Greenspace and human health: An umbrella review

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Graphical abstract

Living in greener place

- Mortality
- Mental disorders
- Cardiovascular diseases
- Low birth weight
- Blood pressure, blood glucose
- Physical inactivity
- Body mass index
- Sleep disorders

Public summary

- The evidence concerning greenspace and health outcomes remains unclear
- We performed an umbrella review of 40 systematic reviews on greenspace and health
- Greenspace exposure was estimated with various objective and subjective parameters
- Greenspace was beneficially associated with several aspects of human health
MULTIPLE SYSTEMATIC REVIEWS ON GREENSPACE AND HEALTH OUTCOMES

INTRODUCTION

Our planet has experienced a rapid urbanization during the last century. Now about 50% of the global population lives in urban areas,1 and by 2050 it is estimated that this proportion will be over 65%.1 In addition to polluted water, soil, and air, urbanization poses a big challenge in providing sufficient access to areas with vegetation (hereon referred to as greenspace).2,3 This is of great concern to public health, since exposure to greenspace may bring many health benefits.4 The underlying mechanisms include encouraging physical activity, reducing environmental hazards (e.g., air pollution, noise, and air temperature), mitigating mental stress and inattention, improving social interaction, and enriching microbial diversity.5,6

Many epidemiological studies have been performed, particularly in high-income countries, to evaluate the associations between greenspace and a range of health outcomes, such as cardiovascular diseases (CVDs),7 birth outcomes,8 mental health,9,10 allergic diseases,11 and blood biomarkers.4 As a response to the increasing literature in the field, a number of systematic reviews and meta-analyses have been performed to synthesize this literature. Evidence for associations between environmental exposures and health outcomes are hierarchical (Figure 1); primary studies exist along a continuum with preclinical studies being lower on the hierarchy and randomized controlled trials (RCTs) being higher on the hierarchy.12 Secondary studies, including reviews and meta-analyses, exist even higher than RCTs on the evidence hierarchy and might have less chance for bias and error. However, with the rapid increase in primary studies on greenspace and health outcomes, the number of reviews and meta-analyses are also accumulating. For example, between 2014 and 2020, there have been seven published systematic reviews and meta-analyses on maternal greenspace exposure and birth weight alone.8,13–17 Such rapid updates make keeping up with the systematic reviews difficult for researchers, healthcare practitioners, and policy makers. In addition, many of the systematic reviews and meta-analyses focus on a single disease or one kind of similar health endpoints. Since greenspace exposure is proposed to be linked to numerous health effects,5 the
Overall picture on greenspace and these health effects thus remains unclear from those systematic reviews and meta-analyses.

A tertiary-level study (an umbrella review), systematically collects and evaluates previously published secondary-level systematic reviews and meta-analyses on a research topic to generate even more robust evidence than its constituent parts (i.e., individual systematic reviews and meta-analyses).

We are aware of only one prior systematic effort to review previous reviews and meta-analyses concerning nature environment and health outcomes.

There has been a notable rise in the number of both primary- and secondary-level articles on greenspace and health since August 2016, when the former effort concluded its retrieval of articles. Therefore, in this updated umbrella review, we summarize and appraise all relevant systematic reviews and meta-analyses of epidemiological studies concerning greenspace exposure and any human health outcome through June 2021, in order to provide researchers and healthcare professionals in this field with a more comprehensive and higher quality of evidence on the health effects of greenspace exposure.

**RESULTS**

**Systematic review retrieval**

As shown in Figure 2, the initial search identified 3,917 records. After removing duplicates, the titles and abstracts of 3,125 systematic reviews were assessed and 3,073 articles were removed following title and abstract screening. A total of 52 articles underwent a full-text review. Of these, six were further excluded due to irrelevance to the topic or with other focuses, five more articles were excluded because they duplicated other included articles, and one was removed since it was a conference abstract. Finally, 40 systematic reviews were included in the umbrella review.

Characteristics of systematic reviews included in the umbrella review

Our umbrella review included 9 systematic reviews with meta-analyses, 6 with narrative reviews, and 31 without meta-analyses. These articles were published between 2010 and 2021, and 29 (approximately 73%) were published since 2019 (Table 1 and Table S1). The number of databases used for keyword searches ranged from 1 to 19. The number of primary studies included in the systematic reviews ranged from 7 to 201. Most of the primary studies included were cross-sectional, followed by experimental/intervention studies, cohort studies, and ecological studies. Study populations across all age groups (i.e., from infant to the elderly) were covered, and mostly resided in higher-income countries in North America or Europe. Only a small number of primary studies were conducted in lower- and middle-income countries like China.

