regional differences in brain volume based on three-dimensional magnetic resonance imaging (3DMRI). Outcome variables were differences in brain volume associated with measures of working memory and inattentiveness. While adjusting for maternal education and neighbourhood socioeconomic status reduced the effect size, findings from the study showed a positive association with lifelong exposure to green space and volume development of areas of the brain that are related to measures of working memory and inversely associated with a measure of inattentiveness in children (22).

With another research team, Dadvand et al. (22) focused on the effects of lifelong exposure to green space on childhood attention. They assessed the attention ability of children living in two residential areas of different vegetation levels. Findings indicated that lifelong exposure to green space was associated with test scores consistent with better attention (p ≤ 0.01), which was maintained after adjusting for confounding variables such as sleep duration, TV viewing time and parental marital and socioeconomic status. However, findings were close to null regarding test scores that are relevant to hyperactivity-impulsivity (p = 0.63) (22).

Dadvand et al. (22) also examined the association between measures of cognitive development in primary school children and their exposure to green space. The study compared the green space exposure of 2623
participants from 36 schools in Barcelona and assessed the amount of green space surrounding participants’ home, commuting route and school. The findings of the study indicated that more green space exposure in these environments was associated with a greater 12-month reduction in inattentiveness and enhanced 12-month progress in working memory and superior working memory. After adjusting for confounders, each IQR surrounding greenness exposure increment was associated with a 1% decrease in inattentiveness, 5% increase in the progress of working memory and a 6% increase in the progress of superior working memory. The strongest associations for greenness was found within or surrounding school boundaries. The research team applied traffic-related air pollution to their models and found that exposure explained 20–65% of the estimated effect (22).

McEachan et al. (23) conducted a study in the Born in Bradford (England) longitudinal cohort, which aimed to explore the associations between green space exposure and mental well-being among children aged 4 years in a multi-ethnic sample. Participants in the study were of varying ethnicities, of which 58% were of South Asian origin, 29% of white British origin and 13% of other ethnicities. The study looked at the associations between participants’ residential distance from green spaces computed with the NDVI and parent-reported mental well-being of their children. The study revealed that increased exposure to green space was associated with fewer internalising behavioural difficulties [buffer zones were: mean NDVI 100 m: β = −2.35 (95% CI: −4.20 to −0.50); 300 m: −3.15 (−5.18 to −1.13); 500 m: −2.85 (−4.91 to −0.80); 1000 m: −4.27 (−7.65 to −0.90); 3000 m: −5.22 (−8.91 to −1.54); 5000 m: −4.82 (−8.57 to −1.07)] among South Asian children (23). However, no associations were observed among white British children, suggesting that the benefits of green spaces on children’s mental well-being are moderated by ethnicity. It is to be noted that the study was conducted in a highly deprived location of the UK and therefore lacked variability between participants’ socioeconomic status. Further, satisfaction with their green space was an independent predictor of South Asian children’s mental well-being, after controlling for confounders, suggesting that the quality and quantity of green space in an important factor for children’s health and well-being (24).

### Respiratory health

Three of the identified studies examined the impact of green space exposure on the respiratory health of children. Studies were conducted in the USA, Canada and Spain (24–26). Dellavalle et al. (24) investigated the relationship between pollen emitted from green spaces, green space exposure and asthma symptoms and medication use among children aged 4–12 years. By assessing the total and separate ambient pollen concentration at each subject’s home, and after adjusting for participants’ severity of respiratory symptoms, Dellavalle et al. (24) found that even low-level exposure to grass or weed pollen was positively associated with daily respiratory symptoms. These findings suggest that sensitive populations, such as asthmatic children, are more at risk for respiratory symptoms when exposed to more green space that emits certain types of pollen (24). In a case-control study conducted in Canada, Shihi et al. (25) investigated the asthma incidence of children who have early-life exposure to residential green space. After adjusting for confounders, they found that during preschool years, children had a decreased risk of asthma per interquartile (0.11) NDVI increase [adjusted OR (aOR): 0.96, 95% CI: 0.93–0.99] (25). These findings were stronger after accounting for co-exposures to air pollutants and road proximity, suggesting that the presence of green space may act as a protective factor from such pollutants. However, this study did not find any association between green space exposure and asthma incidence among children of primary school age. Additional analysis suggested that birth weight modified the effect as increased green space exposure reduced the odds of asthma incidence during preschool years by 44% for children with birth weight <2500 g compared to those weighing ≥2500 g at birth. Further, green space exposure had a greater effect size for children born to mothers with low education levels.

