Universitat Autònoma de Barcelona

Urban Green Space and Human Health: the Role of Quality Characteristics

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PhD Thesis / September 2020

PhD in Environmental Science and Technology

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Abstract

The ongoing urbanization is leading to an increasing number of people living in urban areas worldwide. Concurrently, epidemiological evidence accumulates regarding the beneficial effects of green space on urban residents' physical and mental health. To date, most of the epidemiological studies of urban greenspaces exposure effects have only focused on the presence (or lack) of urban green, overlooking its quality. However, when looking for a source of inconsistency amongst the findings of the studies of the health benefits of green space exposure, the available literature points towards quality. This thesis aims to evaluate how the association between urban green spaces and human health is impacted by green space quality and the use of different greenspace measures.

First, the stage is settled by systematically reviewing the currently available tools to assess the quality of urban green space. Second, the development and implementation of RECITAL, a novel quality assessment tool, is explained. Next, the quality assessment from RECITAL in Barcelona (ES) is used to analyze the role of quality in the association between urban green space and green space use, physical activity, and overweight/obesity. Finally, the associations of different greenspace exposure metrics with cardiovascular risk factors are evaluated and compared in a study based in Philadelphia (US).

The results of this thesis suggest that both green space quality and the use of different greenspace measures play an essential role in the association between urban green spaces and human health. Moreover, this relationship is modified by the social, demographic, and economic personal context.

Resum

La creixent urbanització està portant a un augment del número global de persones vivint en nuclis urbans. Simultàniament, l'evidència epidemiològica creix en referència als efectes beneficiosos dels espais verds urbans sobre la salut física i mental. Tot i això, fins ara, la majoria d'estudis epidemiològics sobre els efectes de la exposició a espais verds urbans s'han centrat en la presència (o absència) de verd urbà, passant per alt la seva qualitat. Tanmateix, la literatura apunta cap a la qualitat com a una font de possible incongruència en els resultats dels estudis on s'associa espais verds amb salut humana. Aquesta tesi té com a objectiu avaluar el rol de la qualitat dels espais verds i l'ús de diverses mesures d'aquests en la relació entre espais verds i salut humana.

Primer, es posiciona la recerca mitjançant una revisió sistemàtica de les eines actualment disponibles per avaluar la qualitat dels espais verds urbans. Segon, es desenvolupa i implementa RECITAL, una nova eina per avaluar la qualitat dels espais verds urbans. Seguidament, les mesures generades per RECITAL a Barcelona (ES) són utilitzades per analitzar els efectes de la qualitat dels espais verds sobre el seu ús, l'activitat física i el sobrepès/obesitat. Finalment, s'analitzen les associacions de diverses mesures d'espai verd amb factors de risc cardiovascular en un estudi a Philadelphia (EE.UU.).

Els resultats d'aquesta tesi suggereixen que tant la qualitat dels espais verds com l'ús de diferents mesures d'espai verd urbà juguen una funció essencial en l'associació entre espais de verd urbà i salut humana. A més, aquesta relació es veu modificada per factors socials, demogràfics, i econòmics.

Resumen

La creciente urbanización está llevando a un aumento del número global de personas viviendo en núcleos urbanos. Simultáneamente, la evidencia epidemiológica crece en referencia a los efectos beneficiosos de los espacios verdes urbanos sobre la salud física y mental. Aun así, hasta ahora, la mayoría de estudios epidemiológicos sobre los efectos de la exposición a espacios verdes urbanos se han centrado en la presencia (o ausencia) de verde urbano, pasando por alto su calidad. Sin embargo, la literatura apunta hacia la calidad como una fuente de posible incongruencia en los resultados de los estudios donde se asocia espacios verdes con salud humana. Esta tesis tiene como objetivo evaluar el rol de la calidad de los espacios verdes y el uso de varias medidas de estos en la relación entre espacios verdes y salud humana.

Primero, se posiciona la investigación mediante una revisión sistemática de las herramientas actualmente disponibles para evaluar la calidad de los espacios verdes urbanos. Segundo, se desarrolla e implementa RECITAL, una nueva herramienta para evaluar la calidad de los espacios verdes urbanos. Seguidamente, las medidas generadas por RECITAL en Barcelona (ES) son utilizadas para analizar los efectos de la calidad de los espacios verdes sobre su uso, la actividad física y el sobrepeso/obesidad. Finalmente, se analizan las asociaciones de varias medidas de espacio verde con factores de riesgo cardiovascular en un estudio en Philadelphia (EE. UU.).

Los resultados de esta tesis sugieren que tanto la calidad de los espacios verdes como el uso de diferentes medidas de espacio verde urbano juegan una función esencial en la asociación entre espacios de verde urbano y salud humana. Además, esta relación se ve modificada por factores sociales, demográficos, y económicos.

Acknowledgments

Although the thesis starts with this piece, is the last one I'm writing. It is the only part where I am feeling comfortable using the first person singular instead of the plural. Throughout the writing of the thesis I've used a lot words like "suggest" or "hint" to acknowledge that the results presented are open to discussion and still there is a long evidence trail to follow. However, there is one fact that I can assert that is not open to discussion: this thesis would not be possible without the help of a lot of people. I'll do my best to acknowledge their essential role in the following paragraphs.

Growing up in a household with two physicians as parents, normal dinner included discussions about lethal infections or watching a gruesome medical TV show. When choosing my undergrad, studying something surrounding human health seemed like my obvious choice. I delved in the world of environmental sciences and though that that option was gone for me. I want to thank both my parents, Ana and Hernando, for their way of balancing support and pressure, for worrying about my future while trusting me with my own decisions, and for, maybe unknowingly, grow my interest in science. Also as physicians, for always gladly engage and ask the right questions when I brought my own health-related discussion to the supper table.

My parents had reasons to worry about my future, as ending my undergrad I was considering way too many possible paths. A real matter of chance brought me to Martí Boada, who deposited his trust in me without much reason. I always carry with me the small pieces of wisdom he relentlessly shared with us. I also want to thank Esteve for stepping-in when Martí could not continue being my tutor. Even before being my tutor, he was someone to look up to, with his contagious upbeat character.

If this story about helping a PhD student find its way had a protagonist, that would be Roser. She was there when everything happened: good and bad. I’m quite sure that she had a lot to do with Marti’s predisposition to take me on. Since then, she has always showed enthusiasm about what I was doing, even when I felt lost. She knows how to guide without pushing, how to turn mistakes into learning opportunities, and, almost utopicaly, how to handle me and her other students without any murderous thoughts. Second runner for protagonist would be Payam, he came in a little bit latter as co-supervisor, but brought everything he could to the table. He knows what works and how to do it, an invaluable skill in academia and one I’m thankful to learn.

This story also has a wonderful line-up of companions. The merry people from the *Conservation, Biodiversity and Global Change* group: Albert, Quim, Toni, Mari Carmen, Antonio, Jaume, and Sonia. For always having a warm hug ready, no matter how many fires were waiting to be extinguished. From the *Green Team*: Lucia, Maria, Lilly, and Mariska. For making me feel more accompanied in my first steps into epidemiology, which felt like a spinous path. The *not-so-green-people* at ISGlobal: Laura, Laura, Marta, Paula, Ana, Alba, and Carlos. For making me feel at home at PRBB with an unprecedented swiftness.

I found people that made my thesis experience easier. I was lucky to be able to rely on Lucia, Anna, Anna, Llorenç and Antonia for both their high level technical expertise and their willingness to patiently share it. When I had to confront one of my biggest enermies, bureaucracy, I had Cristina, Isabel, and Pere always by my side. I also want to remember the undergrad and master students I worked with, especially Maria and Luis, for forcing me to rethink parts of my research to be able to explain them.

I want to mention some people that have had an important role in this thesis, although they might not be aware. JM Antó and Manolis Kogevinas for opening the doors to ISGlobal and all the good things that came with it. Jaume Lanaspa, JM Moran, and Joan Rosàs from La Caixa Fundation and the Club of Rome for healing me secure the funding that has made this research possible. People from GEMOTT and BCNEJ, for always having their door open for discussion. Finaly, Leah Schinasi and Michelle Kondo, for helping me make the most out of the last months of my PhD.

Last, but not least, I want to remember the people that helped me forget about the thesis when I needed (or just wanted). *La Social disfunktion*, for giving me a place to unwind (pun intended) and funk around. The boardgames crew, for reminding me that thinking very intensively can also be fun - especially of you play like a railroad baron, a humble farmer, or a fierce shopkeeper. To the friends that do not share this hobbies with me: you are also important! And, of course, Maria.

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1. Introduction.

Context

Cities are growing worldwide. While high-income countries run ahead with around 79.1% of their population living in urban areas, low- and middle-income countries (LMICs) sit close to 51.7% with a large margin to urbanize. For the upcoming years, a non-stop increase in the urban population is anticipated, mainly in LMICs, with the proportion of the urban population being projected to reach a 68.4% globally in 2050 (World Urbanization Prospects - Population Division - United Nations).

Urbanization is not just “another piece" in global change: interestingly, it is both one of its main drivers and one of its main consequences. Urban systems depend on complex supply chains and establish intricate socioeconomic interactions, making cities and citizens susceptible to the consequences of the ongoing changes in the global climate. Since the industrial revolution (XVII-XVIII centuries), cities have become the powerhouse of development and wealth generation. As cities grow, they demand more resources, including materials, energy, water, and workforce. This increased demand steers changes in areas both surrounding the cities and in faraway lands (Grimm et al., 2008). These changes translate into broad effects worldwide mainly: increase of temperatures, loss of biodiversity (Penuelas & Boada, 2003), change in land use and land covers, alteration of biogeochemical cycles, spread of socioeconomic inequalities and segregation. Some of these effects lead to the displacement of the rural population, contributing to further urbanization. (Oliver-Smith, 2012)

Urban dwellers are often exposed to higher levels of urban-related environmental hazards than rural areas: like air pollution, noise, and heat. Furthermore, urban living is often associated with a sedentary lifestyle and increased psychological distress. Another main difference between urban and rural life is access to natural environments. Cities are in the center of the discussion regarding the relationship between humans and nature. On the one hand, as cities expand, urban dwellers grow apart from nature: relegating it to the outskirts or confined areas of the city (such as urban greenspaces), setting it aside from the daily life. Consequently, cities harbor a considerable number of people who do not have access to nature. On the other, the city-nature binomial has many potential benefits to offer each other, from the preservation of local biodiversity to the improvement of human health and well-being (Dearborn & Kark, 2010).

The potential beneficial health effects of urban green spaces have gained much momentum in the last years. An example of this is the inclusion of new terms in the vocabulary of academics and urban decisionmakers: like ecosystem services (or "the benefits human populations derive from ecosystems" (Bolund & Hunhammar, 1999)) or nature-based solutions (or "actions which are inspired by, supported by, or copied from nature" (European Commission, 2015)). Moreover, "access to safe, inclusive and accessible green and public space" is one of the aims of the UN Sustainable Development Goal 11:Cities ("Goal 11 | Department of Economic and Social Affairs," n.d.).The body of scientific evidence on the association between urban greenspaces and human health has flourished from the first steps taken by Ulrich in 1984 (Ulrich, 1984). He studied the postoperative stay of 23 patients and showcased a decrease in stay time, nurses' complaints and use of potent analgesics in patients with a view of nature from their window. Earlier studies were mainly experimental, looking at the short-term effects of the exposure to greenspace on predominantly mental health. More recently, epidemiological observational studies started to relate long-term greenspace exposure with not only mental health outcomes but also with physical health. Current research sustains potential associations for a wide variety of illnesses spanning through all age groups: from prevention of modern living risk factors, as obesity or stress, to child neurodevelopment. (Kondo, Fluehr, McKeon, & Branas, 2018)

Although evidence points towards the existence of an association, the details are still uncertain: some studies have found non-robust results while others have contradictory findings. There is still a long road to understanding the mechanisms underlying the health effects of green spaces and which are the relevant socio-economic, environmental, and personal characteristics to consider. On top of this, two critical questions remain: what is urban green space? And how do its features and characteristics influence its health exerting capabilities?

Depending on their scope and background, studies define and use urban green space differently: different words are used, and there is no single accepted definition of what urban green space is. In most cases, urban greenness is used as a direct synonym. However, such an assignment has two critical limitations: on the one hand, it conceptually omits fauna from the narrative. On the other, it unintentionally homogenizes the definition of green space, which is inherently diverse. As putting an end to the conceptual babelism surrounding green space is beyond the aim of this thesis, I will use the word greenspace as an interchangeable synonym with urban nature and urban greeness while fully acknowledging that nature is not only vegetation and that vegetation is not only green, it is also grey and blue.