Greenspace exposure measures

Greenspace exposures were evaluated using a number of metrics, including objective parameters, such as the normalized difference vegetation index (NDVI), percentage of greenspace in a certain area, distance to the nearest greenspace, number of parks in an area, act of walking or running or gardening in a natural environment, or viewing simulations of natural environments. Subjective parameters were also presented and included self-reported exposure, perceived access to greenspace through window views, and reported visitation to natural settings for outdoor activities.

Health outcomes

Over 100 health outcomes were investigated with greenspace exposures, including mortality, CVDs, pregnancy outcomes, mental health, general health, allergic diseases, and blood biomarkers. These health outcomes were measured using various methods, including doctor diagnoses, questionnaires, records from hospitals or other health-related departments, self-reported health status, and laboratory tests.

Methodological quality

Many of the included systematic reviews failed to meet the seven critical domains of the “Assessing the Methodological Quality of Systematic Reviews” (AMSTAR2) checklist (Table 2). Four systematic reviews (10%) provided a list of excluded studies and justified the exclusions. Fifteen (38%) developed an a priori protocol for the review. Twenty-eight (70%) accounted for the risk of bias in the primary studies when discussing the results of the systematic reviews. Twenty-eight (70%) assessed the risk of bias in the primary studies. Finally, 37 (93%) performed a comprehensive literature search. The remaining two critical domains related to meta-analysis were hard to evaluate since most of the included systematic reviews did not perform a meta-analysis.

Many of the included studies also failed to meet at least one of the nine, non-critical domains of the AMSTAR2 checklist (Table 2). None of the systematic reviews reported the sources of funding for the primary studies. Fifteen (38%) included the components of the PECO. Fourteen (39%) performed data extraction in duplicates. Twenty-nine (73%) performed study selection in duplicates. The other non-critical domains were met by most of the included systematic reviews.

Associations between greenspace exposure and health outcomes

Table 1 and Table S1 summarize the detailed information on the associations between greenspace exposure and health outcomes in each of the included systematic reviews.

**Mortality.** A few systematic reviews have examined all-cause or non-accidental mortality and greenspace exposure. One example was a systematic review and meta-analysis of nine longitudinal cohort studies that showed
that a 0.1-unit increase in greenness within 500 m of the home was associated with a 4% decrease in all-cause mortality.77 Another systematic review and meta-analysis limited to elderly populations found that higher greenspace levels reduced odds of both all-cause mortality and stroke-related mortality. No significant associations were found for CVD-related mortality and ischemic heart disease-related mortality.7 Primary studies have also investigated greenspace and other cause-specific mortality rates, such as respiratory diseases, but the number of these studies was too low and the results were too mixed to draw conclusions.7

**Cardiovascular and metabolic health.** Cardiovascular health was one of the most widely studied outcomes in the included systematic reviews. In a systematic review by Yuan et al.,7 eight studies investigated associations of greenspace exposure and total CVD risk. Among them, seven showed beneficial associations. Less consistent evidence was reported for other CVD outcomes, including stroke, myocardial infarction, and coronary heart disease.47,23 Greenspace was also linked to preclinical cardiometabolic factors. Our research group’s recent systematic review and meta-analysis found that greater NDVI was associated with lower odds of being overweight or obese.47 Another systematic review with meta-analysis showed that people who lived in areas with little greenspace had higher odds of having diabetes compared with people who lived in areas with abundant greenspace.47 Similar beneficial associations were found between greenspace and heart rate, diastolic blood pressure, and high-density lipoprotein cholesterol.4,45 However, no significant associations were observed for systolic blood pressure, total cholesterol, low-density lipoprotein cholesterol, and glycosylated hemoglobin.4,45