Tischer et al. (26) assessed the effect of three different types of urban environments in Spain on allergic and respiratory conditions in children up to 4 years of age. After adjusting for potential confounders such as maternal education levels, maternal allergies and other possible allergens, e.g. pets at home, they found that compared to residential surrounding greyness (non-natural built-up infrastructure) and residential proximity to green space, higher residential surrounding greenness was statistically significantly associated with a lower risk of wheezing in the Euro-Siberian region (aOR: 0.61, 95% CI: 0.44–0.85), but not in the Mediterranean region (aOR: 0.92, 95% CI: 0.70–1.20). Further, residential proximity to green spaces was negatively associated with wheezing in subjects in the Euro-Siberian region (aOR: 0.67, 95% CI: 0.45–0.99) and with doctor-diagnosed bronchitis among children in the Mediterranean region (aOR: 0.77, 95% CI: 0.61–0.98). Finally, the study found that children growing up around more greyness were at higher risk of suffering...
from bronchitis and wheezing in the Mediterranean areas; however, the association for wheezing was close to null (third tertile vs. first tertile: aOR: 1.58, 95% CI: 1.19–2.08 vs. aOR: 1.29, 95% CI: 0.98–1.70, respectively) (26).

**Discussion**

The body of evidence suggests that green space is associated with better pregnancy outcomes including birth weight, a lower likelihood of LBW and a lower likelihood of preterm birth (16). Evidence shows that children’s contact with the natural environment and its consequence such as physical activity affects their well-being and their health in later life (25). Higher surrounding greenness and parks impact life in many ways, such as increasing physical activity, promoting social interaction and reducing psychological stress and depression. Grazulevicience et al. (10) suggested an association between external environments and health (10). However, this association is stronger in low socioeconomic status and varies by sex and urbanisation although not all these differences are clearly established or explained. The association between an absence of neighbourhood green spaces and worse overall mental health among children is consistent with some other studies, although conducted mainly for adults.

A study conducted by Bowler et al. (27) focused mainly on the short-term effects of green spaces in different age groups suggested that green environments may have positive effects on well-being and emotional health and the psychological health of children (27). In addition, there is evidence supporting the restorative and stress reductive effects of green spaces (28).

Annerstedt et al. (29) found an association between green space exposure, physical exercise and improved mental well-being in Swedish women (29), although a study conducted in Australia by Astell-Burt et al. (30) found that access to green space is specifically beneficial for the mental health of men, and that the importance of green space varied by age (30). Another study conducted by Sugiyama et al. (31) also found that a perceived surrounding greenness is strongly associated with mental health than physical health (31), whereas studies conducted by Triguero-Mas et al. (32), de Vries et al. (33) and Gascon et al. (7) show that a higher exposure to green space has influenced both physical and mental health considering all across socioeconomic strata and genders (32, 33, 7). Annex 1 contains more detail about these selected articles.

The literature highlights that exposure to green space has greater benefits among more deprived populations. This is likely because groups of lower socioeconomic status generally have the worst health, are more likely to participate in unhealthy behaviours and live in areas with more environmental problems. As such, they are more likely to benefit from health-promoting environmental exposures. A follow-up of the longitudinal study of children aged 3–16 years in the USA found an inverse relationship between satellite imagery-based green space and children’s 2-year BMI z-scores tended to be lower in areas with green space (20).

There is, however, a lack of direct evidence for the relation of green space and early childhood development. Early childhood development is important as it guides and shapes the future of an individual particularly physical, mental and cognitive development. This review identified that exposure to green space and greater surrounding green space of a child would have influences for a better physical growth and cognitive development and could reduce disease burden. Consequently, it is important to know further, how and under what conditions the green spaces in the living environment can contribute to childhood development.

