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Influence of Green Areas on the Urban Sound Environment

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Abstract

Purpose of Review Urban green spaces provide benefits for human health and well-being, among other properties, thanks to their ability to attenuate environmental pollutants. The sound environment is not healthy in most cities, and this situation has not changed in recent decades. These green spaces are potential quiet areas with good acoustic quality if they are designed and planned properly from a multidisciplinary perspective. Although the mitigating effects of green infrastructure have been extensively studied, their application in green areas has been very limited. The objective of this study is to analyze those characteristics of green spaces that contribute to a healthy soundscape and, in turn, the benefits that this would give them to the characteristics of green areas, users, and their physical environment.

Recent Findings Current studies show that to accurately determine the relationship between green spaces and health and well-being benefits, it is necessary to know the interaction with other environmental variables, including the soundscape. The development and application of ISO/TS 12913-2 have promoted the consideration of the soundscape and the use of appropriate procedures for its evaluation.

Summary The inclusion of soundscape quality in epidemiological studies will improve the quantification of the effects of green spaces on the health and well-being of citizens. Only the consideration of global indicators, such as L_{den} (dB), show the importance of the sound environment in the interaction with other environmental variables and user activities for the determination of the effects of green spaces on health.

Keywords Urban green spaces · Sound environment · Soundscape · Health and well-being

Introduction

Over the past century, there has been a significant rural-to-urban migration around the world. The United Nations estimates that by 2030, 60% of the world's population will live in cities [1]. This rapid urbanization has brought social, economic, and environmental hazards such as air pollution, noise, heat, and water pollution. Exposure to pollution harms health and reduces the quality of life. In the European Union, over 10% of annual premature deaths are attributed to environmental pollution [2]. Reducing the negative impacts of environmental pollution is a key objective of the EU's Zero Pollution Action Plan [3]. Consequently, a monitoring framework and targets to be achieved by 2030 have been established.

Urban green areas have become a primary means of contact with the natural environment for many citizens in this urbanized world [4]. Green spaces are defined as "land that is partly or completely covered with grass, trees, shrubs, or other vegetation which includes parks, community gardens, and cemeteries" by the US Environmental Protection Agency (EPA). Numerous studies show the benefits of exposure to urban green spaces on health and well-being [5•, 6, 7].

The two main methods used to characterize exposure with green spaces are surrounding greenness and physical access to green spaces [8, 9]. Nearby green environments are commonly used to establish relationships between greenness and health effects. For this purpose, these studies have relied on remote sensing-based indices of greenness (usually, the Normalized Vegetation Difference Index (NDVI)) or green land cover percentages available on land-cover maps [10]. NDVI is dynamic and depends on weather and climate conditions [11]. Therefore, similar periods should be considered if this index is related to other variables. In addition, some studies show that dense vegetation, especially trees, plays a more important role in environmental perception than shrubs and ground cover [12]. Regarding

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physical access to green spaces, the distance (Euclidian or road network distance) between the address of interest and the closest green is usually quantified, or buffer distances are considered. Greenness buffer distances generally used are between 50 and 500 m. The distance recommended by the European Commission for the selection of urban green space indicators in health studies is 300 m from the current residence [13•]. Some studies also mention the World Health Organization's (WHO) recommendation of 10 to 15 m^2 of green space per inhabitant [14]. However, there is some uncertainty regarding whether the WHO has indeed made this recommendation.

Other less common methods associate the visibility, use, or quality of green spaces with health [9]. Social media platforms such as Instagram, Flickr, and Weibo are used to estimate the frequency of visits to green spaces [15]. Questionnaires have also been used to determine the frequency of activities in green spaces, generally asking about sports activities [8]. However, there are other potential uses of parks that are important for the health and well-being of citizens, such as relaxing, socializing, and reading [16••]. Studies that relate the visibility of green spaces and their beneficial effects on quality of life typically use the Green Soundscape Index (GSI) [17]. These studies often assess virtual scenarios, which may deviate from actual conditions. Some results show that the prediction of GSI is limited to low-traffic areas [18, 19].