**Mental health and behavioral issues.** The effects of greenspace exposure on mental and behavioral diseases have been widely evaluated, although studies have differed substantially in study population composition, greenspace assessment, outcome assessment, and study design. Four systematic reviews with overlap but mutually different primary studies concluded that greenspace exposure was associated with improved cognition, including cognitive development, attention, and dementia across the life course.22,23,39,51 Another systematic review of 57 studies found that built environments lacking greenspace predicted depressive moods across age groups.27 Two systematic reviews, summarizing 52 observational studies78 and 38 nature experiments,31 respectively, concluded that urban greenspace levels (or greenspace intervention) were positively associated with mental well-being. Two more systematic reviews reported that engaging with gardens or wildland recreation had the potential to improve mental health.20,46 In a systematic review of 12 studies, Shuda et al. found that walking in natural settings, hearing natural sounds, or viewing a simulated nature environment was associated with reduced physiologic and perceived stress levels.50 Mygind et al. summarized 26 experimental studies and found that seated relaxation and walking in natural environments might be associated with improved acute psychophysiological stress response.33 Similar results were found in studies restricted to children and adolescents; 2 systematic reviews of 14 and 45 studies, respectively, showed beneficial associations between greenspace exposure and stress, mood, depressive symptoms, emotional well-being, mental health and behavior, and psychological distress in children and adolescents.55,57 Another systematic review found that higher levels of exposure to residential greenness may potentially increase prosocial behavior among children and adolescents.42 Two systematic reviews by Bowler et al.29 and Roberts et al.47 found that spending time in natural environments during walking, running, or wilderness backpacking among other outdoor activities was associated with reduced levels of anger, anxiety, and depression as well as increased levels of attention. In contrast, another systematic review reported that there was insufficient evidence showing outdoor and indoor greenspace around school campuses impacted students’ well-being.44

**Birth outcomes.** Numerous systematic reviews have synthesized the evidence regarding maternal greenspace exposure and birth outcomes.5,4,23,40,69 The latest and the most comprehensive was performed by Hu et al. In that systematic review with meta-analysis, the authors found that higher residential greenness levels were generally associated with higher birth weight and lower odds of low birth weight. More specifically, a 0.1-unit increase in greenness within 100 m of the home was associated with a 15.22-g increase in birth weight and a 13% lowered odds of low birth weight. No significant associations between greenness and preterm birth or small gestational age were observed. The authors evaluated the credibility of the pooled evidence and concluded that the associations above had “moderate” certainty.

**Allergic endpoints.** Lambert et al.11 published the first systematic review and meta-analysis of studies on residential greenness and allergic respiratory diseases in children and adolescents. Neither asthma nor allergic rhinitis were associated with greenness exposure. Hartley et al.50 performed an updated systematic review by synthesizing literatures that were published after Lambert and colleagues’ review, and also found a null association. In addition, Lambert et al.67 summarized 11 cohort studies on residential greenness and atopic sensitization and found that 4 of these studies reported protective effects, 2 reported deleterious effects, and 5 reported null effects. The diversity of these findings makes it difficult to draw a conclusion on the association between greenspace and allergic diseases.

**Physical activity.** Since greenspace is usually hypothesized to benefit human health by encouraging physical activity, a large number of studies have explored this topic. A systematic review by Lambert et al.36 included four studies on neighborhood greenspace levels and outdoor play among children and adolescents. Three showed more outdoor play time with higher neighborhood greenspace levels. Another systematic review by Thomesen et al.46 included 34 studies on physical activity that were mainly performed in adults and reported that wildland recreation had the potential of improving physical activity levels. In addition, de Keijzer et al.39 reviewed 17 studies on physical activity, which were conducted in middle- and older-aged populations, and found that approximately two-thirds of the primary studies observed beneficial associations between residential greenness and physical activity.

**Other health outcomes.** Effects of greenspace on other health aspects have also been investigated. For instance, a systematic review of 13 studies reported that greenspace exposure was associated with reduced odds of short sleep and/or poor sleep quality.41 A systematic review of 29 studies summarized greenspace exposure and cancers, but the evidence was limited and mixed.55 Another systematic review of 45 studies concluded that the presence of parks and other types of greenspace may reduce urban crime.29
Table 1. Main findings of the included systematic reviews on greenspace and health with or without meta-analyses (N = 40)