**Conclusion**

This review found positive associations between the quantity of green space and birth outcomes, physical activity, psychological health and respiratory health. However, all those benefits may differ according to the individual, age, gender and socioeconomic status. The underlying mechanism(s) of these associations is yet unclear. Furthermore, this review found a positive association between green space exposure and early childhood development. This review strengthens the evidence base on the health benefits of green spaces and provides support for urban planning and public health professionals to build healthy cities incorporating green space for health promotion.

**Author contributions:** Mohammad Zahirul Islam co-designed the study, prepared the methods, created the figures and prepared the first draft of the manuscript. Jessika Johnston designed the study’s analytic strategy, interpreted the results, prepared the tables and provided critical revision of the manuscript. Peter D. Sly conceived and co-designed the study, oversaw the analyses and provided critical revision of the manuscript.

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**Informed consent:** Informed consent is not applicable.

**Ethical approval:** The conducted research is not related to either human or animal use.
### Annex 1: Summary of findings of all 23 articles selected for this systematic review.

| Outcomes          | Author, year     | Location of study                        | Study type/design                                      | Findings                                                                                                                                                                                                 |
|-------------------|------------------|------------------------------------------|--------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Perinatal health  | Agay-Shay et al., 2014 (8) | Tel Aviv, Israel                        | Cross-sectional/registry birth cohort (n = 39,132)     | An increase in measures of surrounding greenness was associated with increased birth weight and a decreased risk for LBW and VLBW No association between maternal measures of surrounding greenness and gestational age, PTD and VPTD |
|                   | Casey et al., 2016 (34) | Pennsylvania, USA                     | Cross-sectional/electronic health record data from 2006 to 2013 (n = 16,913) | In cities only, higher levels of green space were associated with a decreased odds of preterm and small-for-gestational age births In communities with higher absolute levels of green space, additional greenness does not benefit neonate health |
|                   | Cusack et al., 2017 (35) | Texas, USA                            | Cross-sectional/birth records from 2000 to 2009 (n = 3,026,603) | Unadjusted results demonstrated protective effects of residential greenness on adverse birth outcomes; however, associations attenuated when adjusting for maternal and paternal race, ethnicity and education |
|                   | Dadvand et al., 2012 (9) | Four biogeographical regions of Spain    | Prospective cohort (n = 2393)                           | Increased maternal exposure to surrounding greenness was associated with increased birth weight and head circumference. No statistical significance with surrounding greenness and gestational age Stronger association among children of mothers with low and moderate levels of education |
|                   | Glazer et al., 2018 (15) | Rhode Island, USA                      | Cross-sectional/birth records from 2001 to 2012 (n = 61,640) | In unadjusted models green space exposure was associated with a slightly lower risk of preterm birth, higher birth weight and lower risk of small for gestational age After adjustment for patient demographics and markers of individual SES, higher NDVI was associated with a higher risk of preterm birth and a small, but still a statistically significant, increase in birth weight and decrease in risk of SGA Living close to freshwater was associated with higher birth weight but not associated with risk of preterm birth or SGA, and proximity to coast was not associated with any outcome |
|                   | Grazuleviciene et al., 2015 (10) | Kaunas, Lithuania                      | Prospective cohort (n = 3292)                           | An increase in distance to city parks was associated with an increase in risk of preterm birth, low birth weight and term low birth weight No statistically significant associations between surrounding greenness level of 100-, 300- and 500-m buffer sizes and birth outcomes |
|                   | Hystad et al., 2014 (11) | Vancouver, Canada                      | Cross-sectional/vital statistics data retrieval (n = 64,705) | Increase in green space exposure and decreases in the likelihood of small for gestational age, very preterm and moderately preterm birth No change in association after adjusting for built environment factors, such as air pollution and noise exposures, neighbourhood walkability and park proximity |
| Outcomes       | Author, year       | Location of study | Study type/design                               | Findings                                                                 |
|---------------|--------------------|-------------------|------------------------------------------------|--------------------------------------------------------------------------|
|               | Ji-Young et al.,   | Republic of Korea | Prospective cohort and                          | The risk of infantile AD significantly increased with an increase in air | during the first trimester of pregnancy An increase in the green space |
|               | 2018 (12)          |                   | cross-sectional (n = 659)                      | pollution exposure during the first trimester of pregnancy An increase | within 200 m of residence was associated with a decreased risk of AD |
|               |                    |                   |                                                | An increase in the green space within 200 m of residence was associated | of AD                                                                 |
|               |                    |                   |                                                | with a decreased risk of AD                                              |
|               | Kihal-Talantikite  | Lyon, France      | Cross-sectional                                 | Neighbourhood greenness level and socioeconomic deprivation explain part | the spatial distribution of infant mortality                           |
|               | et al., 2013 (13)  |                   |                                                | of the spatial distribution of infant mortality                           |
|               | Markevych et al.,  | Munich, Germany   | Cross-sectional (n = 3203)                     | Birth weight was positively associated with surrounding greenness within | Birth weight was positively associated with surrounding greenness |
|               | 2014 (14)          |                   |                                                | a 500-m buffer around the residence at birth; however, no association | within a 500-m buffer around the residence at birth; however, no |
|               |                    |                   |                                                | found in regard to neighbourhood green spaces in the same buffer        | association found in regard to neighbourhood green spaces in the  |
|               |                    |                   |                                                | After adjusting for maternal education, the association between        | same buffer                                                          |
|               | Nichani et al.,    | New Zealand       | Cross-sectional (n = 5091 mother-newborn       | Exposure to green space for women in general is not beneficial in       | Birth weight was only significant for those with less than 10 |