This thesis focuses on the urban green space features and characteristics issue. It will contribute to dissipating some of the uncertainty regarding their role in nature and human health relationships.

1.1. Urban greenspaces exposure metrics.

Epidemiological studies focusing on the effects of urban green space can rely on different methods to measure exposure to greenspace.

Surrounding greenspace

The most available literature on the health effects of urban green spaces has relied on surrounding greenspace metrics. These measures capture the greenness surrounding the participants' residence (in some cases also their school or workplace) as an approximate of the overall greenspace in the participant's living environment. There are two methods available to produce this measure. First, the use of remote sensing-based indices of greenspace, like the Normalized Difference Vegetation Index (NDVI), a satellite-based greenness measure based on the vegetation reflectivity characteristics. Second, the use of land cover maps that include green space data. Both measures are abstracted for each participant, commonly using buffer areas surrounding the address of interest (residence, school, or workplace).

Proximity to green spaces

Similarly, most available literature regarding access to green spaces has used objective proximity to green spaces. These studies rely on Euclidian distances or network distance between the address of interest and the closest green space that fulfills some pre-defined requirements. This measure can be used as a continuous variable (distance to closest green space: X meters) or as a dichotomous one (access to green space: yes/no). Alternatively, some studies now rely on perceived access to green spaces, using questionnaires regarding the time-distance between their closest green space and their residence.

Visual access to greenspace

Some early experimental studies investigated the associations between visual access to greenspace and a range of health benefits (e.g. (Ulrich, 1984)). Epidemiological studies delving into the long-term health effects of visual access to green are relatively scarce, with some exceptions (e.g. (Torres Toda et al., 2020)). These studies rely on the assessment of the participants' window views either through using questionnaires with the participants or by systematic evaluation of window views by trained fieldworkers.

Use of green space

Lastly, some studies have focused on the participants' use of green spaces. This is done mainly through two methodologies. First, the use of questionnaires including questions about green space use, incorporating questions on frequency, time, and type of activity (e.g. (Dadvand et al., 2019)). Second, the use of tracking devices (Global Positioning System (GPS) or smartphones) to record the participants' movements, including the time spent in green spaces (e.g. (Miralles-Guasch et al., 2019)).

1.2. Mechanisms underlying health effects of greenspace

There have been many attempts to conceptualize the mechanisms underlying the health effects of greenspace exposure; however, these mechanisms have not been well established yet. Nieuwenhuijsen et al. (2017) explored these mechanisms from a human physiology perspective. They suggested six pathways through which urban greenspaces could potentially affect human health: inducing mental restoration and stress reduction, increasing physical activity, enhancing social contacts/cohesion, mitigating urban-related environmental hazards (such as air pollution, noise, or heat), and enriching microbial input from the environment.

Markevych *et al.* (2017), looked at the functions of greenspaces and divided the pathways into three main categories: mitigation, restoration, and instoration (or establishing). Mitigation pathways are those through which urban greenspaces could reduce the harm of exposure, such as mitigating urban-related environmental hazards. Restoration pathways are those through which urban greenspaces could induce citizens' recovery, such as improving mental restoration and stress reduction. Establishing pathways are those through which urban green could facilitate activities or promote behaviors such as physical activity.

Pretty (2004) focused on the spatial interaction of humans with greenspaces and classified it into three pathways: view of the green, incidental exposure to green and direct interaction with green. To update this approach based on current findings, it is necessary to add a fourth pathway: proximity to green spaces, as direct interaction with greenspace, is not required to be positively influenced by it. For example, the mitigation of air pollution or heat by a nearby green space that could influence a participant's health without having a direct interaction with that space.

All three conceptualizations are useful on their own, but they need each other to fully portrait the association between urban green spaces and human health and inform and influence decision-makers.

1.3. Human health benefits of urban green spaces

For long, people have appreciated the mental health benefits of green space. In the mid 20th century, experimental studies started looking at the short-term health effects of greenspace exposure, mainly on mental health. From the beginning of the 21st century, observational epidemiological studies started to look at the effects of long-term exposure to greenspace on not only mental health but also physical health.

Pregnancy outcomes and complications

Exposure to greenspace has been linked to beneficial associations regarding pregnancy outcomes. Mainly, increased surrounding greenspace has been associated with improved fetal growth, including increased birth weight and reduced risk of low birth weight (Akaraci, Feng, Suesse, Jalaludin, & Astell-Burt, 2020). Regarding pregnancy length, some studies reported no association (Dadvand et al., 2012), while others suggested a reduced risk of preterm birth (Hystad et al., 2014). Greenspace has also been suggested to have a protective association with pregnancy complications, like diabetes and hypertension. However, a recent systematic review by (Zhan et al., 2020)did not found any significant association.

Neurodevelopment in children

Neurodevelopment in children has been suggested to be positively associated with contact with nature (Kellert, 2006). Children with the deficit-hyperactivity disorder (ADHD) spending time in green spaces might have improved attention and reduced symptoms severity (van den Berg & van den Berg, 2011). Higher residential greenness has also been linked to a reduced risk of behavioral and emotional problems (Markevych et al., 2014) and enhanced cognitive development (Wilma L. Zijlema et al., 2017)

Cognitive function in adults

Similar to children, exposure to greenspace has been suggested to have a beneficial influence onto adults' cognitive function. Although the evidence is scarce, studies suggest an association between visual aces to greenspace and improved direct attentional capacity as well as lower concentration problems (de Keijzer, Gascon, Nieuwenhuijsen, & Dadvand, 2016).

Mental health and well-being

One of the most robust associations in the literature is the one between exposure to greenspace and mental health. Potential mental health effects of greenspace exposure include improved mood, lower risk of psychological distress and psychiatric conditions, and reduced likelihood of use of psychiatric medicine (Gascon et al., 2015). Moreover, the beneficial associations also impact well-being and self-reported health: including improved perceived general health in adults (Gascon et al., 2015) and self-satisfaction in children (Dadvand et al., 2019).

Other non-communicable diseases

The current literature also suggests beneficial effects of exposure to greenspace upon other non-communicable diseases. Including, amongst others, lower risk of cardiovascular conditions (Maas et al., 2009), diabetes (Dalton et al., 2016), and prostate cancer (Iyer et al., 2020).

Aging

Long-term exposure to greenspace has also been found suggestive of promoting healthy aging and improved both mental and physical health in the elderly (de Keijzer, Bauwelinck, & Dadvand, 2020).

Mortality

Recent meta-analyses have revised the role of greenspace exposure in mortality and found that higher residential greenness is associated with premature all-cause mortality (Rojas-Rueda, Nieuwenhuijsen, Gascon, Perez-Leon, & Mudu, 2019), especially cardiovascular mortality (Gascon et al., 2016a)

1.4. The role of urban greenspaces quality

To date, most of the epidemiological studies of urban greenspaces exposure effects have only focused on the presence (or lack) of urban green, overlooking its quality (W. L. Zijlema et al., 2020). However, urban green spaces can be very diverse in their quality - understanding quality as the attributes that affect the use and interaction of the population with the UGS, including characteristics (e.g., size or location), features (e.g., facilities or amenities), and fitness for purpose (e.g., maintenance or condition) (C. Gidlow et al., 2018a). Evidence shows that quality influences the use of green spaces (McCormack, Rock, Toohey, & Hignell, 2010) and their salutogenic potential (Wheeler et al., 2015). Among others, Nieuwenhuijsen *et al.* (2017) promote the characterization of multidimensional quality indicators and the their inclusion in epidemiological studies. In this context, the available literature points towards quality when looking for a source of inconsistency amongst the findings of the studies of the health benefits of greenspace exposure (Markevych et al., 2017). Quality is a broad concept that is commonly divided into different quality dimensions. Each dimension refers to a specific facet of quality, like the presence of amenities and facilities, accessibility, safety, or biodiversity.

To assess the quality dimensions, different quality assessment tools are currently available. The *in situ* quality assessment tools are considered the most promising ones. They could offer a standardized and objective characterization of different quality aspects of green spaces with a high level of detail (C. Gidlow et al., 2018b). Some of these tools focus on a few specific quality dimensions, closely related to a single health outcome, which allows for high reliability (C. J. Gidlow, Ellis, & Bostock, 2012). Being very focused on a single health outcome comes at the cost of its generalizability, not being useful for other outcomes (C. Gidlow et al., 2018b).

An alternative option to capture the differences amongst green spaces is the use of different measures. While NDVI is the most used greenspace measure, it homogenizes all greenspace by capturing data only on vegetation presence and density. Some studies have started using different measures, like other remote-sensing based indexes (Enhanced Vegetation Index (EVI), Modified Soil Adjusted Green Index (MSAVI), Vegetation Continuous Fields (VCF)), or land-cover databases that differentiate between greenspace typologies. Reid et al. (2017), for example, found differences in the associations between tree cover, grass cover, and overall vegetation with self-reported health.

2. Aim & Objectives

The overarching aim of the thesis was to investigate the association between urban green spaces and human health and to disentangle the role of the quality of urban greenspace in this association. Towards this aim, I accomplished the following five specific objectives:

- Reviewing the available quality assessment tools for urban green spaces. (**Paper I**)
- Developing and implementing a reliable multidimensional quality assessment tool for green spaces that could be applied by epidemiological studies of the human health effects of green spaces. (**Paper II**)
- Analyzing the associations between different quality dimensions of urban green spaces and selected health outcomes. (**Paper III**)
- Comparing the associations between different urban green measures with selected health outcomes. (**Paper IV**)
- Assessing the potential effect modification of sociodemographic variables in the association between urban green spaces and human health (**Papers III & IV**)

3. Publications

This section presents the four main publications I have developed during the PhD. As intended, the third first papers follow a typical publication structure. The first one could be considered as the introduction, as it sets the stage by systematically reviewing the currently available tools to assess the quality of urban green space. The second one tackles the methodology and explains how my quality assessment tool (RECITAL) was developed, implemented and assessed the reliability. The third paper links the results from the RECITAL to human health, allowing for the better understanding of the links between the two. The fourth paper, which was the outcome of my international stay in Philadelphia, US, expands on the previous paper by evaluating and comparing the effects of different metrics of the greenspace exposure on human health.

The interdisciplinary perspective of this thesis allowed me to submit and publish in journals of different specializations, including urban planning, urban ecology, and epidemiology. The articles have only undergone aesthetic modifications to fit the thesis design, the content is presented as submitted to the journals.

Paper I: A systematic review of multi-dimensional quality assessment tools for urban green spaces.

Paper II: Development of Urban Green Space Quality Assessment Tool (RECITAL)

Paper III: Quality of Urban Green Spaces Influences Residents' Use of These Spaces, Physical Activity, and Overweight/Obesity.

Paper IV: Associations of urban green space with cardiometabolic risk factors: A comparative ecological study in Philadelphia

A systematic review of multi-dimensional quality assessment tools for urban green spaces.

PABLO KNOBEL, PAYAM DADVAND, ROSER MANEJA.

Abstract: We conducted a systematic review of quality assessment tools for urban green spaces to evaluate their replicability, comparability and validity. We assessed the characteristics of 15 published, multi-dimensional, direct observation tools regarding: publication, development, features and included dimensions. Even though all tools show acceptable inter-rater variability, there is a notable variability in their characteristics, from required time to conduct the assessment to the number of included items. Additionally, some specific dimensions are underrepresented, and the study units' definitions are feeble. We showcased the need for new tools that are more comprehensive and include more consistent reporting measures.

Published in *Health and* Place: Received 11 March 2019; Received in revised form 19 July 2019; Accepted 22 August 2019

1. Introduction

The presence of urban green spaces within cities has a critical role in urban habitability, particularly regarding health and wellbeing of urban residents. Evidence is accumulating regarding the association of the presence or proximity of urban green spaces with a wide range of health benefits such as improved mental health (Gascon *el al.*, 2015), increased physical activity (Lachowycz & Jones 2014), improved pregnancy outcomes (Dzhambov *et al.,* 2014) and child development (de Keijzer *el al.*, 2016), and reduced mortality (Gascon *et al.,* 2016) and morbidity (Maas *et al*., 2009). Besides these beneficial health effects, there are also some unwanted effects including allergies (Cariñanos & Casares-Porcel, 2011) and vector-borne diseases (Randolph, & Dobson 2012).