| Author (year)          | Number of included studies | Finding(s)                                                                                                                                                                                                 |
|------------------------|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Bowler et al.20        | 25                         | Short-term exposure to natural environments was associated with better emotional states and attention (effect sizes ranged from 0.35 to 0.76).                                                                 |
| van den Berg et al.21  | 40                         | Positive associations between the quantity of greenspace and perceived mental health, general health, and all-cause mortality. However, the evidence was not convincing due to the lack of high-quality studies. |
| de Keijzer et al.22    | 13                         | Inadequate but suggestive evidence for a positive association between long-term greenspace exposure and cognitive functioning over the life course.                                                          |
| Kondo et al.23         | 68                         | Positive associations between urban greenspace and attention, mood, and physical activity. Negative association between greenspace and mortality, short-term cardiovascular markers and violence. |
| Lambert et al.11       | 15                         | No significant association between residential greenness and asthma.                                                                                                                                       |
| Houlden et al.28       | 52                         | Adequate evidence for protective associations between local greenspace and life satisfaction, but not personal flourishing. Insufficient evidence for associations between mental wellbeing and visits to greenspace, accessibility, types of greenspace, views of greenspace, and connectedness to nature. |
| Lambert et al.25       | 11                         | Protective effects of greenspace were reported in four cohorts; deleterious effects were reported in two cohorts; no significant associations were reported in another five cohorts. |
| Rautio et al.27        | 11                         | Built environments lacking greenspaces were related to depressive mood although the results were mixed.                                                                                                   |
| Schulz et al.24        | 4                          | Greenspace tended to be associated with acute respiratory symptoms but not with chronic respiratory conditions.                                                                                             |
| Twohig-Bennett and Jones4 | 143                       | Greenspace exposure was beneficially associated with a wide range of health outcomes including salivary cortisol, heart rate, diastolic blood pressure, high-density lipoprotein cholesterol, heart rate variability, preterm birth, type 2 diabetes, all-cause mortality, small size for gestational age, cardiovascular mortality, self-reported health, stroke, hypertension, dyslipidemia, asthma, and coronary heart diseases. Non-pooled studies showed health-denoting associations for neurological and cancer-related outcomes as well as respiratory mortality. |
| Vanaken and Danckaerts76 | 21                        | Beneficial association between greenspace exposure and emotional and behavioral problem. Limited evidence on a beneficial association between greenspace exposure and mental well-being and depressive symptoms. Physical activity, air pollution and social interaction mediated these associations. |
| Browning and Rigolon35 | 13                        | Approximately two-thirds of the reviewed studies showed non-significant associations between greenspace and academic performance, and the other studies reported mixed associations. |
| Shepley et al.28       | 45                         | Presence of parks and other greenspaces reduced urban crime.                                                                                                                                               |
| Hunter et al.31        | 38                         | Strong evidence for park-based and greenway/trail interventions on park use and physical activity and for greened vacant lots on health and wellbeing (e.g., reduction in stress) and social outcomes (e.g., reduction in crime, increased perception of safety). Sufficient evidence for urban street trees increase biodiversity. |
| Jo et al.30            | 37                         | Viewing natural scenery and visual contact with flowers, green plants, and wooden materials had positive effects on cerebral and autonomic nervous activities.                                                  |
| Lakhani et al.34       | 18                         | Engaging with gardens and gardening favorably impacted the emotional and social health of people with dementia.                                                                                           |
| Lambert et al.45       | 18                         | Neighborhood greenness was a predictor of more time spent in outdoor play (one longitudinal reported reverse association).                                                                                 |
| Mygind et al.33        | 26                         | Seated relaxation and walking in natural environments enhanced heart rate variability. Associations between nature exposure and cortisol were mixed.                                                        |
| Roberts et al.32       | 33                         | A small effect was found for a reduction in depressive moods following exposure to nature environments (effect sizes ranged from -2.30 to 0.84).                                                       |
| de Keijzer et al.39    | 59                         | Limited evidence for protective associations between greenspace and morbidity, mental health, cognitive function, physical capability, cardiometabolic risk, and perceived wellbeing. |
| Hartley et al.48       | 7                          | No significant association between greenness and children asthma.                                                                                                                                          |
| Hu et al.8             | 29                         | An increase in residential greenness was generally associated with higher birth weight and lower odds of low birth weight. No associations were found between residential greenness and preterm birth and small gestational age. |
| Islam et al.49         | 23                         | An increase in greenspace was associated with increased birth weight, decreased risk for low birth weight, increased levels of physical activity, lower risk of obesity, and inattentiveness. Associations between greenspace and respiratory diseases were mixed. |
| Kim et al.56           | 27                         | Greenspace improved physiological and psychological indicators as well as expanded the social networks of older people.                                                                                   |

(Continued on next page)
A handful of studies have also explored school greenspace and students’ academic performance, but a systematic review by Browning and Rigolon reported that the evidence was insufficient to support a link between them. Jo et al.30 concluded that visual contact with flowers, green plants, and wooden materials had more positive effects on cerebral and autonomic nervous activities than viewing built environments without these natural elements. A systematic review of 20 human studies also reported that there exist positive effects of nature exposure on immunological health parameters.54 Effects of greenspace on hormones and brain activity have been evaluated, but the effects were based on too few studies and participants to draw conclusions.55