Improved mental health [20], reduced cardiovascular morbidity and mortality [21, 22•], obesity and risk of type 2 diabetes [23, 24], and better pregnancy outcomes [25] are some of the beneficial effects of urban green spaces reported in current studies and evidenced in a 2016 report by the WHO [13•] as shown in Fig. 1. Recent studies' findings suggest the beneficial effects of green area exposure on human immune responses [26]. Thus, people are less prone to illness and recover more readily from disease states. Green areas also provide visual and sensory stimuli that can enhance concentration and cognitive function [27, 28] and the connection with nature has been associated with increased psychological resilience [29]. In general, citizens

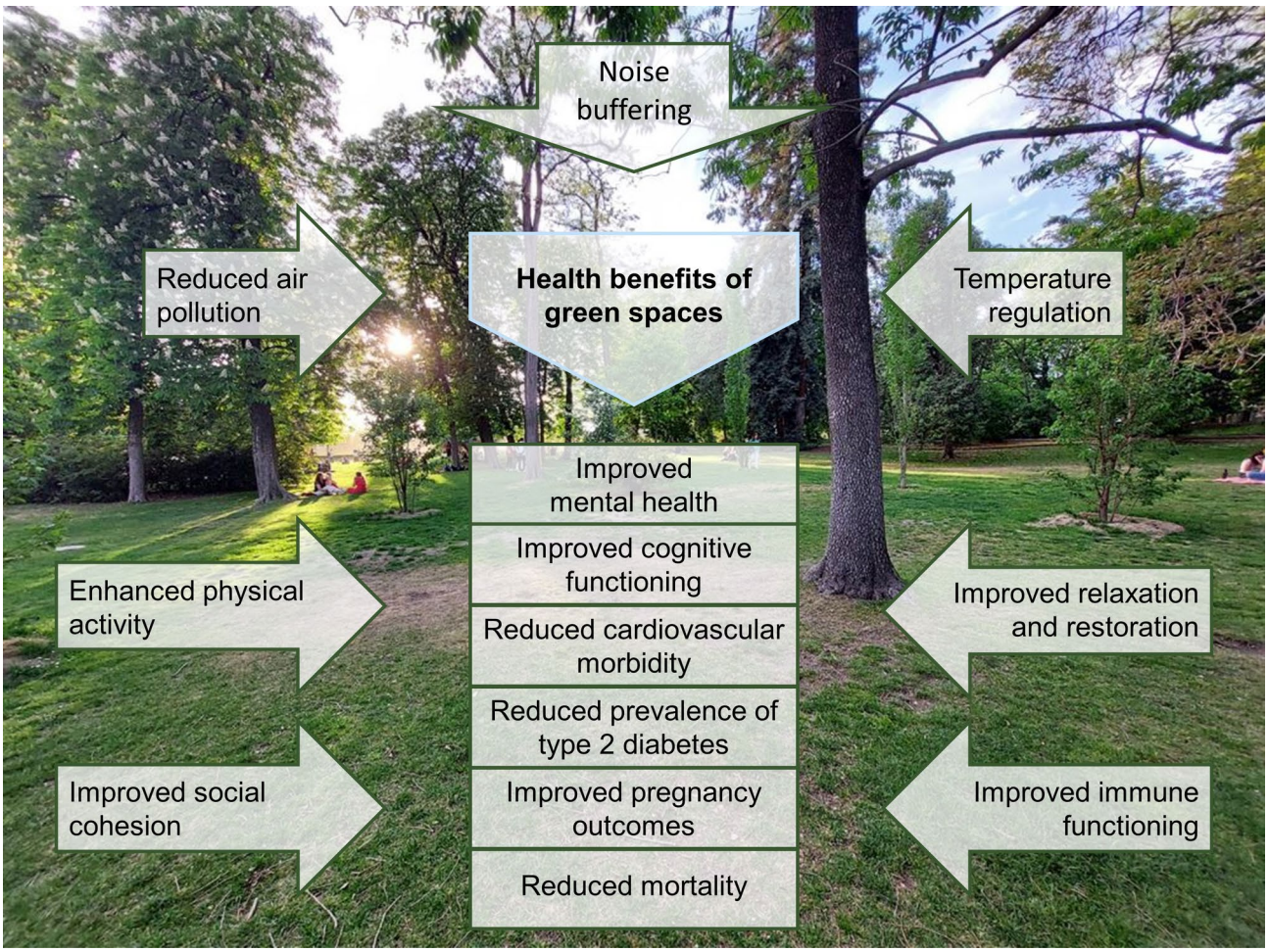

Fig. 1 Health and quality of life benefits of green spaces [13•]

who live in green neighborhoods are happier and live longer [22•, 30]. If the WHO recommendation for access to urban green spaces within a 300-m radius of each home were met, 2.3% of mortality from natural causes could be prevented [31•]. Furthermore, Iungman et al. [5•] show that increasing tree cover to 30% would lead to a 1.84% reduction in all-cause summer deaths. Providing universal access to safe, inclusive, and accessible green spaces and public spaces is one of the targets for 2030 included in Sustainable Development Goal 11: Make cities inclusive, safe, resilient, and sustainable. Despite the numerous health benefits of green areas, their increase, along with that of tree cover, can also have negative effects. Allergy and asthma risk is often among the most common negative effects [32].