In addition to the health outcomes of the interaction between urban green spaces and humans, there have been attempts to conceptualize the way that such an interaction exerts its effects. Nieuwenhuijsen *et al.* (2017) suggested six main pathways through which urban green spaces could potentially influence human health: improving mental restoration and stress reduction, increasing physical activity, enhancing social contacts/cohesion, mitigating urban-related environmental hazards such as air pollution, noise, and heat, and enriching microbial input from environment. Pretty (2004) proposed three possible levels of interaction between humans and urban green spaces: the viewing of nature (either a real or reproduced); incidental engagement with nature (defined as *exposure while engaged in some other activity*); and direct engagement with nature (defined as *implying a positive decision to go to places where there is green nature, rather than being incidentally exposed to it while doing something else)*. Although differently, all three levels of interaction seem to influence human health.

To date, most of epidemiological studies of urban green exposure effects have only focused on presence (or lack) of urban green spaces, overlooking the quality of these spaces. These studies have applied Geographical Information System (GIS)-based measures or resident surveys to characterize proximity and accessibility to urban green spaces (Smith *el al.*, 2017). GIS-based measures can be coupled with satellite imagery to evaluate quality aspects of green spaces(Taylor *et al.*, 2011); however, remote sensing data still lacks the capability of detecting subtle changes in quality-related elements (Edwards *et al.*, 2013; Gidlow *et al.*, 2012). Resident surveys are another way of collecting data on quality-related elements and can be combined with in-deep questionnaires to both residents and users to evaluate the perceived quality of green spaces (Agyemang *et al.*, 2007) but perceived quality is very prone to subjectivity (Gidlow & Ellis, 2011).

Urban green spaces can be very diverse in their features (e.g. beautiful views or a specific selection of plant species) and characteristics (e.g. physical characteristics or size) which can be translated into variation in their quality. Quality of urban green spaces have been postulated to influence their salutogenic potential. van Dillen *et al.* (2011) suggested that specific features and characteristics might facilitate the effects of specific health interactions. For instance, research studies suggest that the presence of specific amenities and facilities is related to an increase of physical activity in children and adolescents (Edwards et al. 2015, Timpero et al, 2008). Incivilities and insecurity can generate an antagonization of the green space, reducing its use, while its attractiveness can increase it. (Knapp et al. 2018, Lo et al. 2018). Biological diversity, including land covers, and animal and plant diversity, as well as potential use and accessibility positively influence the psychological restoration capacities of urban green. (Wood et al. 2018, Wood et al. 2017). Each dimension of quality might affect different outcomes and the relations are not independent. Each feature or characteristic might be simultaneously influencing many pathways and interaction levels. To study different health effects of urban green spaces and their underlying pathways it is necessary to have a multi-perspective approach to urban green spaces. In-situ observational audits allow for objective standardized characterization and quality evaluation of urban green spaces (Gidlow *et al*., 2018).

Recently, there has been an increase in the development and availability of in-situ observational tools to evaluate the quality of urban green spaces. Some of these tools focus on specific dimensions of urban green spaces (e.g. biodiversity or quality of trails and paths) or are multi-dimensional but focusing on a specific pathways, such as physical activity. These tools often benefit from a larger reliability for characterizing the dimension on which they focus (Gidlow *el al.,* 2012) however, they have limited capability to characterize other relevant key quality dimensions of green spaces, making them less applicable by studies dealing these other aspects. (Gidlow et al., 2018). In this context, comprehensive multi-dimensional assessment tools seem to have the most potential to be applied by the studies of the health effects of green spaces as they allow for the inclusion of different dimensions that need to be explored and dimensions that might be relevant to different pathways underlying health benefits of green spaces. Nevertheless, all tools come from different backgrounds and have their own specific aim. This diversity contests the validity, comparability and reliability of their methodologies and their results. For example, the definition of urban green space in not the same for every tool and a modification of the study unit selection criteria might be very relevant in the results.

Since features and characteristics of urban green spaces have an important role in their health effects, it is critical to promote studies that consider and include comprehensive multidimensional quality indicators (Mitchell & Popham, 2007; Nieuwenhuijsen *el al.,* 2017) and use synthetized and multidimensional definitions and tools to do so. In this context, this review aimed to systematically review the available multidimensional tools for evaluating the quality of the urban green space. Towards this aim, we also investigated the validity, replicability and comparability of the assessed quality by these tools.

2. Methods

The review was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Liberati at al., 2009) (See Supplementary Table S1). Tool selection was made through a systematic keyword search in "Web of Science" and "Scopus" using Boolean operators. The keyword selection was divided into two blocks: (1) the "quality tool" section which included 3 elements: "quality assessment", "audit" and "assessment tool"; and (2) the "urban green spaces" section that included 12 elements: "green space", park, garden, forest, greenway, "natural environment", greenness, greenery, "urban green", "open space" and "public space". "OR" operator was used between the terms in each block and then an "AND" operator between the two blocks. Selected articles should include at least one element of each block. We included (1) original articles, (2) presenting multi-dimensional quality assessment tools for urban green spaces based on direct observation that (3) were published in peer-review journals (4) in English (5) until July 6th, 2019.

Rayyan QCRI (https://rayyan.qcri.org), an online tool specifically designed to facilitate literature reviews, was used to conduct the review. After removing the duplicatesthere were subsequent exclusion rounds by the reading of the titles, then the abstract and finally the full articles.. Once selected, a checklist was completed for each tool through the reading of the article where they are explained and validated and, if available, their field guide, where they were more technically and meticulously developed. The items included in the checklist were selected by their possible relevance in tool validity, replicability, comparability and overall quality. The checklist included 27 items divided in 4 thematic groups: (1) general information about the tool authorship and publication; (2) tool development process; (3) features of the tool; and (4) inclusion of specific quality dimensions elements in the tool. (TABLE 1). The dimensions were defined from the different factors that research studies point as possibly relevant for the effects of urban green spaces onto human health and wellbeing. Additionally, surroundings and policies were also included because they are cross-cutting dimensions that might affect all the others, even though literature does not point them directly as relevant dimensions.

Table 1: items checklist.

Thematic group	Item
General information	Tool name. Tool acronym. Authors. Year of publication.
Tool development	Is the tool based in other tools? Does the tool have an outcome focus? Does the tool have a population focus? Was the tool co-designed?
Tool features	How long was the training of the technicians? How long does it take for each site? Inter-rater reliability What scoring system does it use? Are the study units well defined? How many items does the tool have? How many dimensions does the tool have?
Dimensions of green spaces quality.	**Surroundings**: inclusion of elements regarding the surrounding area and not only the urban green spaces itself. Examples can be surrounding street form or surrounding buildings aesthetics. **Accessibility**: inclusion of elements regarding the accessibility of the site in a broad sense. Examples can be indicators about the urban green spaces entrances or walking and cycling paths. **Facilities**: understood as the green space features that allow for the realization of a specific activity. Examples can be the presence of playgrounds or outdoor gyms. **Amenities**: understood as the park features that make the urban green spaces more comfortable, convenient or enjoyable. Examples can be the presence of bike racks or benches.

Aesthetics and attractions: elements referring to the beauty or the attractiveness of the urban green spaces. Examples can be presence of public art or viewpoints.
Incivilities: presence of elements that make the urban green spaces less enjoyable. Examples can be excessive noise or vandalism.
Safety: in reference to the presence of elements or characteristics that make urban green spaces feel safer. Examples can be: Vision form surrounding streets, or the presence of security cameras.
Usage/activities: suitability for different activities. Examples can be suitability to relax or the go walking.
Covers: measures of land covers.
Policies: the evaluation of the park policies. Examples can be the banning of dogs or ball play.
Animal biodiversity: measures of animal diversity.
Plant biodiversity: measures of plant diversity.

The described methodology complied with all the items that applied from the Critical Appraisal Skills Programme Checklist for Systematic Reviews (2018). It has a clearly defined aim and a accurate keyword search. Therefore, we believe that all relevant studies were included. Additionally, the quality assessment of the found tools was done in a structured and systematic way.

3. *Results and discussion*

Our initial search retrieved 2130 articles from Web of Science and 1909 from Scopus. After removal of 972 duplicates, 482 were excluded because they were not original articles from peer-reviewed journals and 27 because they were not in English. From the 2.505 remaining, 2.357 were excluded by the title and 90 by their abstract. A total of 58 articles were read in full, from which 27 were excluded for using tools that did not fulfill the requirements and 19 because they were not presenting a tool but referencing it in another article. The systematic review ended with 12 tools plus 3 tools found by the referencing of tools in read articles. The final number of included tools is 15. (Figure 1).

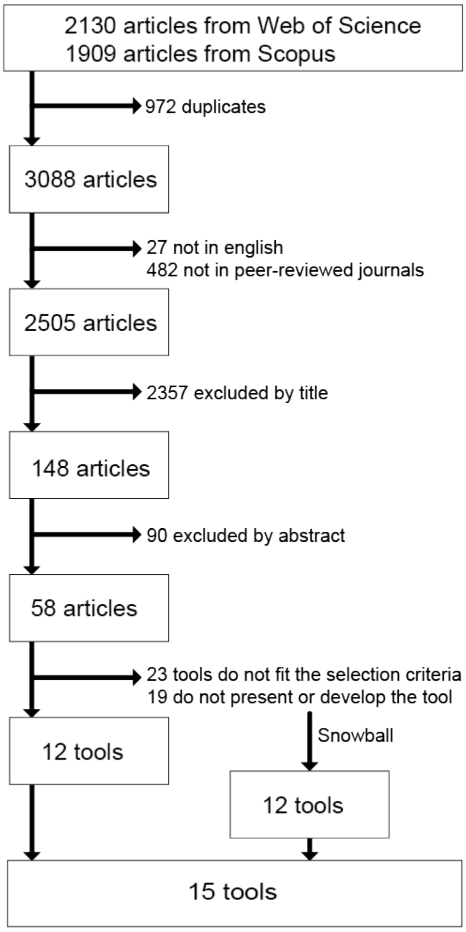

Figure 1: Study selection process.

The assessment of the different tools allowed for the showcasing of considerable variability amongst them including differences (or lack of information) in (1) the tool focus; (2) the tool design process; (3) the "time per visit" and "training time" on these aspects); (4) the number of included items; (5) the study unit definition and inclusion criteria differences; and (6) the structure, definition and inclusion of tool dimensions (Table 2).

Tool publication

The number of available tools is steadily increasing over time. The creation of new tools seems to have been motivated by three possible circumstances. Some large studies required a multi-dimensional urban green spaces assessment tool and created their own, tailored to their needs and resources (POST, EARPS, BRAT-DO are amongst these tailored tools). Other studies intended to use previously existing tools but needed to adapt them to their requirements (e.g. focus in a specific activity, population group or geographic context; or resource availability) (NZ- POST, NGST, PARK are amongst these adapted tools). Finally, studies with very specific requirements applied one-time tools that could fit their needs and did not have a specific aim towards replicability (Timperio *el al.* van Dillen *el al. Veinberga et al* are amongst these stand-alone tools). Additionally, the research around the effects of urban green spaces on human health, including or not quality assessment, is evolving very quickly. Tool availability needs to stay updated to the new trends in the research and the need for new or adapted tools. (TABLE 2)

Tool development

Tools used to focus on physical activity until early 2010s, then tools with broader focus started to appear and became more common. Contrarily, tools focusing specifically on children do not seem to follow any temporal trend as they appear scattered through the years. These tools with specific foci (as children or physical activity) tend to have high reliability. They are especially useful in specifically focused studies but tend to oversee or to differently define and measure items that might be critical for other focuses. Therefore, tools with a specific focus are commonly sub-optimal for broader scoped studies. Consequently, the appearance of tools without a specific focus is a result of the increasing demand for this kind of studies. If future research requires tools designed for new specific activities, outcomes, pathways or population groups the number of specifically focused tools might increase in the future. (TABLE 2)

Table 2: general information about the tool authorship and publication and tool development proces

Tool	Name	Authors	Year of publication	Focus: outcome	Focus: population group	Participatory co-design
POST	Public Open Space Tool	Giles-Corti et al.	2005	Physical activity	No.	Expert input
EARPS	Environmental Assessment Of Public Recreation Spaces	Saelens et al.	2006	Physical activity	No.	Professionals and users survey
BRAT-DO	Bedimo-Rung Assessment Tool	Bedimo-Rung et al.	2006	Physical activity	No.	Expert input
C - POST	Children Public Space Tool	Crawford et al.	2008	Physical activity	No.	-
Timperio et al.	-	Timperio et al.	2008	Physical activity	Children	-
NZ - POST	New Zeeland Public Open Space Tool	Badland et al.	2010	Physical activity	No.	-
van Dillen et al	-	van Dillen et al	2011	No.	No.	-
CPAT	Community Park Audit Tool	Kaczynski et al.	2012	Physical activity	No.	Community stakeholders
NGST	Neighborhood Green Space Tool	Gidlow et al.	2012	No.	No.	Focus groups & survey
READI Park Tool	Resilience for Eating and Physical Activity Despite Inequality Park Audit Tool	Veitch et al.	2013	Physical activity	No.	-
Voigt et al.	-	Voigt et al.	2014	No.	No	-
PSQUAT	Playable Space Quality Assessment Tool	Jenkins et al.	2015	No.	Children	-
PARK	Parks, Activity and Recreation Among Kids	Bird et al.	2015	No.	Children	-
Veinberga et al.	-	Veinberga et al.	2016	No.	No.	-
NEST	Natural Environment Scoring Test	Gidlow et al.	2018	No.	No.	Expert input