|               | 2017 (16)          |                   | pairs)                                        | increasing birth weight and gestational age                              | years of education                                                   |
|               |                    |                   |                                                | Increased green space exposure was associated with increased gestational| Increased green space exposure was associated with increased gestational |
|               |                    |                   |                                                | age, but not birth weight, for participants with a low level of        | age, but not birth weight, for participants with a low level of |
|               |                    |                   |                                                | education. No association was found between green space exposure and    | education. No association was found between green space exposure  |
|               |                    |                   |                                                | gestational age and birth weight for mothers with a high level of      | and gestational age and birth weight for mothers with a high level |
|               |                    |                   |                                                | education. Exposure to green space was not associated with physical     | education. Exposure to green space was not associated with          |
|               |                    |                   |                                                | activity during pregnancy for the whole cohort, irrespective of their   | physical activity during pregnancy for the whole cohort,           |
|               |                    |                   |                                                | level of education                                                      | irrespective of their level of education                           |
| Physical      | Aggio et al.,      | Scotland          | Prospective longitudinal                       | Children living the furthest distance from green/ open spaces (>20 min  | displayed over 2 h more weekly TV time than the reference category  |
| activity      | 2015 (17)          |                   | cohort (n = 3586 children aged 5.9 years)      | of walking distance) displayed over 2 h more weekly TV time than the   | (<5 min of walking distance) Compared to children in the reference  |
|               |                    |                   |                                                | reference category (<5 min of walking distance) Compared to children in  | category, those in the >20-min category had worse                           |
|               |                    |                   |                                                | the reference category, those in the >20-min category had worse          | mental and general health and were more likely to be from a low    |
|               |                    |                   |                                                | mental and general health and were more likely to be from a low         | socioeconomic group household                                       |
|               | Bell et al., 2008  | Indiana, USA      | Retrospective cohort (n = 3831)                | Higher greenness was significantly associated with a lower BMI and      | Higher greenness was significantly associated with a lower BMI and  |
|               | (18)               |                   |                                                | lower odds of children and youth increasing their BMI scores over the   | lower odds of children and youth increasing their BMI scores over  |
|               |                    |                   |                                                | 2-year period                                                          | the 2-year period                                                    |
|               |                    |                   |                                                | Higher residential density was not associated with BMI scores in models  | Higher residential density was not associated with BMI scores in    |
|               |                    |                   |                                                | regardless of greenness                                                | models regardless of greenness                                       |
| Outcomes                  | Author, year  | Location of study     | Study type/design       | Findings                                                                                                                                                                                                 |
|--------------------------|---------------|-----------------------|-------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                          | Lovasi et al., 2011 (19) | New York, USA        | Cross-sectional (n = 428) | Children living in areas with more street trees were more physically active and those living in areas with more park access had smaller skinfolds                                                                 |
|                          | Sanders et al., 2015 (20) | Australia            | Longitudinal cohort (n = 4423) | While there is an apparent inverse relationship between neighbourhood green space and high child BMI scores, associations are not constant across childhood, but become evident as they grow older. This is further modified by gender, with stronger associations with boys rather than girls. There is little additional benefit beyond a modest quantity of green space |
| Neuro-behavioural health | Balseviciene et al., 2014 (21) | Kaunas, Lithuania  | Cross-sectional (n = 1468 mothers of children aged 4–6 years) | For children who lived in urban environments and whose mothers had lower education levels, living farther from city parks was associated with worse mental health problems. However, more residential greenness was associated with more emotional and behavioural problems and less prosocial behaviour in the higher maternal education group. Conversely, no significant associations between hyperactivity and residential greenness were found with this maternal education group |
|                          | Dadvand et al., 2018 (22) | Barcelona, Spain     | Cross-sectional/cohort (n = 253) | Exposure to green space throughout childhood, and thus during brain development, was positively associated with volume development of areas of the brain that are related to measures of working memory and inversely associated with a measure of inattentiveness |
|                          | Dadvand et al., 2017 (36) | North-eastern and eastern Spain | Prospective cohort (n = 1875) | Higher lifelong residential surrounding greenness was associated with results on computer-based tests that are consistent with better attention |
|                          | McEachan et al., 2018 (23) | Bradford, UK         | Prospective cohort (n = 2954) | More green space was associated with fewer internalising behavioural difficulties as well as less total behavioural difficulties for the South Asian participants, but not the British participants. Associations were found for each buffer zone, suggesting that distance to green space was not associated with child’s mental well-being. When analysing ‘satisfaction of’ and ‘use of’ green spaces, only satisfaction was associated with child’s mental well-being. No moderation of effects from socioeconomic status was found. Study suggestions that quality, as well as quantity, of green space is important for children’s mental well-being |
|                          | Dadvand et al., 2015 (37) | Barcelona, Spain     | Prospective cohort (n = 2954) | Exposure to surrounding greenness at school, home and during commuting was associated with enhanced indicators of working memory and reduction in inattentiveness in schoolchildren. The strongest associations for greenness was found within or surrounding school boundaries |
### Annex 1 (continued)