The presence of urban green spaces alone does not always determine the health benefits. The presence of certain facilities in urban green areas and the quality of their environmental characteristics lead to health and well-being benefits. In turn, these facilities and characteristics influence their use and promoting these activities can provide health benefits. The influence of green areas on health benefits is well known, while pathways are less understood [4].

Green infrastructure (trees, shrubs, or grass) and water features in public spaces (ponds, streams, etc.) provide a habitat for a variety of animal species (birds, small mammals, etc.), promoting connection with peri-urban ecosystems and, therefore, bringing the natural environment closer to citizens [33]. Hunter et al. [34] found that exposure to nature reduced two biomarkers of stress (salivary cortisol and alpha-amylase). This connection with the natural world is also associated with improved cognitive function, creativity, and emotional well-being [35]. Trees and vegetation in cities prevent monotony and ensure diversification [36]. These green spaces can lead to an aesthetic improvement of urban areas. Aesthetic aspects can improve self-esteem because we associate beauty with positivity and happiness [37]. Therefore, aesthetic aspects can improve the quality of life. However, if maintenance and cleaning are inadequate, it can significantly affect its perception, as happened in some American cities during the COVID crisis [38]. Inadequate maintenance and lack of cleanliness in green spaces can produce unpleasant odors, thereby impacting the perception of the environment's quality [39]. Another important feature of park functionality is size. The size of green areas, besides influencing the provision of ecosystems, will also impact their usage [40]. In fact, the social and recreational interest in green spaces has been taking precedence over ecological interest in recent research [6, 40]. The benefits of parks have become even more evident during social crises such as the COVID pandemic [41].

Green spaces can promote healthy behaviors, factors that may be more prevalent in urban areas [42]. Physical activity is one of the main mediators in the relationship between green spaces and health benefits. Physical activity reduces the risk of chronic diseases, improves cardiovascular health, controls weight, strengthens bones and muscles, improves cognitive function, reduces stress, and improves sleep [43]. The relationship between physical activity in green spaces and health benefits has been one of the most studied aspects [13•, 44]. However, there are other activities that park users frequently engage in (walking, meditating, reading, taking children, social interaction, etc.) that also have health benefits [16••, 45, 46].

Noise and air pollution are the most important environmental pollutants that affect the health and well-being of citizens [3]. European Union recorded 238,000 premature deaths caused by fine particulate matter ($PM_{2.5}$) pollution in 2020. Nonetheless, this death toll has decreased by 45% since 2005. However, no significant decrease has been observed in the number of people exposed to harmful noise levels since the European Environmental Noise Directive required Member States to elaborate noise maps in 2007. At least one in five citizens is exposed to harmful levels of road traffic noise [47]. Green spaces can help to reduce the negative effects of exposure to environmental pollutants [42]. Vegetation acts as a buffer against anthropogenic noise and serves as a source of natural sounds [13•]. Furthermore, trees and plants absorb air pollutants and trap airborne particles. Despite these environmental benefits they provide, most urban green spaces have not been designed to actively remove these pollutants. Urban green spaces also play an important role in reducing the urban heat island effect [13•]. This is a growing concern as global warming, and urban development are expected to lead to an increase in urban heat islands. An increase in tree cover by 30% could reduce the average summer temperature by 0.4 °C [5•]. As a result of the current energy crisis in Europe, research on urban green spaces is also focusing on how they can help alleviate energy problems. Farkas et al. [6] indicate that, as a consequence of the current energy crisis in Europe, research on urban green spaces will focus on alleviating energy problems.

In summary, there is a wide variety of facilities and features in urban green spaces that can influence the benefits to human health. The quality of these features will also determine their use and influence on environmental pollutants related to well-being and health [48, 49]. However, most studies only examine some of the factors (NDVI, distance to green space or green cover area) or activities (physical activities) [9]. Van Dillen et al. [50] conducted a questionnaire to evaluate the quality and quantity of green spaces in Dutch cities. The overall assessment of green space quality improved the prediction of health indicators. Rey Gozalo et al. [16••] showed that features such as aesthetics, biodiversity, air, noise, users, and vegetation are important to consider for the type of activity people engage in within the park and their influence on health and well-being. In a

systematic review by Hunter et al. [8], 78% of studies found no significant positive impact on physical activity, park use, or overall health from urban green space interventions that only involve physical environment changes. The URBAN 40 study also found no significant impact on physical activity and overall health after a set of ecological interventions in green areas of 24 neighborhoods in the Netherlands at a cost of €5 million [51]. Mouratidis [52] shows that residents may perceive a low level of satisfaction with their neighborhood despite the uniform distribution of green space, public transportation, and local services. These studies did not consider the sound environment, which should be a key factor to consider in the design and management of green spaces due to its influence on people's well-being and health, and on other characteristics and activities that take place there, as recent studies show [53, 54••, 55•]. The sound environment is a key factor in the relationship between green spaces and the quality of life of citizens. Still, green spaces can also contribute to noise reduction and sound environment quality [47]. Road traffic is the main source of noise and air pollution in most cities around the world. The introduction of electric cars can lead to a significant decrease in air pollutants, but it will have a low contribution to noise reduction [56•]. There has been no decrease in noise in recent decades. Therefore, an analysis of current studies that relate green spaces and sound environments can help urban managers and planners make future decisions that involve concrete actions to reduce noise levels and improve the sound environment of cities.