Tools features

It was not possible to answer all checklist items for each tool since the information was not available neither in the published paper or the field guide. This is especially critical for *Training Time* and *Time per Visit*, which were only available for four tools. Nevertheless, there is variability amongst the different tools regarding these two items: training time ranged from nine full days for PARK to half a day in POST and average time per site ranged from 11 minutes for NGST to 67 minutes for EARPS. Both these items are good indirect indicators of the tool complexity and efficiency, which are critical for tool replicability. The time required to train the technicians responsible for the fieldwork should be directly related to the number of items included, the complexity of the scoring system and the knowledge and skills from different disciplines required to use to tool. For example, PARK with 92 items and a mixture of binary, 5-poit scale and writing answers requires nine days of training while POST with 42 items and answers limited to binary and short writing demands needs only half a day of training. The amount of time can be heavily modified by the technician's previous experience. The time required per site is an indicator of tool efficiency, as it is related to the same items as the training time, but in this case, it is heavily modified by tool design. For example, EARPS with 646 items averages 67 minutes conducting each visit to each site while NGST with 36 items averages 11 minutes. Considering this, in order to assess the tool replicability, it would be necessary to include both time measures and information about the technician's expertise and experience.

Although there were different scoring options for different tools and the number of items for each scoring framework varied considerably, all showed a rather acceptable inter-rater reliability, taking into consideration that all tools eliminated the items without good enough values. Therefore, using more items or technical scoring systems could not affect the results consistency. Concurrently, and without comprehensive information about the training time and time per visit, it was not feasible to assert a correlation between the number of items and scoring framework with time requirements of the tools.

The synthetized and clear definition of the study units is critical for tool validity but also for replicability and comparability. The complicated process of comparing results due to different methodologies is exacerbated by the uncertainty about what elements are being studied. The definition of green space (or an equivalent as public open space, park or garden) is contested as each city, scientific discipline and even research communities might use it and define it differently. Therefore, it is necessary to provide a precise definition of selection criteria for the study unit. Despite this, green space definition was only included in eight of the tools and in most cases, they were short and unspecific.

The definition of the study units must be accompanied with a unit selection criterion. On the one hand, the inclusion criteria must be thorough and clear. The application of broad and unclear criteria on critical aspects such as accessibility or main use of the site could hamper the systematic selection of sites. On the other hand, relying on GIS or planning to steer the study unit selection can be useful for doing a first approach but also lacks precision. Planning does not always represent reality and GIS might not be temporally matched with the study. Nevertheless, the use of GIS or planning could be useful as a starting point in the selection of study units. In consequence, a proper selection might require the combination of a proper site selection criteria, a preliminary deskwork and a final selection through fieldwork. (TABLE 3)

Table 3: tool features

Tool	Time: technician training	Time: average per visit	Inter-rater reliability	Scoring	Definition of green	Number of items	Number of dimensions
POST	Half-day training	-	Kappa from 0.6 to 1.0	Binary + few writing	Size and access	42	4
EARPS	-	67 minutes	65.6% of items showed ICC=>.60%	Scale	Access and main use	646	1 6
BRAT-DO	Training	-	Overall validity against tool developers 78.8%	Checklist + scale	-	181	9
C - POST	-	-	at least adequate reliability	Cumulative + Binary	GIS	27	3
Timperio et al.	-	-	ICC greater than 80%	Binary	-	10	- -
NZ - POST	-	-	-	Cumulative + scale	Access	39	4
van Dillen et al	short training	-	Cranbach's Alpha = .65	5-point scale	-	10	- -
CPAT	-	32 minutes	-	Checklist	Planning,	140	3
NGST	-	11 minutes	moderate-good reliability	Scale	GIS and main use	36	6
READI Park Tool	-	-	Mean percent agreement 70% to 100%	Cumulative + scale	-	84	- -
Voigt et al.	-	-	-	Binary	-	38	3
PSQUAT	-	-	All ICC >0.85	Scale	-	24	3
PARK	9 days	-	86% has ≥ 75 % agreement	Binary + scale + text	Size and equipment	92	5
Veinberga et al.		-	-	Mixed items 5-point scale	Size, potential use and location	27	1 2
NEST	-	16 minutes	Agreement for the Overall Score (R2=.76, r=.87)	Checklist + scale	-	47	8

Tools dimensions

After the allocation of each tool item, the number of included checklist dimensions varied substantially from tool to tool, form three in CPAT to eight in POST, NZ – POST and Veinberga et al. Similarly, the number of times that each checklist domain was included in the evaluated tools also varied substantially, from 0 tools that included policies to 15 that included amenities (TABLE 4). We identified patterns according to the different checklist domain appearance amongst tools, checklist dimensions can be divided into three groups: first, the ones that appear frequently in the tools (Accessibility, Facilities, Amenities, Aesthetics and Attractions and Incivilities): these are dimensions that are more directly related urban green spaces and human health pathways. Second, the dimensions that appear in a scarce number of tools (Surroundings, Usage/Activities, Covers, Policies, Animal diversity and Vegetal diversity): these are checklist dimensions that seem to be related with pathways that are not as thoroughly studied as the other ones, but literature is starting to point to them as relevant ones. Finally, safety lays in between the other two groups, appearing in eight out of 14 tools.

The tool design process, including its focus, might be influential in the inclusion of specific checklist dimensions. The design process of the tool (whereas is based in another tool, is based on research studies and/or is co-designed) might have an impact in the final content and methodology selection of the tool, especially depending on the references they use or the stakeholders they engage in the design process. Additionally, the underrepresentation of some checklist dimensions in the tools might be relevant to the proper understanding of the relations between urban green spaces and human health. Understudied pathways can be heavily conditioned by these dimensions and their exclusion from studies might lead to lack of robustness as they might be playing an important role that is not considered.

Table 3: specific quality dimensions elements of each tool.

Tool	Surroundings	Accessibility	Facilities	Amenities	Aesthetics and attractions	Incivilities	Safety	Usage/activities	Covers	Policies	Animal biodiversity	Vegetal biodiversity	Total numer of dimensions included by this tool
POST	X	X	X	X	X	X	X				X		**8**
EARPS		X	X	X	X	X	X						**6**
BRAT-DO	X	X	X	X	X	X							**6**
C - POST		X	X	X	X		X						**5**
Timperio et al.		X	X	X	X								**4**
NZ - POST	X	X	X	X	X	X	X				X		**8**
van Dillen et al		X		X	X	X	X						**5**
CPAT	X		X	X									**3**
NGST		X	X	X	X	X		X					**6**
READI Park Tool		X	X	X	X	X	X						**6**
Voigt et al.			X	X	X		X		X			X	**6**
PSQUAT		X	X	X		X	X	X					**6**
PARK			X	X	X	X							**4**
Veinberga et al.			X	X	X	X		X	X		X	X	**8**
NEST		X	X	X	X	X		X					**6**
Total number of tools including this domain.	**4**	**11**	**14**	**15**	**13**	**11**	**8**	**4**	**2**	**0**	**3**	**2**	

Tool validity, replicability and comparability.

The wide diversity amongst tools makes it impossible to define general highlights about the validity, replicability and comparability of all the tools. Still, it is possible to outline some common tendencies and critical point that must be considered.

Tool validity is the most critical factor for the usability of the tool, but it can be contested by many different elements. It is necessary to evaluate if the selected dimensions are in line with the tool focus and aims. Studies with broad scopes must include a wide diversity of dimensions and the studies with an exploratory aim must have an even wider selection. Moreover, inter-rater reliability values must be reported in order to ensure the tools quality. Finally, the diversity of definitions problematizes the general validity of the tools since different researchers might conceive it differently, making it valid in some cases and not in others. Considering all this, reviewed tools can be subdivided following two different criteria: tools that might be valid but it is not possible to evaluate because there is not enough available information about them; and tools that might be valid or not depending on the research aims of the particular project.

Tool replicability depends mainly on two factors: fieldwork requirements and definition of urban green space. The requirements of the fieldwork (including training time, time per visit and required previous knowledge) can make the tools inaccessible to future research, especially when it is not clarified and might lead to changes in the application of the tool. The definition of urban green space also affects replicability as changes in the selection criteria of study units might also change the obtained results. The reviewed tools replicability changes from case to case. In some cases, it is impossible to assess and in others there is a variability on their requirements. Definition of urban green space remain problematic for all cases.

Tool comparability is linked to both tool validity and tool replicability. It is not possible to compare results between tools that aggregate different kinds of data or from a tool that has been applied differently each time. Using the reviewed tools it would not be possible to obtain straight quality comparable results between tools and it would be complex to obtain comparable results using the same tool. Although, it is possible to generate correlations between the results obtained by different tools in order to validate each tool results.

4. *Recommendations for future research*

Future tools should focus on three elements for their improvement: refining of used definitions, increase of comprehensiveness and increase reportability. The use of synthetized and clear definitions is necessary for the validity, comparability and replicability of the tools as it generates a shared framework to work with. Greater comprehensiveness might be critical to improve the tools' capability to analyze currently understudied interactions between urban green spaces and human health while enriching studies in interactions that are well studied. While reportability measures might not affect the quality of the tool results, they are critical for their quality assessment, especially regarding validity and replicability. Therefore, the inclusion of reporting measures, as time required per visit, expertise of the technicians or inter-rater variability, increases the tool reliability.

5. *Conclusions*

An increasing number of tools are becoming available for multi-dimensional quality assessment of urban green spaces. The dimensions included by each tool varied considerably and some dimensions are underrepresented (Surroundings, Usage/Activities, Covers, Policies, Animal biodiversity and Vegetal biodiversity) while others are always present in most tools (Accessibility, Facilities, Amenities, Aesthetics and Attractions and Incivilities). Studies with a broad scope or those dealing with unexplored interactions require as many dimensions as possible to include the unknown relevant factor as much as possible. A clear definition of green space is especially important, as it is not included in any of the tools and can have a great relevance in the study outcomes. This lack of a standardized definition for urban green spaces coupled with the lack of available data for some of the tools, difficulties tool replicability and makes comparability amongst tools rather complex. Nevertheless, there are enough currently available tools that showed acceptable inter-rater reliability and can offer very valuable information, especially considering that the exclusion of some dimensions can be interesting for studies that focus on specific interactions, reducing their time and resources requirements.

The use of quality assessment tools and their appliance in epidemiological studies can have an impact on how cities are designed and managed. City planners and managers with a concern about their citizens' health and wellbeing will be able to improve the positive effects of urban green spaces by precisely pinpointing and enhancing the key elements.

Acknowledgements

We would like to specially thank professor Martí Boada for his inestimable contributions and Carmen de Keijzer for her help with the systematic review. This study is supported by La Caixa Banking Foundation and the Club of Rome (Spanish Chapter and Barcelona Office). Payam Dadvand is funded by a Ramón y Cajal fellowship (RYC-2012-10995) awarded by the Spanish Ministry of Economy and Finance.

References

Agyemang, C., van Hooijdonk, C., Wendel-Vos, W., Lindeman, E., Stronks, K., & Droomers, M. (2007, 12 1). The association of neighbourhood psychosocial stressors and self-rated health in Amsterdam, The Netherlands. *Journal of epidemiology and community health, 61*(12), 1042-9.

Bird, M., Datta, G., van Hulst, A., Kestens, Y., & Barnett, T. (2015, 12 17). A reliability assessment of a direct-observation park evaluation tool: the Parks, activity and recreation among kids (PARK) tool. *BMC Public Health, 15*(1), 906.

Brownson, R., Hoehner, C., Day, K., Forsyth, A., & Sallis, J. (2009, 4 1). Measuring the Built Environment for Physical Activity: State of the Science. *American Journal of Preventive Medicine, 36*(4), S99-S123.e12.

Cavnar, M. M., Kirtland, K. A., Evans, M. H., Wilson, D. K., Williams, J. E., Mixon, G. M., & Henderson, K. A. (2004). Evaluating the Quality of Recreation Facilities: Development of an Assessment Tool. *Journal of Park & Recreation Administration*, 22(1).