**DISCUSSION**

**Key findings**

This umbrella review included a total of 40 systematic reviews (9 with meta-analyses and 31 without meta-analyses) and the vast majority of them were published since 2019. The primary studies included in these systematic reviews and meta-analyses had investigated more than 100 health outcomes and covered populations across the lifespan; however, they were mostly cross-sectional and carried out in high-income countries. Greenspace exposures were evaluated using both objective and subjective parameters but varied greatly across studies. Overall, we observed that exposure to greenspace was beneficially associated with all-cause and stroke-specific mortality, total CVD morbidity, cardiometabolic factors, mental disorders, low birth weight, and physical inactivity. We also observed that greenspace exposure was beneficially associated with sleep problems, urban crime rate, and immunological health parameters in the singular review articles that studied each of these respective outcomes. In contrast, exposure to greenspace was not associated with stroke, coronary heart disease, preterm birth, small gestational age, asthma, and allergic rhinitis in the included systematic reviews. Evidence for other health outcomes, including cancer, respiratory-specific mortality, and hormone levels, was limited and not conclusive. AMSTAR2 evaluations indicated that most of the included systematic reviews and meta-analyses had one or more limitations in their methodology, which may have comprised the credibility of the pooled evidence.

**Potential mechanisms underlying greenspace and health**

Several mechanisms have been proposed to explain the beneficial health effects of greenspace. First, physical activity is a well-documented protective factor for health, and living close to greener areas may encourage people to engage in physical activity more often and/or more vigorously.56 Three of the included systematic reviews provided support for this mechanism by concluding that greenspace...
**Table 2. Methodological quality of included systematic reviews on green space and health with or without meta-analyses (N = 40)**

| Author (year) | AMSTAR 2 Items |
|--------------|----------------|
|              | I | II* | III | IV* | V | VI | VII* | VIII | IX* | X | XI* | XII | XIII* | XIV | XV* | XVI |
| Bowler et al.20 | Y | N | P | Y | Y | N | P | Y | N | Y | Y | Y | Y | Y | Y |
| van den Berg et al.21 | N | N | Y | P | Y | Y | N | Y | P | N | N/A | N/A | Y | Y | N/A | N |
| de Keijzer et al.22 | N | N | Y | P | N | N | P | Y | Y | N | N/A | N/A | Y | Y | N/A | Y |
| Kondo et al.23 | N | N | Y | P | Y | N | N | Y | N | N | N | N | N | N | N/A | Y |
| Lambert et al.24 | N | N | Y | P | Y | P | Y | Y | N | N | N | N | N | N | N | N/A | Y |
| Houlden et al.25 | Y | P | Y | P | Y | N | N | Y | Y | N | N | N/A | Y | Y | Y | N/A | Y |
| Lambert et al.26 | Y | N | Y | P | Y | Y | P | Y | Y | N | N/A | N/A | Y | Y | N/A | Y |
| Rautio et al.27 | N | N | Y | P | Y | N | Y | P | N | N | N/A | N/A | Y | Y | N/A | N |
| Schulz et al.28 | N | N | Y | P | N | N | N | Y | P | N | N/A | N/A | Y | Y | N/A | Y |
| Twohig-Bennett and Jones8 | Y | P | Y | P | Y | N | N | Y | Y | N | Y | Y | Y | N | Y |
| Vanaken and Danckaerts29 | N | N | Y | P | N | N | N | Y | N | N | N/A | N/A | N | N | N/A | Y |
| Browning and Rigolot35 | N | N | P | Y | Y | N | P | N | N/A | N/A | Y | N | N | Y | N | Y |
| Hunter et al.30 | Y | P | Y | P | Y | N | N | P | N | N/A | N/A | Y | Y | N/A | Y |
| Jo et al.31 | N | N | Y | N | N | N | N | P | N | N/A | N/A | N | N | N | N/A | Y |
| Lakhani et al.32 | Y | P | Y | P | N | N | N | P | P | N | N/A | N/A | Y | N | N/A | Y |
| Lambert et al.33 | Y | P | Y | P | Y | N | N | Y | Y | N | Y | Y | Y | N | Y |
| Mygind et al.34 | Y | P | Y | P | Y | N | N | Y | Y | N | Y | Y | Y | N | Y |
| Roberts et al.35 | Y | P | Y | P | Y | Y | N | Y | P | N | Y | Y | Y | Y | Y | Y |
| Rojas-Rueda et al.36 | Y | P | Y | Y | N | N | Y | Y | N | Y | Y | Y | Y | N | Y |
| Shepley et al.37 | N | N | Y | P | Y | N | P | N | N/A | N/A | N | N | N | N | N | N/A | Y |
| de Keijzer et al.38 | N | N | Y | Y | Y | N | N | Y | Y | N | N/A | N/A | Y | Y | N/A | Y |
| Hartley et al.39 | N | N | Y | P | N | N | N | N | N | N | N/A | N/A | N | N | N | N/A | N |
| Hu et al.40 | Y | N | Y | P | Y | Y | N | Y | Y | N | Y | Y | Y | Y | Y |
| Islam et al.41 | N | N | Y | Y | Y | N | N | P | N | N | N/A | N/A | N | N | N | N/A | Y |
| Kim et al.42 | N | N | Y | Y | Y | Y | N | N | P | N | N/A | N/A | N | N | N | N/A | N |
| Luo et al.43 | N | N | Y | Y | Y | Y | N | Y | Y | Y | Y | Y | Y | Y | Y |
| Mmako et al.44 | N | N | Y | Y | Y | N | N | P | N | N | N/A | N/A | N | N | N | N/A | Y |
| Putra et al.45 | N | N | Y | Y | Y | N | N | P | N | N | N/A | N/A | N | N | N | N/A | Y |
| Rugel and Brauer46 | Y | P | Y | Y | N | N | N | Y | Y | N | N/A | N/A | Y | Y | N/A | Y |
| Shin et al.47 | N | N | Y | P | Y | N | N | Y | Y | N | N/A | N/A | Y | N | N/A | Y |
| Shuda et al.48 | N | N | Y | P | N | N | N | P | Y | N | N/A | N/A | Y | Y | N/A | Y |
| Thomsen et al.49 | N | P | Y | N | N | N | N | Y | N | N | N/A | N/A | N | N | N | N/A | N |
| van den Bogard et al.50 | Y | Y | Y | P | Y | N | N | Y | Y | N | N/A | N/A | Y | Y | N/A | Y |
| Wolf et al.51 | N | N | Y | Y | N | N | N | P | Y | N | N/A | N/A | Y | N | N/A | Y |
| Yuan et al.52 | Y | Y | Y | Y | Y | N | Y | P | N | Y | Y | Y | Y | Y | Y |
| Zhang et al.53 | Y | Y | Y | Y | N | N | Y | N | N | N | N/A | N/A | Y | Y | N/A | Y |
| Andersen et al.54 | N | N | Y | Y | N | N | N | Y | Y | N | N/A | N/A | Y | N | N/A | Y |
| Davis et al.55 | N | N | Y | Y | N | N | Y | N | N | N | N/A | N/A | N | Y | N/A | Y |
| Li et al.56 | N | N | Y | Y | Y | N | N | Y | N | N | N/A | N/A | Y | Y | N/A | Y |
| Porcherie et al.57 | Y | Y | Y | Y | N | N | Y | N | N | N | N/A | N/A | Y | Y | N/A | Y |