Quiet Areas in Noisy Urban Environments

Noise pollution is a major environmental problem in cities around the world. The European Environment Agency (EEA) published a report showing that 20% of Europe's population (i.e., 113 million people) are exposed to noise levels that are harmful to their health [47]. Long-term exposure to noise produces a variety of health effects including annoyance, mental health, hearing system, pregnancy outcomes and cognitive impairment in children, sleep disturbance, and negative effects on the cardiovascular and metabolic system, potentially leading to premature death [57]. Noise is the second largest urban environmental stress factor affecting people's health according to the World Health Organization (WHO). The 7th Environment Action Program's objective of reducing noise pollution in Europe by 2020 was not achieved. The Zero Pollution Action Plan for 2030 sets a new goal: to reduce the number of people chronically disturbed by transport noise by 30%, compared to 2017 [3].

The Environmental Noise Directive (END) 2002/49/EC is the main European legislative framework for the assessment and management of environmental noise. The Directive has also been taken as a reference in non-European countries. Reducing the number of persons harmfully affected by environmental noise is one of its objectives, but also protecting quiet areas. Urban green spaces are potential quiet areas, but they are also used as noise buffer areas. While there are other ways to reduce road traffic noise, green areas also help to improve air quality, reduce temperatures, and enhance the aesthetic appeal of cities. The shape and size of green spaces are determined by the availability of urban open spaces, but they are also linked to the city's functionality. Shan et al. [58] provide a review of the different types of green space distribution, considering the distribution of urban functions. They identify four main types of distribution: core, star, satellite, and linear. If green spaces are used to reduce noise in adjacent residential areas, these green spaces may have high noise levels and, therefore, may not be considered as quiet areas. For example, numerous parks and green areas are located adjacent to the M-30 highway in Madrid, Spain, which serves as the main inner ring road. The acoustic environment is a significant factor in the relationship between urban green spaces and human health [59••].

Rey Gozalo et al. [60, 61] show the sound levels registered in different types of roads in a large Spanish city and small towns. Considering the road traffic spectrum, the attenuations due to linear geometric divergence, atmospheric absorption (temperature 20 °C and humidity 50%), ground (soft), and foliage (dense foliage of trees and shrubs) were calculated for distances ranging from 10 to 100 m, following ISO 9613–2 standards (see Table 1). In the case of a large city such as Madrid, Spain, noise levels of 55 dB(A) would only be reached if the green area, with a high density of foliage, is located 70 m from the center of major urban roads [60]. On residential streets, it would be necessary to exceed 30 m. The situation in small Spanish and Portuguese towns is similar [61]. Residential streets must be located 30 m from the green area to reach a daytime noise exposure level of less than 55 dB(A). However, when green areas are located 40 m or more from main roads in the towns, the recommended noise level for quiet areas is achieved. These results highlight the difficulty in attaining daytime sound levels between 55 and 45 dB(A) recommended by the EEA for quiet areas [62], unless large parks or other noise-attenuating elements are used (acoustic barriers, raised berm, etc.). In fact, studies conducted in parks in different cities show noise levels higher than those recommended for quiet areas [63–65]. Galangash et al. [66] show that distances of less than 200 m from the access road to the Saravan forest park are unsuitable for tourism accommodation.

A number of studies have been conducted on the attenuation of sound by foliage. The density of trees or shrubs is not the only factor that affects it; other factors include the type of leaf, tree canopy, trunk, and weather conditions [67–70]. Pudjowati et al. [71] propose different equations

Table 1 Attenuation of road traffic noise with distance, according to the ISO 9613-2 standard