Cariñanos, P., & Casares-Porcel, M. (2011, 6 15). Urban green zones and related pollen allergy: A review. Some guidelines for designing spaces with low allergy impact. *Landscape and Urban Planning, 101*(3), 205-214.

Chaudhury, M., Oliver, M., Badland, H., Garrett, N., & Witten, K. (2017, 3 4). Using the Public Open Space Attributable Index tool to assess children's public open space use and access by independent mobility. *Children's Geographies, 15*(2), 193-206.

de Keijzer, C., Gascon, M., Nieuwenhuijsen, M., & Dadvand, P. (2016, 12 11). Long-Term Green Space Exposure and Cognition Across the Life Course: a Systematic Review. *Current Environmental Health Reports, 3*(4), 468-477.

Dzhambov, A., Dimitrova, D., & Dimitrakova, E. (2014, 1 1). Association between residential greenness and birth weight: Systematic review and meta-analysis. *Urban Forestry & Urban Greening, 13*(4), 621-629.

Edwards, N., Hooper, P., Trapp, G., Bull, F., Boruff, B., & Giles-Corti, B. (2013, 3 1). Development of a Public Open Space Desktop Auditing Tool (POSDAT): A remote sensing approach. *Applied Geography, 38*, 22-30.

Francis, J., Wood, L., Knuiman, M., & Giles-Corti, B. (2012, 5 1). Quality or quantity? Exploring the relationship between Public Open Space attributes and mental health in Perth, Western Australia. *Social Science & Medicine, 74*(10), 1570-1577.

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Forns, J., Plasència, A., . . . Nieuwenhuijsen, M. (2015, 4 22). Mental Health Benefits of Long-Term Exposure to Residential Green and Blue Spaces: A Systematic Review. *International Journal of Environmental Research and Public Health, 12*(4), 4354-4379.

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. (2016, 1 1). Residential green spaces and mortality: A systematic review. *Environment International, 86*, 60-67.

Gidlow, C., & Ellis, N. (2011, 11). Neighbourhood green space in deprived urban communities: issues and barriers to use. *Local Environment, 16*(10), 989-1002.

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., . . . Nieuwenhuijsen, M. (2018, 1). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening, 29*, 322-333.

Heerwagen, J. H., & Orians, G. H. (1995). Humans, habitats. *Biophilia Hypothesis*, *138*, 138-172.

Joseph, R., & Maddock, J. (2016, 12 15). Comparative Analysis of Five Observational Audit Tools to Assess the Physical Environment of Parks for Physical Activity, 2016. *Preventing Chronic Disease, 13*, 160176.

Kaczynski, A., Wilhelm Stanis, S., & Besenyi, G. (2012, 3 1). Development and Testing of a Community Stakeholder Park Audit Tool. *American Journal of Preventive Medicine, 42*(3), 242-249.

Knapp, M., Gustat, J., Darensbourg, R., Myers, L., & Johnson, C. (2018, 12 30). The Relationships between Park Quality, Park Usage, and Levels of Physical Activity in Low-Income, African American Neighborhoods. *International Journal of Environmental Research and Public Health, 16*(1), 85.

Lachowycz, K., & Jones, A. P. (2014). Does walking explain associations between access to greenspace and lower mortality?. *Social Science & Medicine*, *107*, 9-17.

Liberati, A., Altman, D., Tetzlaff, J., Mulrow, C., Gøtzsche, P., Ioannidis, J., . . . Moher, D. (2009, 7 21). The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions: Explanation and Elaboration. *PLoS Medicine, 6*(7), e1000100.

Maas, J., Verheij, R., de Vries, S., Spreeuwenberg, P., Schellevis, F., & Groenewegen, P. (2009, 12 1). Morbidity is related to a green living environment. *Journal of epidemiology and community health, 63*(12), 967-73.

Mitchell, R., & Popham, F. (2007, 8 1). Greenspace, urbanity and health: relationships in England. *Journal of epidemiology and community health, 61*(8), 681-3.

Nieuwenhuijsen, M., Khreis, H., Triguero-Mas, M., Gascon, M., & Dadvand, P. (2017, 1). Fifty Shades of Green. *Epidemiology, 28*(1), 63-71.

Pretty, J. (2004, 6 1). How nature contributes to mental and physical health. *Spirituality and Health International, 5*(2), 68-78.

RANDOLPH, S., & DOBSON, A. (2012, 6 16). Pangloss revisited: a critique of the dilution effect and the biodiversity-buffers-disease paradigm. *Parasitology, 139*(07), 847-863.

Smith, G., Cirach, M., Swart, W., Dėdelė, A., Gidlow, C., van Kempen, E., . . . Nieuwenhuijsen, M. (2017, 12 26). Characterisation of the natural environment: quantitative indicators across Europe. *International Journal of Health Geographics, 16*(1), 16.

Taylor, B., Fernando, P., Bauman, A., Williamson, A., Craig, J., & Redman, S. (2011, 2 1). Measuring the Quality of Public Open Space Using Google Earth. *American Journal of Preventive Medicine, 40*(2), 105-112.

Timperio, A., Giles-Corti, B., Crawford, D., Andrianopoulos, N., Ball, K., Salmon, J., & Hume, C. (2008, 11 1). Features of public open spaces and physical activity among children: Findings from the CLAN study. *Preventive Medicine, 47*(5), 514-518.

Parsons, R., Tassinary, L. G., Ulrich, R. S., Hebl, M. R., & Grossman-Alexander, M. (1998). The view from the road: Implications for stress recovery and immunization. *Journal of environmental psychology*, *18*(2), 113-140.

van Dillen, S., de Vries, S., Groenewegen, P., & Spreeuwenberg, P. (2012, 6 1). Greenspace in urban neighbourhoods and residents' health: adding quality to quantity. *Journal of epidemiology and community health, 66*(6), e8.

Veitch, J., Salmon, J., Ball, K., Crawford, D., & Timperio, A. (2013, 2 1). Do features of public open spaces vary between urban and rural areas? *Preventive Medicine, 56*(2), 107-111.

Voigt, A., Kabisch, N., Wurster, D., Haase, D., & Breuste, J. (2014, 5 17). Structural Diversity: A Multi-dimensional Approach to Assess Recreational Services in Urban Parks. *AMBIO, 43*(4), 480-491.

Whitehouse, S., Varni, J., Seid, M., Cooper-Marcus, C., Ensberg, M., Jacobs, J., & Mehlenbeck, R. (2001, 9 1). Evaluating a children's hospital garden environment: utilization and consumer satisfaction. *Journal of Environmental Psychology, 21*(3), 301-314.

Development of the Urban Green Space Quality Assessment Tool (RECITAL)

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Abstract: The quality of green spaces could play a crucial role in the health benefits of green spaces and their underlying mechanisms. We developed and implemented the RECITAL: a multidimensional *in situ* quality assessment tool for urban green spaces, primarily aimed to characterize quality aspects with relevance to human health. The tool includes 90 items divided into eleven thematic dimensions. Applying RECITAL, we assessed the quality of 149 urban green spaces in the city of Barcelona, Spain, and the obtained results showed overall good-to-excellent reliability. Decision-makers could use the quality scores generated by RECITAL to fine-tune the design and management of urban green spaces. At the same time, researchers could apply it to study how different quality aspects of urban green spaces would affect their potential to exert health benefits.

Submitted to *Urban Forestry & Urban Greening*: Received 7 March 2020; major revisions pending.

1. *Introduction:*

Urban Green Spaces (UGS) have been associated with different aspects of health and wellbeing of urban residents including better mental and perceived general health (Gascon *et al.*, 2015), improved pregnancy outcomes and reduced risk of pregnancy complications (Banay *et al.*, 2017), enhanced child development (de Keijzer *et al.*, 2016), reduced morbidity (Maas *et al.*, 2009) and mortality in adults (Gascon *et al.*, 2015), and improved physical health status and enhanced healthy aging in the elderly (de Keijzer *et al.*, 2020). To date, the vast majority of the available epidemiological studies on health benefits of UGS have relied on quantity or presence of green spaces, not considering the potentially important effect of the quality of these spaces in the investigated health benefits.

UGS quality can be defined as the attributes that affect the use and interaction of the population with the UGS, including characteristics (e.g., size or location), features (e.g., facilities or amenities), and fitness for purpose (e.g., maintenance or condition) (Gidlow *et al*. 2018). Quality has been suggested to predict the use of green spaces (McCormack *et al.* 2010) and can intervene in the relationship between UGS and human health (Wheeler *et al*., 2015). The quality variability between UGS and the resulting differences in their potentials to exert health effects can have implications on how cities are planned and how UGS are designed and implemented to promote the health of urban dwellers.

Tools assessing the quality of UGS include different dimensions depending on their scope(s), target population, and anticipated applications. A recent review of the available multidimensional *in situ* quality assessment tools for UGS (Knobel *et al*., 2019) highlighted the scarcity of tools that encompass a broad selection of quality dimensions relevant to human health. As the growing literature points towards new health benefits and pathways associated with UGS, the UGS quality assessment tools need to stay updated and include new dimensions relevant to health (Knobel *et al*., 2019). Considering this, we aimed to: (1) develop and implement the RECITAL (uRban grEen spaCe qualITy Assessment tool) to assess the quality of UGS, focusing on aspects with the potential to be relevant to human health and (2) evaluate the reliability of RECITAL and the internal consistency of its dimensions.

RECITAL rationale:

Although the literature points towards an essential role of quality in the link between urban green spaces and human health, the strength of the evidence is uneven between specific quality elements. For example, the presence of specific amenities has been thoroughly studied, while the study of the presence of a specific bird species is anecdotal (Knobel *et al.*, 2019). RECITAL aims to encompass all potentially relevant quality aspects so it can be useful when analyzing associations between urban green spaces and human health, both if they are well known or have little supporting evidence.

Data obtained from RECITAL can be used at three levels: single-item scores, scores by dimensions, or overall score. Although all three could provide useful information for UGS exposure assessment, the use of single-item scores could offer information to directly pinpoint the aspects of UGS that interact with human health. Additionally, future users of the tool can employ selected sections to focus on a specific quality aspect and even can update some elements to the future literature developments or better fit their city.

2. *Methods:*

2.1.Tool development:

We selected three existing quality assessment tools and used them as main references for the development of RECITAL: Bedimo-Rung Assessment Tool (BRAT-DO) (Bedimo-Rung *et al*., 2006), Natural Environment Scoring Tool (NEST) (Gidlow *et al*., 2018) and Public Open Space Tool (POST) (Giles-Corti *et al*., 2005). We worked with a cross-disciplinary team of experts in environmental health, ecology, and urbanism to select all relevant quality items based on their expertise and appropriate available literature. We selected a total of 90 quality items. Subsequently, all 90 items were organized into eleven thematic quality dimensions: Surroundings, Access (Mowafi et al., 2012), Facilities (Roberts et al., 2019), Amenities, Aesthetics and Attractions (Richardson et al., 2020), Incivilities (Richardson et al., 2020), Safety (Groshong et al., 2020), Potential usage (Peschardt et al., 2012), Land Covers (Miralles-Guasch et al., 2019), Animal biodiversity (Wood et al., 2018), and Birds biodiversity (Wood et al., 2018). We selected the quality dimensions based on a previously exiting systematic review of in situ UGS quality assessment tools by Knobel et al. (2019). (Table 1)

Table 1: Dimensions definitions and item scoring

Dimension	Dimension Description	Item	Type of scoring
Surroundings	Characteristics of the neighboring area.	Surrounding buildings visibility	Reversed quantity
		Surrounding buildings facades maintenance	Quality
		Surrounding buildings facades greenness	Quality
		Connection to the site	Quality
Access	Measures of accessibility to the site.	Space entries	Combined
		Fences	Combined
		Walking paths	Combined
		Bike lanes	Combined
		Car parking spaces	Quantity
		Guiding signage	Quantity
		Handicapped adaptations	Combined
		Slope	Quantity
Facilities	Presence and quality of features that allow for the realization of specific activities.	Playgrounds	Combined
		Grass pitches	Combined
		Courts	Combined
		Dog playing grounds	Combined
		Skateboard/BMX ramps	Combined
		Open space for multichoice usage	Combined
		Water-related facilities	Combined
		Outdoor gym	Combined
Amenities	Presence and quality of features that make the UGS more comfortable, convenient, or enjoyable.	Seating and benches	Combined
		Litter disposal	Combined
		Informational signage	Combined
		Picnic tables	Combined
		Drinking fountains	Combined
		Public toilets	Combined
		Shelter	Quantity
		Shade	Quantity
		Dog excrement bins	Combined
		Specific sports amenities	Combined
		Barbeques	Combined
		Cafe/Kiosk	Combined
		Bike parking	Combined
		Vegetable garden	Combined
		Aromatics garden	Combined
Aesthetics and Attractions	Measures of beauty and attractiveness.	Views	Combined
		Primary surface	Quality
		Material of primary surface	Quality
		Seasonal and high maintenance vegetation	Quality