N, no; Y, yes; P, partly; N/A, not applicable since no meta-analysis was conducted.

*Critical domains.
exposure was positively associated with physical activity levels. Further, Vanaken and Danckaerts reported that physical activity mediated the beneficial associations between greenspace exposure and emotional and behavioral problems. Second, greenspace can mitigate environmental hazards, such as air pollution, noise, and air temperature, which are well-documented environmental risk factors for a range of health outcomes. Dzhambov and colleagues carried out a scoping review of studies testing pathways linking greenspace to health and found that 43 studies explored the mediating role of air pollution, 11 explored the mediating role of noise, and 5 explored the mediating role of heat. Significant mediating effects were found in about half of these studies. Stanhope et al. has recently suggested that attention should also be placed on the potential of greenspace to mitigate artificial light at night and its downstream health impacts. Third, stress reduction theory and attention restoration theory propose that greenspace provides the opportunity to restore attention, alleviate stress, and improve relaxation. Each of these are closely related to numerous health benefits. Consistent with this, several systematic reviews included in this umbrella review concluded that greenspace exposure does have beneficial effects on mental health. Finally, exposure to greenspaces may increase microbial diversity and alter human microbiota composition, which further leads to positive effects in human health. We did not identify any reviews on greenspace exposure, microbial diversity, and human health. Despite the above possible hypotheses, the exact mechanisms underlying greenspace and health are complex and remain unclear, which are thus urgently needed to be uncovered by future mechanistic studies.