Distance (m)	Geometrical divergence (dB)	Atmospheric absorption (dB)	Ground attenuation (dB)	Foliage attenuation (dB)	Total attenuation (dB)
10	15.0	0.2	0.0	1.0	16.2
20	18.0	0.2	2.3	1.0	21.6
30	19.8	0.3	3.4	1.9	25.4
40	21.0	0.4	3.9	2.5	27.7
50	22.0	0.4	4.1	3.1	29.6
60	22.8	0.5	4.2	3.7	31.2
70	23.5	0.6	4.3	4.3	32.6
80	24.0	0.6	4.4	4.9	33.9
90	24.5	0.7	4.4	5.5	35.1
100	25.0	0.7	4.5	6.0	36.3

for sound attenuation based on plant species. Average noise reductions between 4 and 5 dB are achieved in the distance range of 16 to 20 m. Some species, such as *Pithecellobium dulce*, reached an attenuation of 7 dB. Despite these values differing from those shown in Table 1, they are lower than those indicated by other authors [72]. Ow and Ghosh [73] obtained noise reductions similar to those indicated in Table 1 for plantations with low to moderate densities. In the case of dense plantations, reductions between 3 and 4 dB were achieved for distances of 10 and 20 m from the sound source. Trucks and ambulances with sirens are the types of sound sources registered in this study. The study of noisy events is of interest due to the effects they have on health [74]. Recent studies propose an alternative approach for calculating sound propagation in green areas. De Oliveira et al. [75] found a highly significant relationship between the visual quality of the landscape and noise attenuation.

The density of trees or shrubs is not the only factor that influences sound attenuation. The bark and crown of trees are also important. Zhao et al. [68] found that the volume and height of the tree crown centroid are more strongly related to sound levels than NDVI. These results suggest that tree characteristics should be used instead of NDVI in noise mitigation studies. Studies conducted in the impedance tube show that rougher barks and those with moss absorb sound better [69]. The trunks of conifers are better at absorbing sound than the trunks of other, more leafy species.

A significant portion of current studies focus on investigating the attenuation of tree leaves. Sağlam [67] analyzed the absorption and attenuation of leaves from plants commonly found in urban areas. Roughness had a greater impact on sound attenuation than thickness. Furthermore, apparent density also had a significant contribution to sound absorption. In addition to the physical properties of leaves, the vibrations of leaves in response to environmental sounds also help to reduce noise. Li and Kang [76•] studied the amplitude, velocity, and frequency of leaf vibrations before and during sound stimulation. The length, width, and thickness of the petiole also influenced the vibration in addition to the size, mass, and thickness of the leaf. Coriaceous leaves vibrated more than succulent leaves. Van Renterghem et al. [77] also show the absorbing properties of leaves when they are part of the leaf litter. Litter helps to reduce the impedance of the soil, which is benefited by the organic content and raking of the soil. Regular maintenance of green areas is essential to keep the vegetation and soil healthy and to make the absorbing and attenuating properties of these more effective. Jamaludin et al. [78] register attenuations between 5 and 10 dB in tropical tree leaves. Seasonal changes can also alter the characteristics of trees and the properties of soils [70]. Evergreen trees, such as conifers, are particularly effective due to their year-round foliage. Pine trunks also have good absorbing properties, as mentioned above. However, soil moisture in winter increases soil impedance, as shown in the study by Van Renterghem et al. [77].

The proximity of noise sources or the size of the park can limit the attenuation and absorption of trees and shrubs. Recent studies show that the design of natural raised berms or landscape depressions can produce significant noise reductions [79, 80]. Van Renterghem et al. [80] registered reductions of up to 6–7 dB in landscape depressions of only a few meters in depth. The use of noise barriers can produce reductions of between 3 and 20 dB [81]. There are studies which inform that scattering is the major reason of noise attenuation [82].

In summary, the proper planning and design of green areas, the selection of plant species with specific characteristics, and their maintenance can generate significant benefits in the attenuation and absorption of environmental noise in urban areas.

Healthy Sound Environment and its Assessment

The evaluation of noise in public parks and quiet areas is within the goals of the END. Furthermore, action plans aim to protect these quiet areas from noise increase. Different researchers have questioned the quantitative noise abatement approach proposed by the WHO and END [83, 84, 85••]. While noise reduction measures should still be implemented, this strategy is not always effective in achieving the desired health and quality of life improvements because "quietness" is not necessarily sufficient to define a healthy acoustic environment [83]. Sound helps us communicate, orient ourselves in space, and feel emotions [84]. Citizen participation is particularly important in assessing the quality of urban environments. In fact, the END indicates that the public should be consulted and informed about proposed action plans. However, the common practice is to present citizens with nearly finished plans with the option of modifying a small number of corrective measures, which are often less effective [86]. Soundscape, defined by ISO as the "acoustic environment as perceived or experienced and/or understood by a person or persons, in context," emphasizes the importance of people's perception and considers sound as a positive environmental variable, not just as noise. Urban green spaces could play a more important role than other types of urban public spaces in providing quality soundscapes [87].