		Year-round vegetation	Quality
		Water fountain	Combined
		Public art	Combined
		Historic structures or buildings	Combined
		Public attractions	Combined
Incivilities	Elements or characteristics that make the UGS less enjoyable.	General liter	Reversed quantity
		Alcohol use	Reversed quantity
		Other drugs	Reversed quantity
		Sex work	Reversed quantity
		Vandalism	Reversed quantity
		Noise	Reversed quantity
		Smells	Reversed quantity
Safety	Elements or characteristics that make UGS feel safe.	Lighting	Combined
		Visibility from ground level	Quality
		Visibility form surrounding buildings	Quality
		Safety adaptations form cars	Quantity
		Safety adaptations from bikes	Quantity
		CCTV	Quantity
Potential usage	Measures of suitability for different activities.	Sports activities in courts	Potential use
		Informal games	Potential use
		Walking or running	Potential use
		Children's play	Potential use
		Conservation or biodiversity	Potential use
		Enjoy landscape	Potential use
		Dog walking	Potential use
		Social activities	Potential use
		Relaxing	Potential use
		Cycling	Potential use
		Water sports	Potential use
		Fishing	Potential use
Land Covers	Measures of land covers.	Tree cover	Braun-Blanquet
		Bush cover	Braun-Blanquet
		Grass	Braun-Blanquet
		Soft soil cover (gravel, dirt or similar)	Braun-Blanquet
		Tough soil cover (paved or similar)	Braun-Blanquet
Animal biodiversity	Measures of animal diversity.	Rhopalocera (suborder)	Quantity
		Blattodea (order)	Quantity
		Rodentia (order)	Quantity
		Chiroptera (order)	Quantity
		Other mammals (class)	Quantity
		Reptiles and amphibians (class)	Quantity
		Aseriformes (order)	Quantity

Birds biodiversity	Measures of bird diversity.	Charadriiformes (order)	Quantity
		Falconiformes and Accipitriformes (order)	Quantity
		Palumbiformes (order)	Quantity
		Psittaciformes (order)	Quantity
		Strigiformes (order)	Quantity
		Coraciiformes (order)	Quantity
		Pisciformes (order)	Quantity
		Paseriformes (order)	Quantity
		Ciconiformes (order)	Quantity

2.2.Tool scoring:

RECITAL items are scored with a five-point Likert scale (Likert, 1932). We developed a guideline with the different scoring methods that encompassed all different typologies of items (Table 2) and assigned a scoring method to each item depending on their nature (Table 3).

Table 2: Guidelines for scoring RECITAL items

Scoring methods	**Scores**				
	0	1	2	3	4
Quantity	No presence	Almost no presence	Present in some areas	Mostly present	Always present
Quality	No presence	Poorly maintained and aesthetically unpleasant	Poorly maintained or aesthetically unpleasant	Well maintained and aesthetically pleasant	Exceptionally maintained and aesthetically pleasing
Combined quantity and quality	Not present	Not fit for purpose	Fit but need repair or insufficient amount	Fit and sufficient.	Fit, sufficient, and aesthetically pleasing.
Reversed quantity	Always present	Mostly present	Present in some areas	Almost no presence	No presence
Potential use	Activity completely impossible	Activity possible but with many limitations	Activity possible with some limitations	Good conditions for the activity.	Perfect conditions for the activity.
Braun-Blanquet (adaptation from Braun-Blanquet (1932))	5% or less cover	5% to 25% cover	25% to 50% cover	50% to 75% cover	75% or more cover

2.3. Case study:

We applied RECITAL to characterize the quality of UGS in Barcelona, Spain. The combination of historical and natural characteristics makes Barcelona a distinct context for urban studies, especially regarding UGS. The city has 1.6 million inhabitants, 102.16 km^2 in area (Ajuntament de Barcelona, 2018), 1076 ha of public parks and gardens, 30 ha of beaches, 30 ha of fields, approximately 740 ha of privately-owned natural areas and 10.5m^2 and 7.0 m^2 per inhabitant of forest and urban green, respectively. Additionally, there are about 153.000 street trees from 150 different species and 75 common bird species within the city (Hàbitat Urbà, 2013). Its Mediterranean climate marks Barcelona's green: hot summers with maximums around 34ºC, mild winters with minimums around 3ºC, mean annual temperature around 18ºC, and an annual rainfall average of 592mm (Ajuntament de Barcelona, 2018). The squared geometry of Barcelona's streets developed during the 20th century defines the current form of large areas of the city: 20-meter-wide streets with trees alongside and a few withstanding green spaces within the squares.

2.4. Technician training:

A four-day workshop was organized to train the technicians on how to conduct surveys using RECITAL. The training included: one day of methodology description and criteria explanation, one day of biodiversity and species recognition, and two days of practical training with fieldwork, mainly visiting UGS to practice and homogenize the criteria.

2.5. UGS identification and sampling:

UGS were selected systematically through the following consecutive steps:

1. Preliminary selection of all areas labeled as UGS in Barcelona's urban planning (Ajuntament de Barcelona, 2017).
2. All polygons that were closer than 20m from one another were merged.
3. Performed a round of verification through the latest available satellite image (Ajuntament de Barcelona, 2017).
4. Only publicly owned spaces larger than one hectare were kept due to time and resource constraints.

5. *In situ* assessment of the fulfillment of our six-point definition of UGS:
    i. It must be located inside the municipality and urban areas. The urban area was defined by subtracting natural parks from the municipality area.
    ii. It must have vegetation.
    iii. It must have an identity of their own: spaces that were next to each other but had different official names or were divided (by fences or similar) were to be considered separately.
    iv. All sections within the UGS must be connected.
    v. It must be accessible to the public.
    vi. It must be mainly used for recreational activities.
6. Created new UGS's shapes or redefined the limits of existing ones if necessary.

2.6.Fieldwork:

Fieldwork was performed by a team composed of eight fieldworkers with different academic backgrounds. We implemented the RECITAL in all the selected spaces between March and May 2018. Daily fieldwork was conducted for approximately four hours per day, from 10 AM to 2 PM. Each day the technicians were randomly assigned to two teams, and each team was allocated between three and five visits, depending on spaces proximity and size. Each space was visited once by an autonomous working technician, who visited the space freely, and filled the tool questionnaire for each UGS. We did not conduct fieldwork when raining.

2.7.Statistical analysis:

We estimated the intraclass correlation coefficient (ICC) (2, *k) (*Two-way random effects, absolute agreement, multiple raters) to assess the inter-rater reliability of each item. The ICC results were classified according to Koo and Li (2016) guidelines: values of less than 0.5 indicate *poor* reliability, between 0.5 and 0.75 *moderate*, between 0.75 and 0.90 *good*, and more than 0.90 *excellent*. Additionally, Cronbach's Alpha was used to assess the internal consistency of the measures for each dimension to assess their internal consistency. Cronbach's Alpha 95% confidence interval was calculated using a fixed seed bootstrap method. These analyses were conducted applying R statistical package (R Core Team, 2018).

3. Results:

3.1.Sample description

There were 149 UGS with an area of more than 1ha throughout the city of Barcelona that fulfilled our inclusion criteria (Figure 1). Mean UGS size was 2.4ha, with 42% of the spaces between 1ha and 2ha, 33% between 2ha and 5ha, 24% between 5ha and 25ha, and only two spaces were larger than 25ha. The largest UGS was 27.6ha.

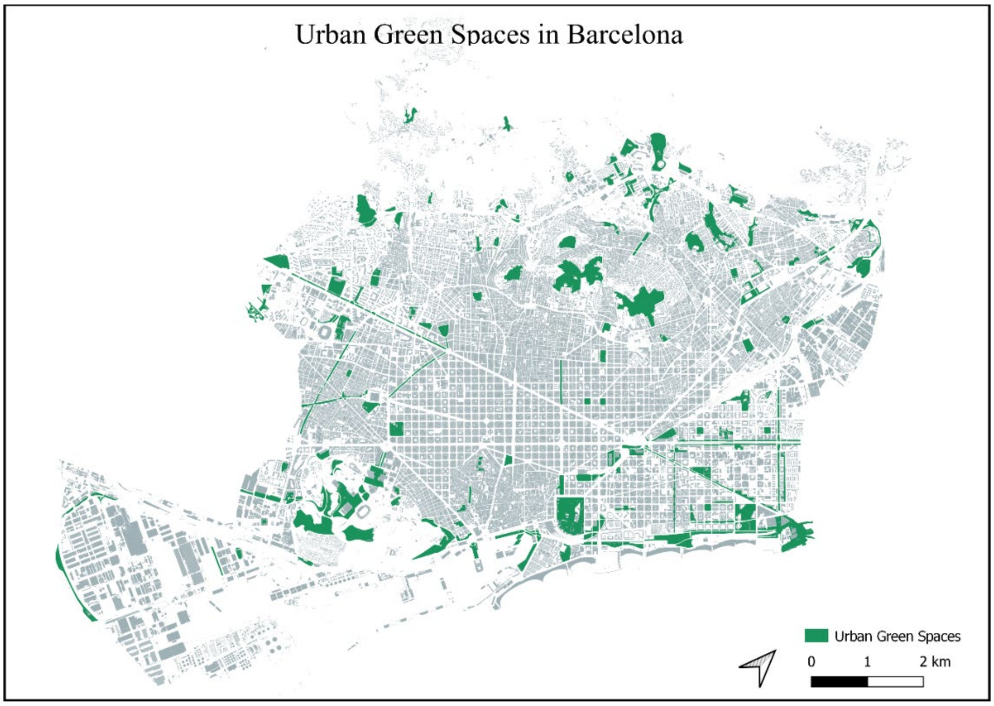

Figure 2:Urban Green Spaces in Barcelona

3.2.Tool reliability

The intraclass correlation for the RECITAL items was overall good (mean 0.84): 35% of the items scored excellently, 45% good, 19% moderate, and only "Other Drugs" scored poorly (ICC of 0.46 ± 0.32). ICC of five items could not be calculated (Chiroptera, Falconiformes and Accipitriformes, Coraciiformes, Strigiformes, and Blattodea – all part of biodiversity dimensions) due to the lack of variability between our urban green spaces in these items.

Reliability scores also varied among dimensions: items in "Land Covers" and "Facilities" had the highest and items in "Incivilities" had the lowest reliability (Table 3).

3.3.Dimensions internal consistency.

Regarding Cronbach's Alpha for each one of the dimensions: amenities, aesthetics, incivilities, safety, and potential usage scored more than 0.7; Surroundings and Land Covers have negative values, and the remaining four have moderate values between 0.4 and 0.7. Additionally, no dimension had a Crbomach's Alpha higher than 0.9 (Table 3)

Table 3: Dimension's Cronbach's alpha and item's intraclass correlation.