Strengths and limitations

This umbrella review has some strengths. First, this is the most comprehensive "tertiary-level" article that summarizes and assesses the evidence on greenspace and human health using a pooled sample of systematic reviews and meta-analyses, which otherwise would be difficult to be obtained from individual primary studies or isolated systematic review. These tertiary-level studies are higher on the hierarchy of evidence than other study designs, including primary- and secondary-level studies. Second, we applied a comprehensive search of three international databases to identify relevant systematic reviews, and study selection and data extraction were carried out by two independent authors. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were rigorously followed, and we assessed the methodological quality of the included articles with the AMSTAR2 checklist. This provided an objective appraisal for the current evidence, identified gaps and limitations of the existing literature, and could give some hints and guidance for future systematic reviews. However, during the AMSTAR 2 appraisal process, we observed that the methodological quality of the included systematic reviews and meta-analyses should be critically reevaluated. Most systematic reviews only performed narrative evidence synthesis rather than quantitative meta-analyses. Meta-analysis may provide more precise effect estimates of greenspace exposure than individual studies, which are of significance for policy makers, practitioners, and researchers in this field to take targeted strategies to improve greenspace quality, perform greenness intervention, evaluate current evidence, and improve such studies in future. The underuse of meta-analytical pooling thus has hindered the reporting of quantitative effect estimates, appraisal of the robustness of the effect estimates, and detection of publication bias. However, a meta-analysis is not an option in systematic reviews when there is high methodological or statistical heterogeneity as well as limited study numbers. Also, nine of ten systematic reviews did not fully account for the primary studies they excluded; exclusions were relatively invisible and might have caused exclusion (or inclusion) bias. More than half of the reviews did not report an a priori well-developed protocol, which might have increased the risk of sampling bias, selection bias, and within-study bias. Another 60% did not extract data and 30% did not select studies in duplicate, which challenged the accuracy of the extracted data and the eligibility of studies for inclusion. The sources of funding for the primary studies were not reported in all the included systematic reviews. Components of PECO were absent from more than half of the included systematic reviews, and the risk of bias was not assessed in several of the included systematic reviews. These flaws might have reduced the quality of synthesized evidence and reporting standardization. Finally, our umbrella review could only synthesize the associations of greenspace with health outcomes in the published systematic reviews, and thus we might have missed or underestimated associations not covered in these systematic reviews (e.g., latest original high-quality studies that may be neglected).

In addition, interpretation of findings from this umbrella review was also limited by the primary studies included in the systematic reviews. The cross-sectional design of most of the primary studies precludes us from establishing a causal link between greenspace exposure and health outcomes. Second, the short follow-up period in experimental/intervention studies has limited the ability to evaluate long-term effects of greenspace exposure. An ideal greenspace exposure metric would include different dimensions, such as quality, quantity, use of greenspace, physical access, visual/auditory access, biodiversity, and composition. However, most of the primary studies evaluated only one or two dimensions of greenspace exposure, which is far from a comprehensive assessment. Among the objective parameters, vegetation indexes derived from satellite images (e.g., NDVI, soil adjusted vegetation index, and enhanced vegetation index) within various buffers were commonly used, but these indexes are limited in differentiating specific vegetation types and species. Furthermore, health outcome assessment was heterogeneous between studies. Questionnaires and self/parental reports were commonly used but doctor-diagnosed outcomes were rarely used. Most studies to date were also from European countries and North America. The generalizability of the current evidence to other geographical areas is limited, although the bodies of literature from China and some other Global South countries is mounting. Finally, in addition to only a few health outcomes (e.g., all-cause mortality and overweight/obesity) that were widely explored, evidences concerning most of the studied health outcomes were based on a small number of studies.

Concluding remarks and future perspectives

The current evidence shows protective effects of greenspace exposure on aspects of cardiovascular health, mental health, low birth weight, mortality, physical activity, sleep quality, urban crime, and immunity function. The effects of exposure on other health outcomes are limited or inconclusive. However, this evidence is drawn largely from cross-sectional studies with high levels of heterogeneity and higher-income countries. Better designed primary studies are needed to validate the association between greenspace and health. Particularly needed are longitudinal or intervention study designs to test for cause-and-effect; accurate and dynamic greenspace exposure assessments to account for dimensions beyond the presence/absence of greenness; non-linear relationships between greenspace and health; study populations outside of higher-income countries to lower- and middle-income countries; “gold standard” health outcome measures and full adjustment for confounding factors; improved results reporting, such as providing numerical estimates and describing bias concerns; and mediation analyses to explore underlying mechanisms. In addition, future systematic reviews should strictly follow standard guidelines to improve their methodological quality, including comprehensive literature search, accurate literature selection and data extraction, assessments of both study quality and risk of bias, use of appropriate statistical method (particularly for meta-analysis), and detailed results reporting.

METHODS

We performed this umbrella review following the PRISMA reporting guideline (Table S2 in the supplemental information).