Sztubecka et al. [88] indicate several approaches or tools for assessing the sound environment: objective methods: obtaining information about the sound environment from the analysis of physical parameters or spectrograms; subjective methods: obtaining data about the soundscape from questionnaires or interviews, as well as through on-site observation and evaluation; and mixed methods: combining objective and subjective sound environment analysis techniques. Some recent studies have only considered people's perception to assess green spaces [89, 90]. Koprowska et al. [91] show that sound levels are the most influential factor in noise perception. Other studies only analyze noise levels [92]. Gasco et al. [15] suggest that that integrating sound levels and public perception would improve the predictive power of sound on health. Therefore, mixed methods will provide more accurate information on the quality about the sound environment quality of green spaces.

The sound sources recorded in studies conducted in green spaces are diverse. In many cases, noise levels are estimated using calculation models and most only take into account the traffic noise source [93]. Traffic is the main urban noise source, but trains and aircraft also contribute significantly to the soundscape [94]. In addition, green or public areas also have other sound sources (birds, water, people, dogs, maintenance machinery, etc.) that can be relevant [95]. Several studies show the benefits of natural sources (birds, water, rustling leaves) on the quality of the soundscape [96, 97]. However, natural sources are not always pleasant. Zhou et al. [98] found that the sound generated by the wind in trees in winter was annoying. Birdsong is generally regarded as a positive element in the soundscape, but not all species produce pleasant calls [99]. The diversity and size of the bird population are usually related to the spatial structure of vegetation [100]. Vegetation structure is one of the reasons birds select their habitat, but there is also influence of predators, temperature, food offer, etc. [101]. However, this tree density can also reduce the propagation of bird calls [102•]. Birdsong can also be influenced by road traffic noise, which might mask it [4]. Birds are often the only animal sound sources analyzed in most studies. However, parks have areas for domestic animals, usually dogs, which generate unpleasant sounds [16••]. Water is another sound source that has been studied extensively. Although some studies only analyzed the psychological and physiological effects of water sound levels [103], there is a diversity of aquatic sounds in terms of spectrum and dynamic process [85••]. Park users are also another sound source that is perceived as positive in some studies [104], but in other studies (shouting, laughing, etc.) it is perceived as annoying [16••]. The presence of natural sound sources is very limited in some green areas. Recent studies show that the introduction of natural sounds through audio playback devices improves the perception of green space [105, 106].

The measurement of sound sources is also very variable depending on the sound indicators recorded. ISO/TS 12913-2 recommends, in addition to equivalent sound pressure levels and percentile levels, recording psychoacoustic indicators (loudness, sharpness, tonality, roughness, and fluctuation strength). These indicators provide information about specific characteristics of the sound spectrum and its temporal variability. Also, some researchers record the sound spectrum [85••]. A current growing trend is the use of soundecology indicators. These indicators can be calculated by different software: *R* (*Soundecology* packages) or Kaleidoscope Pro [107]. Benocci et al. [108] used these indicators to zone soundscapes, and Fisher et al. [109] showed that the Normalized Difference Soundscape Index (NDSI) is significantly correlated with pleasantness and naturalness in tropical green and blue spaces. NDSI estimates the effect of anthropogenic sounds on the sound environment by the ratio between mechanical sounds (1 and 2 kHz is the frequency range considered for anthrophony) and biological sounds (2 and 11 kHz is the frequency range considered for biophony) [110]. Fu et al. [111] showed the effectiveness of

soundecology indicators for analyzing the spatial and temporal variability of recreational activities in green areas. However, Devos [112] questions the use of soundecology indicators in areas where anthropogenic sources are dominant, and indicates that the reliability of these indicators is associated with the measurement duration, as well as other acoustic indicators, due to the variability of the analyzed sound sources. Xiang et al. [113] show that soundscape diversity indices are more suitable than soundecology indicators for assessing sound diversity in green spaces.

As previously mentioned, subjective assessment of the soundscape is also important in determining its quality. The most commonly used methods include soundwalks, questionnaires, and interviews. Binaural measurements are also a procedure listed in ISO/TS 12913-2. These could be considered a combination of objective and subjective measurements. Recent research has conducted binaural recordings to determine the impact of birds on the soundscape of tourist routes in green spaces [102•]. Soundwalks are usually carried out in different urban environments and generally, questionnaires and sound measurements are conducted simultaneously [114]. Jiang and Nellthorp [93] point out the low number of samples in questionnaires and questions that only address the perception of the soundscape in their review of studies conducted in public urban areas. The required sample size depends on several factors, such as the level of variation between variables, the level of factor overdetermination, and the subsequent statistical test [115]. If these considerations are not taken into account, the results may not be correctly interpreted and only applicable to a specific case [116]. Questionnaires must also be validated and used so the results can be compared across different contexts. In this regard, it is worth mentioning the work of researchers Aletta and Kang to ensure that the attributes defined for the soundscape in ISO/TS 12913-2 can be used in different languages [85••, 117, 118].