Dimension	Cronbach's Alpha (CI 95%)	Item	ICC (CI 95%)
Surroundings	-0.05 (-0.48-0.2)	Surrounding buildings visibility	0.82 (0.77-0.86)
		Surrounding buildings facades maintenance	0.77 (0.7-0.83)
		Surrounding buildings facades greenness	0.74 (0.65-0.8)
		Connection to the site	0.83 (0.76-0.88)
Access	0.59 (0.46-0.69)	Space entries	0.81 (0.73-0.87)
		Fences	0.88 (0.84-0.91)
		Walking paths	0.74 (0.66-0.81)
		Bike lanes	0.85 (0.75-0.9)
		Car parking spaces	0.74 (0.65-0.81)
		Guiding signage	0.86 (0.79-0.9)
		Handicapped adaptations	0.86 (0.82-0.89)
		Slope	0.93 (0.91-0.95)
Facilities	0.66 (0.56-0.72)	Playgrounds	0.98 (0.97-0.98)
		Grass pitches	0.92 (0.9-0.94)
		Courts	0.92 (0.9-0.94)
		Dog playing grounds	0.96 (0.95-0.97)
		Skateboard/BMX ramps	0.97 (0.97-0.98)
		Open space for multichoice usage	0.83 (0.75-0.88)
		Water-related facilities	0.71 (0.63-0.78)
		Outdoor gym	0.97 (0.96-0.97)
Amenities	0.79 (0.72-0.83)	Seating and benches	0.92 (0.9-0.94)
		Litter disposal	0.84 (0.76-0.89)
		Informational signage	0.84 (0.8-0.88)
		Picnic tables	0.97 (0.96-0.97)
		Drinking fountains	0.92 (0.89-0.94)
		Public toilets	0.96 (0.95-0.97)
		Shelter	0.76 (0.63-0.84)
		Shade	0.85 (0.79-0.89)
		Dog excrement bins	0.74 (0.66-0.81)
		Specific sports amenities	0.94 (0.93-0.95)
		Barbeques	0.93 (0.91-0.94)
		Cafe/Kiosk	0.93 (0.91-0.95)
		Bike parking	0.9 (0.87-0.92)
		Vegetable garden	0.79 (0.6-0.87)
		Aromatics garden	0.82 (0.75-0.87)
Aesthetics and Attractions	0.8 (0.74-0.83)	Views	0.88 (0.84-0.91)
		Primary surface	0.85 (0.8-0.89)
		Material of primary surface	0.91 (0.88-0.93)
		Seasonal and high maintenance vegetation	0.68 (0.52-0.78)
		Year-round vegetation	0.81 (0.72-0.87)
		Water fountain	0.97 (0.96-0.97)
		Public art	0.94 (0.92-0.95)
		Historic structures or buildings	0.94 (0.93-0.95)
		Public attractions	0.94 (0.93-0.95)
Incivilities	0.71 (0.63-0.76)	General liter	0.74 (0.65-0.81)
		Alcohol use	0.78 (0.71-0.83)
		Other drugs	0.46 (0.32-0.58)
		Sex work	0.54 (0.42-0.64)
		Vandalism	0.73 (0.64-0.8)
		Noise	0.66 (0.55-0.75)
		Smells	0.7 (0.58-0.78)
Safety	0.7 (0.61-0.75)	Lighting	0.86 (0.79-0.91)

		Visibility from ground level	0.75 (0.67-0.82)
		Visibility form surrounding buildings	0.84 (0.78-0.88)
		Safety adaptations form cars	0.73 (0.62-0.81)
		Safety adaptations from bikes	0.66 (0.53-0.76)
		CCTV	0.84 (0.79-0.87)
Potential usage	0.78 (0.7-0.83)	Sports activities in courts	0.89 (0.84-0.92)
		Informal games	0.84 (0.78-0.88)
		Walking or running	0.8 (0.74-0.84)
		Children's play	0.87 (0.82-0.9)
		Conservation or biodiversity	0.89 (0.84-0.92)
		Enjoy landscape	0.93 (0.91-0.95)
		Dog walking	0.89 (0.85-0.92)
		Social activities	0.77 (0.66-0.84)
		Relaxing	0.87 (0.82-0.91)
		Cycling	0.82 (0.71-0.88)
		Water sports	0.94 (0.93-0.95)
		Fishing	0.9 (0.88-0.92)
Land Covers	-0.2 (-0.55-0.02)	Tree cover	0.84 (0.76-0.89)
		Bush cover	0.94 (0.92-0.95)
		Grass	0.91 (0.89-0.93)
		Soft soil cover (gravel, dirt or similar)	0.9 (0.87-0.92)
		Tough soil cover (paved or similar)	0.93 (0.9-0.95)
Animal biodiversity	0.48 (0.32-0.59)	Rhopalocera (suborder)	0.93 (0.9-0.95)
		Blattodea (order)	-
		Rodentia (order)	0.64 (0.55-0.72)
		Chiroptera (order)	-
		Other mammals (class)	0.83 (0.79-0.87)
		Reptiles and amphibians (class)	0.87 (0.84-0.9)
Birds biodiversity	0.4 (0.17-0.58)	Aseriformes (order)	0.88 (0.85-0.91)
		Charadriiformes (order)	0.94 (0.93-0.95)
		Falconiformes and Accipitriformes (order)	-
		Palumbiformes (order)	0.86 (0.8-0.9)
		Psittaciformes (order)	0.91 (0.88-0.93)
		Strigiformes (order)	-
		Coraciiformes (order)	-
		Pisciformes (order)	0.51 (0.39-0.62)
		Paseriformes (order)	0.85 (0.78-0.89)
		Ciconiformes (order)	0.64 (0.55-0.72)

4. *Discussion*

We developed and implemented the RECITAL as a robust multidimensional tool for assessing different quality aspects of UGS that are relevant to the health of urban residents. Compared to other available tools, RECITAL is the most comprehensive tool in terms of the number of quality dimensions included (Knobel *et al.,* 2019). Additionally, it is the first tool to systematize the definition and selection of UGS (Knobel *et al.,* 2019). Our case study, applying RECITAL to characterize the quality of UGS in Barcelona city, was suggestive for an appropriate reliability of this tool (overall ICC of 0.84).

4.1.RECITAL reliability

The overall good inter-rater reliability was similar to other tools such as BRAT-DO (with 86.9% agreement), NEST (with 80% to 83% agreement), and POST (with 0.60 to 1.0 kappa). However, the use of different reliability measures and how these measures are reported makes it impossible to compare the results directly. Our observed variability amongst different items' reliability was also pointed out by other tools, including BRAT-DO, NEST, and PARK (Bird *et al*., 2015). Differences in reliability in each item could partly be due to three factors: the required expertise to accurately assess some specific elements, the susceptibility to subjectivity in some items and the potential influence of timing in the assessment.

Nature-related items, such as animal biodiversity, commonly require a high level of expertise that could complicate their evaluation (Dallimer *et al*., 2012). As a result, they have been occasionally omitted from UGS quality assessment tools, even when considered relevant (Gidlow *et al*., 2018). As proposed by Voigt *et al*. (2014), RECITAL combined structural measures with biodiversity measures that allowed for a richer characterization of the UGS quality without compensating with the tool's reliability.

Items that investigate the quality, especially aesthetics, can be prone to subjectivity due to their dependence on personal taste and perspectives. While such subjectivity is challenging to homogenize, the use of parallel assessment and robust training of fieldworkers could potentially reduce its influence.

Like Kaczynski *et al.* (2012), low ICC scores in the Incivilities dimension items could be a consequence of the timing of the observation. Noise and "mell, for example, can change very rapidly in the same location, modifying the observers' evaluation. Additionally, the evaluation of the level of incivility is also prone to subjectivity. However, the current items of Incivilities operate as proxies of specific undesired activities (e.g., vandalism, drug consumption, or sex work). These activities could be more objectively measured but would require the use of a different and more time-intensive assessment methodology, such as use assessment by *in situ* repeated observation.

4.2.Internal consistency of individual quality dimensions:

Cronbach's Alpha results must be interpreted with caution. On the one hand, evaluating and comparing Cronbach's alpha measures is complicated because it depends on the number of items and the sample size (Steiner et al., 2015). On the other, a high value is not always desirable (Taber, 2018). However, Cronbach's Alpha value can be informative about the dimensions nature and suggestive of how to use them.

Amenities, aesthetics, incivilities, safety, and potential usage Alphas were above 0.7, the Cronbach's Alpha general accepted value (Steiner et al., 2015). Additionally, they were all below 0.9, which would be suggestive of redundancy in the items (Tavakol & Dennick, 2011). Having acceptable alpha value suggests high internal consistency amongst the items of each quality dimension. Internal consistency hints towards the presence of a latent measure being captured by the dimension that is not very dependent on each one of the specific items (Cortina, 1993). Incivilities (Alpha 0.71), for example, measure the use of the spaces for illicit or undesirable activities that tend to concentrate in specific spaces. Therefore, eliminating one item might not have a great effect on the final score. Principal component analysis can be used to select the main items of this domains and potentially reduce their size. These dimensions can be used in our proposed structure and can be easily adapted to different contexts by deleting or changing some items.

Access, facilities, animal biodiversity, and bird biodiversity have between 0.4 and 0.7 Alpha. Although having an alpha value above 0.7 is sometimes desirable, it is not a requirement for making a quality dimension viable. Streiner et al. (2015) differentiate between two types of indicators (dimensions in our case): effect indicators and causal indicators. While the dimensions with Alphas higher than 0.7 would fall into the first group, the rest could fall into the second. Causal indicators do not require the items within a dimension to be highly correlated or have acceptable alpha value. Access (Alpha 0.59), for example, combines different elements that are relevant for the accessibility of the UGS. However, we have no reason to believe that its items are correlated: a UGS might have great walking paths and be very poorly adapted to the handicaped population. These dimensions can also be used in our proposed structure, but caution is advised when adding or deleting items.

Surroundings and Land Covers have negative Alphas. Similar to dimensions with moderate values, this is not necessarily a problem. However, dimensions with negative Cronbach's Alpha indicates the presence of mutually exclusive items (Steiner et al., 2015). While acceptable for a causal dimension, it might be interesting to explore each one of the items independently. For example, it could be interesting to analyze the items in Land Covers in future studies to explore the effect of each independent item.

4.3. Implications for further research and urban planning:

The quality data generated with RECITAL can enhance public health studies that analyze the association between urban greens space and human health. Having detailed information about many different quality dimensions and items will allow us to better understand the role of quality not just as an abstract construct but also as particular features and characteristics. Urban planners and policymakers would be able to use this detailed information to fine-tune the UGS in their cities to their objectives and the needs of the target population.

The detailed data generated by RECITAL can also be used in the study of relevant aspects of urban habitability aspects such as walkability assessment, physical activity, socioeconomic inequalities (including green gentrification), or urban biodiversity management.

The presented version of RECITAL is tailored to the city of Barcelona. However, the modular nature of RECITAL make it possible for future users to adapt the tools to their needs: explore novel potential pathways, focus on specific quality aspects, analyze unique features of their city or limit their scope to a few number of items. Moreover, each item could have different relevance and hence weight, depending on the setting, target population, and the evaluated health outcome. After using the tool results in future studies, researchers will be able to approximate the importance of each one of the items and tune them to different aims.

4.4.Limitations:

A lower limit for the size of the UGS of one hectare was implemented for practical reasons not related to RECITAL capabilities. RECITAL items and scorings are prepared to assess the quality of smaller spaces, which could be as relevant as the larger ones.

Assessing biodiversity-related items is especially complicated for non-expert fieldworkers (Gidlow *et al.*, 2018). Therefore, although our selection of biodiversity items is mainly aimed towards an easy recognition by the fieldworkers, a single day of training might have lead to errors in the biodiversity assessment. However, we believe that our moderate-to-high ICC values in all biodiversity items point towards a proper recognition of species groups.

5. Conclusions:

RECITAL is a multidimensional tool with 90 items organized in eleven thematic dimensions, assessing different quality aspects of UGS which are relevant to the health of urban residents. It showed overall good-to-excellent reliability and different levels of reliability for each dimension. The quality scores generated by RECITAL can be used by the research community to investigate the relevance of quality aspects of UGS to human health. Urban planners and policymakers can use it to improve the potential of their UGS to serve the needs of their citizens better, especially concerning their health and wellbeing. RECITAL was designed to adapt to the Barcelona characteristics, but it could be adapted to other settings by tailoring and fine-tuning some items.

Acknowledgments

We would like to thank Genís Gil Mañé, Adriana Elizabeth Navarro Arteaga, Ana Victoria Reveles Morales, Alondra Yesenia Regis Villasana, and María Fernanda Suárez del Real Sánchez for their indispensable time as fieldworkers and Dina Kim for her insightful feedback about the tool development. This study is supported by La Caixa Banking Foundation and the Club of Rome (Spanish Chapter and Barcelona Office). Payam Dadvand is funded by a Ramón y Cajal fellowship (RYC-2012-10995) awarded by the Spanish Ministry of Economy and Finance.

References

Ajuntament de Barcelona. (2017). *CartoBCN.* Obtained in http://w20.bcn.cat/cartobcn/default.aspx?lang=en

Ajuntament de Barcelona (2018). Anuari Estadístic de la Ciutat de Barcelona 2017. Obtanied from https://www.bcn.cat/estadistica/catala/dades/anuari/index.htm

Bedimo-Rung, A., Gustat, J., Tompkins, B., Rice, J., & Thomson, J. (2006). Development of a Direct Observation Instrument to Measure Environmental Characteristics of Parks for Physical Activity. *Journal of Physical Activity and Health, 3*(s1), S176-S189.

Bird, M., Datta, G., van Hulst, A., Kestens, Y., & Barnett, T. (2015). A reliability assessment of a direct-observation park evaluation tool: the parks, activity and recreation among kids (PARK) tool. *BMC public health, 15*, 906.