| Outcomes                  | Author, year | Location of study                  | Study type/design      | Findings                                                                                                                                 |
|---------------------------|--------------|------------------------------------|------------------------|------------------------------------------------------------------------------------------------------------------------------------------|
| Respiratory health        | Dellavalle et al., 2012 (24) | Connecticut, southcentral Massachusetts, and New York State | Prospective cohort (n = 466) | Higher risk of respiratory symptoms, wheeze, shortness of breath, persistent cough and rescue medication use with exposures to weed pollen as low as 6–9 grains/m³ exist with sensitive populations (i.e. maintenance-medication users sensitised to a particular allergen) Odds of experiencing asthmatic symptoms also tended to decline with the highest quintile of exposure, which may indicate some behavioural modification when pollen concentrations are very high |
|                           | Sbihi et al., 2015 (25)      | British Columbia, Canada            | Prospective birth cohort (n = 65,000) | Study found that the majority of incident asthma occurred during preschool years, a period during which greenness surrounding the residential address was associated with reduced incidence |
|                           | Tischer et al., 2017 (26)    | Spain                              | Prospective cohort (n = 2472) | Higher residential surrounding greenness and higher proximity to green spaces were negatively associated with wheezing among the children from the Euro-Siberian region Higher residential proximity to green spaces was associated with a reduced risk for bronchitis in the Mediterranean region. However, a higher amount of residential surrounding greyness found to increase the risk for bronchitis in this region; it means that the type and quality of green space plays an important factor for respiratory symptoms |

PTD, preterm delivery; VPTD, very preterm delivery; SGA, small for gestational age; SES, socioeconomic status; TRAP, traffic-related air pollution.

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