Literature search and selection criteria

We systematically searched three international electronic databases—PubMed, Embase, and Web of Science—from database inception to June 28, 2020, to identify...
peer-reviewed systematic reviews with or without meta-analyses of studies concern-
ing greenspace exposure and any human health outcome. Our search strategy used a
combination of search terms related to greenspace (i.e., “green space,” “greenspace,”
“greenness,” “greenery,” “normalized difference vegetation index,” “soil adjusted vege-
tation index,” “enhanced vegetation index,” “vegetation,” and “leaf area index”) and sys-
tematic review and meta-analysis (i.e., “systematic review” OR “meta-analysis”) (a
detailed search strategy is shown in Table S3). We also manually screened the refer-
ce lists of the retrieved systematic reviews and meta-analyses to identify additional
relevant records.

All records identified were downloaded into a reference manager (Noteexpress
3.2, Aegean Software, Beijing, China). Duplicates were deleted using the innate func-
tion of the software, and the remaining records were screened for eligibility by two
independent authors (B.-Y.Y. and L.-X.H.). We deleted irrelevant articles from the re-
maining records by reading first the titles and then the article abstracts. Last, we
evaluated the full text of the articles for eligibility. Any discrepancies during the pro-
cess were resolved by a discussion with a third author (T.Y.Z.). We developed the
inclusion criteria based on the overall PECO framework: (1) population—studies of human populations regardless of age, sex, race, geographical region, and health sta-
tus; (2) exposure—studies of greenspace exposure, including residential greenspace
(evaluated using vegetation index, proportion of greenspace, proximity to green-
space, or number of greenspaces in a certain area, etc.), doing activities (e.g.,
racing or walking in a nature environment as well as gardening), and viewing sim-
ulations of greenspaces or landscapes with leafy green vegetation; (3) comparator—
studies comparing health effects between individuals exposed to different green-
space levels; and (4) outcome—studies investigating any health outcome(s), such as
diseases, conditions, symptoms, mortality, and behaviors.11 In addition, we did
not apply any restriction in study design for the primary studies included in system-
atic reviews and meta-analyses.

We excluded primary studies, non-human studies, and conference abstracts. We
also excluded articles published in languages other than English. For duplicate articles
on the same topic, we included only those published most recently, included most pri-
mary studies, or had the highest methodological quality. For articles investigating mul-
tiple or partially overlapping health outcomes, we included all the articles but focused
only on the one(s) in results reporting and interpreting.

Data extraction
Two authors (B.-Y.Y. and L.-X.H.) independently performed data extraction, and dis-
crepancies were resolved by discussion with a third author (T.Y.Z.). For each eligible
systematic review, the following information was extracted: authors, publication
year, type of study (i.e., systematic review with meta-analysis versus systematic review
without meta-analysis), literature search results (i.e., number of databases and date of
literature search), main findings, and characteristics of the included primary studies,
including study design(s), age ranges, sample sizes, greenspace assessment methods,
and health outcome(s).

Methodological quality assessment
Two authors (B.-Y.Y. and T.Y.Z.) assessed the methodological quality of the
included systematic reviews and meta-analyses using the AMSTAR2 checklist.62 Any
discrepancy was discussed with a third author (L.-X.H.). The AMSTAR2 checklist contain-
ded 16 items that involve questions related to (1) the use of the PECO framework for
study question or inclusion criteria, (2) a priori protocol for the review, (3) the selection
criteria for the study design, (4) the comprehensiveness of the literature search strat-
agy, (5) the number of authors performing the literature selection, (6) the number of
authors performing the data extraction, (7) the reporting of the characteristics of the
excluded studies, (8) the reporting of the characteristics of the included studies, (9)
the risk of bias assessment for the included studies, (10) the reporting of the sources of
funding in the included studies, (11) the use of appropriate statistical methods for any
meta-analyses reported, (12) the impact of risk of bias in the included studies on the
poored results, (13) the explanation for the risk of bias in the included studies and its
impact on the results of the review, (14) the explanation for the heterogeneity in the
review, (15) the investigation of publication bias, and (16) the reporting of conflicts of
interest in the review. Of these, items 2, 4, 7, 9, 11, 13, and 15 were identified as crit-
ical domains and the remaining were considered non-critical domains by the authors
checklists. We chose not to use the AMSTAR2 checklist to rate the overall quality of
each systematic review because we observed in the initial article search that many of
the included reviews did not perform meta-analyses, which are closely related to
two critical domains (items 11 and 15) and one non-critical domain (item 12) of the
AMSTAR2 checklist.

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