Impact of Sound on the Features of Green Spaces

The quality of the sound environment depends on four key elements that interact with each other, as shown in Fig. 2: the features and facilities of the green space, the characteristics of the sound sources, sociodemographic aspects and activities that people develop, and other physical variables and characteristics of the surrounding urban environment [119]. These elements and their interactions must be considered in the design of healthy green spaces, and therefore, the cooperation of specialists in many fields is important [120]. Japanese gardens are an example of this, where sound and other sensory experiences are considered and are known for their high-preference indices [121].

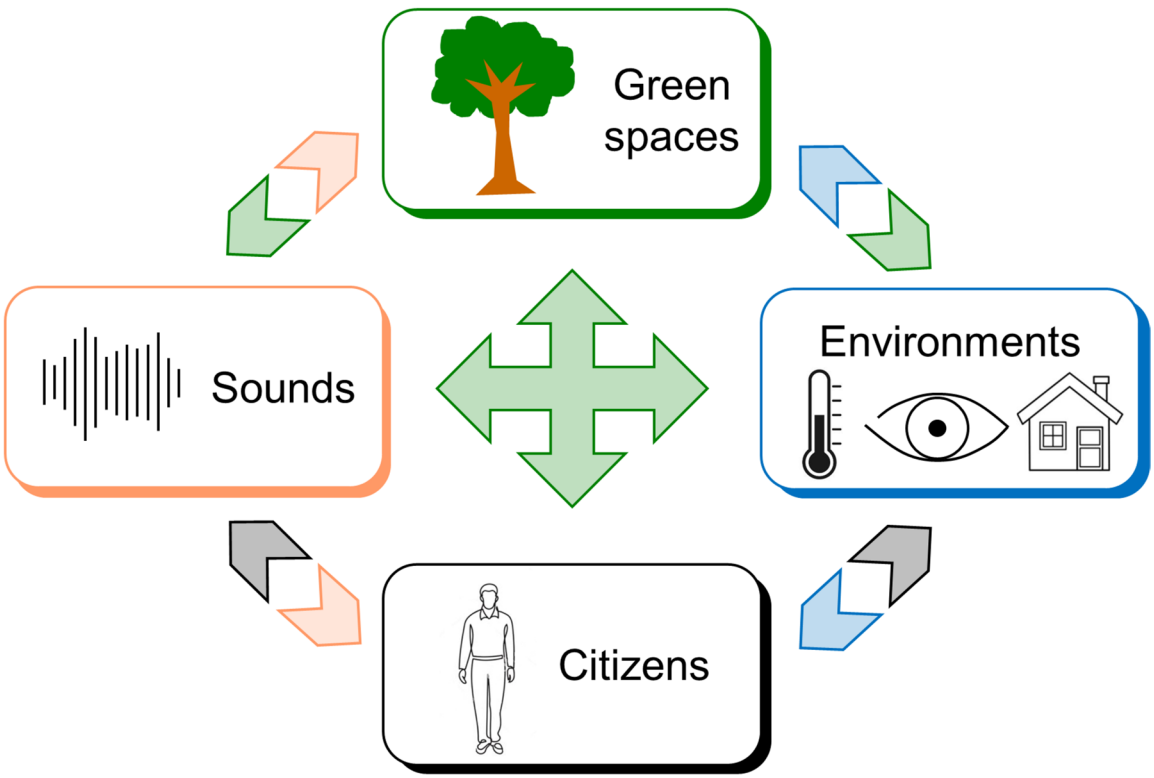

Fig. 2 Green space interactions

Auditory and visual interactions have been extensively studied. The sound environment, particularly when it features natural sounds like bird songs, wind rustling through trees, and water, can enhance the visual landscape's appreciation, whether composed of various types of vegetation or undulating terrain [96]. Some researchers suggest that visual stimuli are more important than auditory ones in environmental perception, though they acknowledge that soundscape quality is crucial for enhancing the restorative potential of urban green areas [122]. When analyzing visibility, it is common to focus solely on the visibility of greenery. In fact, some researchers have quantified this through the Green View Index (GVI) [18, 123]. This indicator moderates acoustic comfort but is effective primarily in areas with low or no road traffic. Other authors include the visibility of green and blue areas, obtaining greater satisfaction when these are present in areas with similar noise levels [123]. Factorial analyses conducted in different European public spaces show that visual and sound aspects are within the same factor, covering between 17 and 19% of the total variance [119]. Van Reterghem et al. [124] indicate that the visibility of greenery is a more dominant factor than the presence of green areas, and that it can reduce noise annoyance by 10 dB.

Other physical variables that interact with the soundscape are smell and temperature. Ba and Kang [125] found that the congruence of the fragrance of lilacs reduced traffic noise annoyance. Mohammadzadeh et al. [126] show that increased thermal sensation is inversely related to both the perception of the soundscape and the environment. These results will depend on the range of temperatures evaluated. Montes González et al. [127] show that an increase in temperature, in ranges of 9–23 °C, reduces the negative effects of noise. Zhou et al. [98] also observe that there is a worse perception of soundscapes in green spaces in winter, which is attributed to increased wind. In addition to these physical characteristics, the urban environment surrounding the green space can influence its perception. Liu et al. [128] reveal that spatial patterns of the local landscape could influence the perception of the soundscape more than the composition of the in situ landscape. Current studies reveal that poorer neighborhoods are exposed to higher levels of pollution and less access to natural environments, even though they are located in cities with a high quality of life [129••]. The characteristics of citizens who use or live near green areas also interact with the relationship between green spaces and their sound environment, as shown in Fig. 2. Noise sensitivity, knowledge of the evaluated green environment feature (greenness, birds, etc.), or length of residence were significant moderators in the relationship between green space and soundscape [4, 130]. Perceived safety in parks is also an important factor determining their use and attractiveness [131]. The activities that park users perform can be influenced by the quality of the soundscape. The beneficial effects of meditation have been shown to be increased in environments rich in natural sounds [45]. Moreover, activities can interfere with each other if the park design is inadequate. The sounds generated in dog areas (barking) or children's areas (screaming) can disturb other activities that require greater tranquility (reading, relaxing, etc.). In fact, noise annoyance in recreational areas is lower compared to other environments with similar noise levels [132]. Rey Gozalo et al. [16••] show the influence of the sound environment on physical activities that require less effort (walking or strolling).

The trend of current research is to analyze the multiple interactions that occur in green spaces and that lead to an improvement in health and well-being. Until recently, studies analyzed the relationship between nature exposure and well-being independently or ignored the existence and interaction of various mediators [133, 134]. Therefore, it implied a gap on the interactions between multiple pathways. The effects of mediators on the interactions between objective and subjective characteristics are gradually being explored, although the number of studies is still limited. Models include a low number of mediators given the complexity of these interactions [55•]. The time of exposure to nature in green spaces, NDVI, physical activity, NO_2 and L_{den} (dB) significantly interact in the relationship between green spaces and self-reported health [54••]. Bloemsma et al. [135] show how noise, air pollution, and green areas (NDVI and percentages of green space) influence the mental well-being of adolescents, and Poulsen et al. [59••] examine their impact on cerebrovascular damage. In addition to noise and air pollution, physical activity is also used as a mediator in the relationship between exposure to nature and well-being [55•].

Conclusions

The features of green spaces determine the quality of the sound environment and, therefore, its perception by people (soundscape). In the relationship between urban green spaces and soundscape, the characteristics and activities of users and the properties of their physical environment also interact significantly. Thus, a multidisciplinary approach is necessary for the design of healthy green spaces. Urban green spaces generate a variety of benefits for the health and well-being of citizens and are a key element in the development of sustainable cities and communities. Their ecosystem function protects and maintains animal and plant biodiversity and allows citizens to interact with nature. In addition, it has a social function that has recently been highlighted after the COVID state of alarm. Future studies will likely focus on its energy function given the current crisis that European countries are experiencing.

Most urban green spaces have not been designed considering the soundscape. Noise pollution is a serious urban environmental problem that has not decreased in recent decades despite the regulations imposed. Parks can be designed as spaces to reduce the noise from the surrounding urban

environments. Hence, if the goal is focused on the quality of the residential sound environment, the soundscape present in green areas may not be healthy. Conversely, if green areas are protected so that their sound levels are low (quiet areas) and that natural sources predominate to generate a high-quality soundscape, the users of green areas would benefit from the positive impact that sound has on their health and well-being and from its interaction with other elements and physical characteristics of the environment.

Current studies show the relevance that the soundscape has acquired in the assessment of different urban environments, the progress in its evaluation and analysis, and the significant effect of this on the relationship between green space and health benefits. In the prediction of health and well-being benefits, the shift has been from bivariate to multivariate models where not only is the direct relationship taken into account, but also the interaction between the different factors is considered. Urban green spaces are multidimensional natural spaces where the quality of them depends on the quality of each of its elements. Current studies are aimed at quantifying the interaction of each of the elements, and the intensity and reproducibility of this interaction depends, to a large extent, on the quality of its measurement.

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- • Of importance
- •• Of major importance

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