Braun-Blanquet, J. (1932). Plant sociology. The study of plant communities. First ed. *Plant sociology. The study of plant communities. First ed.*

Cortina, J. M. (1993). What is coefficient alpha? An examination of theory and applications. *Journal of applied psychology*, 78(1), 98.

Dallimer, M., Irvine, K., Skinner, A., Davies, Z., Rouquette, J., Maltby, L., . . . Gaston, K. (2012). Biodiversity and the Feel-Good Factor: Understanding Associations between Self-Reported Human Well-being and Species Richness. *BioScience*.

de Keijzer, C., Bauwelinck, M., & Dadvand, P. (2020). Long-Term Exposure to Residential Greenspace and Healthy Ageing: a Systematic Review. *Current Environmental Health Reports,* 7(1), 65-88.

de Keijzer, C., Gascon, M., Nieuwenhuijsen, M., & Dadvand, P. (2016). Long-Term Green Space Exposure and Cognition Across the Life Course: a Systematic Review. *Current Environmental Health Reports*.

Gascon, M., Mas, M., Martínez, D., Dadvand, P., Forns, J., Plasència, A., & Nieuwenhuijsen, M. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *International Journal of Environmental Research and Public Health*.

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., Nieuwenhuijsen, M. (2018). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening, 29*, 322-333.

Giles-Corti, B., Broomhall, M. H., Knuiman, M., Collins, C., Douglas, K., Ng, K., & Donovan, R. J. (2005). Increasing walking: how important is distance to, attractiveness, and size of public open space?. American journal of preventive medicine, 28(2), 169-176.

Groshong, L., Wilhelm Stanis, S. A., Kaczynski, A. T., & Hipp, J. A. (2020). Attitudes about perceived park safety among residents in low-income and high minority Kansas City, Missouri, neighborhoods. *Environment and Behavior*, 52(6), 639-665.

Hàbitat Urbà. (2013). *Pla del verd i de la biodiversitat de Barcelona 2020.* Ajuntament de Barcelona, Barcelona.

Kaczynski, A. T., Stanis, S. A. W., & Besenyi, G. M. (2012). Development and testing of a community stakeholder park audit tool. *American journal of preventive medicine*, 42(3), 242-249.

Knobel, P., Dadvand, P., & Maneja-Zaragoza, R. (2019). A systematic review of multidimensional quality assessment tools for urban green spaces. *Health & Place, 59*, 102198.

Koo, T., & Li, M. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. *Journal of Chiropractic Medicine*.

Likert, R. (1932). A Technique for the Measurement of Attitudes. *Archives of Psychology*, 140, 1–55.

Maas, J., Verheij, R., De Vries, S., Spreeuwenberg, P., Schellevis, F., & Groenewegen, P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health*.

McCormack, G. R., Rock, M., Toohey, A. M., & Hignell, D. (2010). Characteristics of urban parks associated with park use and physical activity: A review of qualitative research. Health & place, 16(4), 712-726.

Miralles-Guasch, C., Dopico, J., Delclòs-Alió, X., Knobel, P., Marquet, O., Maneja-Zaragoza, R., ... & Vich, G. (2019). Natural Landscape, Infrastructure, and Health: The Physical Activity Implications of Urban Green Space Composition among the Elderly. *International journal of environmental research and public health*, 16(20), 3986.

Mowafi, M., Khadr, Z., Bennett, G., Hill, A., Kawachi, I., & Subramanian, S. V. (2012). Is access to neighborhood green space associated with BMI among Egyptians? A multilevel study of Cairo neighborhoods. Health & place, 18(2), 385-390

Peschardt, K. K., Schipperijn, J., & Stigsdotter, U. K. (2012). Use of small public urban green spaces (SPUGS). *Urban forestry & urban greening*, 11(3), 235-244.

R Core Team. (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Richardson, A. S., Ghosh-Dastidar, M., Collins, R. L., Hunter, G. P., Troxel, W. M., Colabianchi, N., ... & Dubowitz, T. (2020). Improved street walkability, incivilities, and esthetics are associated with greater park use in two low-income neighborhoods. *Journal of Urban Health*, 1-9.

Roberts, H., Kellar, I., Conner, M., Gidlow, C., Kelly, B., Nieuwenhuijsen, M., & McEachan, R. (2019). Associations between park features, park satisfaction and park use in a multi-ethnic deprived urban area. *Urban Forestry & Urban Greening*, 46, 126485.

Streiner, D. L., Norman, G. R., & Cairney, J. (2015). Health measurement scales: a practical guide to their development and use. Oxford University Press, USA.

Taber, K. S. (2018). The use of Cronbach's alpha when developing and reporting research instruments in science education. *Research in Science Education*, 48(6), 1273-1296.

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's Alpha. International journal of medical education, 2, 53.

Voigt, A., Kabisch, N., Wurster, D., Haase, D., & Breuste, J. (2014). Structural Diversity: A Multidimensional Approach to Assess Recreational Services in Urban Parks. *AMBIO, 43*(4), 480-491.

Wheeler, B., Lovell, R., Higgins, S., White, M., Alcock, I., Osborne, N., . . . Depledge, M. (2015). Beyond greenspace: An ecological study of population general health and indicators of natural environment type and quality. *International Journal of Health Geographics*.

Wood, E., Harsant, A., Dallimer, M., Cronin de Chavez, A., McEachan, R. R., & Hassall, C. (2018). Not all green space is created equal: biodiversity predicts psychological restorative benefits from urban green space. *Frontiers in psychology*, 9, 2320.

Quality of Urban Green Spaces Influences Residents' Use of These Spaces, Physical Activity, and Overweight/Obesity.

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Abstract: The quality characteristics of urban green spaces (UGS) have been suggested to play a critical role in their use and their potentials to exert health effects. However, epidemiological studies evaluating such a role are scarce. These studies have generally focused on a limited number of quality dimensions. We studied the association between 10 UGS quality dimensions, assessed through a comprehensive multi-dimentional tool, and physical activity, overweight/obesity, and UGS use.Our study was based on 2053 adults participating in the Barcelona Health Survey (2016) and the quality of 149 UGS located in Barcelona, Spain. For each participant, we abstracted the average as well as maximum quality score, separately for each of the 10 quality dimensions as well as a overall quality score for the UGS within 300m of the participant's residential address. Data on the study outcomes were obtained through face-to-face interviews. We developed logistic regression and negative binomial models to assess our evaluated associations and conducted mediation analyses between the different outcomes. We observed that the overall quality of UGS was associated with higher likelihood of engaging in moderate-to-vigorous physical activity (OR:1.13; 95% CI:1.00 – 1.27), lower risk of overweight/obesity (OR: 0.88 ; 95% CI: 0.79 – 0.98), and increased use of UGS (exponentiated regression coefficient: 1.08 ; 95% CI :1.01 – 1.15). For the quality dimensions, we observed different patterns of associations depending on the outcome; however, bird biodiversity and amenities seem to be relevant to all of our evaluated outcomes. The mediation analysis suggested that UGS use mediate the association between quality and physical activity, while physical activity mediates the association

between quality and overweight/obesity. The novel results from this study will allow decision-makers better design UGS and directly pinpoint relevant quality dimensions to promote physical activity, reduce the risk of overweight/obesity and boost the use of UGS amongst citizens.

Submitted to *Environmental Pollution*: Received 8 May 2020; major revisions pending.

1. Introduction

The ongoing urbanization is leading to an increasing number of people living in urban areas worldwide (United Nations, 2018). Urban Green Spaces (UGS) are regarded as a critical element for the health of urban dwellers. An accumulating body of epidemiological evidence has associated UGS with improved physical and mental health of urban residents across the life course including reduced risk of pregnancy complications and adverse outcomes (Banay, Bezold, James, Hart, & Laden, 2017), enhanced child development (Zare *et al.*, *submitted*), improved perceived general health (Gascon et al., 2015), reduced morbidity (Twohig-Bennett & Jones, 2018) and mortality in adults (Gascon et al., 2016b), and healthy aging in the elderly (de Keijzer *et al.*, 2020). While several studies have reported that higher neighborhood green space or residential proximity to UGS are linked with higher levels of physical activity and lower risk of overweight/obesity, others have not found such associations (Astell-Burt *et al.*, 2014). One possible explanation for this inconsistency could be that these studies have not taken account of the quality characteristics of green spaces (Markevych *et al.*, 2017). Until now, the vast majority of available epidemiological studies of the health effects of UGS, including physical activity and overweight/obesity, have merely relied on the abundance and proximity to UGS, commonly extracted from vegetation indices (based on remote-sensing data), and land-use/land-cover databases, which generally do not include any information on quality characteristics (James *et al.* 2015; Zijlema *et al.*, 2020).

The quality characteristics of UGS have been suggested to play a critical role in their use (e.g., for physical activity) and hence benefiting from them (McCormack *et al.* 2010). However, to date, epidemiological studies evaluating such a role in the health benefits of UGS are scarce (Kruize *et al.,*2020). Moreover, these studies have generally focused on only a limited number of quality dimensions (Knobel *et al.*, 2019). There is a need to conduct studies simultaneously evaluating and comparing the potentials of different quality dimensions of UGS for exerting health benefits. The findings of such studies could enable decision-makers to pinpoint the most beneficial quality dimensions and apply them to fine-tune newly developed UGS or improve the existing ones to maximize their potentials to exert health benefits. Accordingly, we aimed to evaluate and compare the association of 10 different quality dimensions (based on 90 quality items) of UGS with the use of these spaces as well as physical activity and overweight/obesity of neighboring indiviudals. We also investigated the role of the use of UGS as a potential mediator in the association between the overall quality scores and physical activity and overweight/obesity.

2. *Methods:*

2.1.Study population

Our study was based on 2053 adults (age > 18 years) participating in the Barcelona Health Survey (2016). The Barcelona Health Survey aims to periodically (i.e., every five years) study the health status, life-styles, and use of health services among Barcelona's residents. Subjects were randomly selected from the Barcelona municipal register, but age and sex stratification was used to ensure representation of the age and sex structure across the 10 Barcelona districts. Selected participants were contacted by mail, informed about the survey aims, and asked if they were willing to participate. All non-responders were substituted by randomly previously-selected persons with the same characteristics (age, sex, and district). Trained interviewers conducted face-to-face interview surveys in the residence of a sample of 4000 people. For this study, we excluded 560 participants younger than 18 years old (legal age of majority in Spain), 187 participants with limitations to walk or leave their residence, and 1778 participants without a UGS within 300m of their residence. Note that participants were excluded when at least one of the aforementioned criteria were met.

Barcelona (Spain) is a city with 1.6 million inhabitants and 102.16 km^2 in area, located in the northeast of the Iberian Peninsula (Ajuntament de Barcelona, 2018). The city has

7.0 m^2 of urban green per inhabitant, about 153.000 street trees from 150 different species, and 75 common bird species (Hàbitat Urbà, 2013). Barcelona's climate is typically Mediterranean: hot summers with average maximum temperatures around 34ºC, mild winters with average minimum temperatures around 3ºC, mean annual temperature around 18ºC, and a yearly rainfall average of 592mm (Ajuntament de Barcelona, 2018).

2.2.Exposure assessment

We assessed the quality of 149 of Barcelona's UGS from March to May 2018 using RECITAL (uRban grEen spaCe qualiTy Assessment tooL) (Knobel *et al.*, submitted). RECITAL is an *in-situ* multidimensional quality assessment tool for UGS specifically designed to assess quality dimensions of UGS relevant to human health. A cross-disciplinary team of experts selected RECITAL's ten quality dimensions and 90 quality items (4 to 12 items per dimension; see Table 1). Each item is scored on a five-point Likert scale. The dimension scores are calculated as the average of all items in that dimension, and the overall quality is calculated as the average of all items.

Table 1: quality dimensions and composing items

Dimension	Item
Surroundings	Surrounding buildings visibility
	Surrounding buildings facades maintenance
	Surrounding buildings facades greenness
	Connection to the site
Access	Space entries
	Fences
	Walking paths
	Bike lanes
	Car parking spaces
	Guiding signage
	Handicapped adaptations
	Slope
Facilities	Playgrounds
	Grass pitches
	Courts
	Dog playing grounds
	Skateboard/BMX ramps
	Open space for multichoice usage
	Water-related facilities

	Outdoor gym
Amenities	Seating and benches
	Litter disposal
	Informational signage
	Picnic tables
	Drinking fountains
	Public toilets
	Shelter
	Shade
	Dog mess bins
	Specific sports amenities
	Barbeques
	Cafe/Kiosk
	Bike parking
	Vegetable garden
	Aromatics garden
Aesthetics and attractions	Views
	Primary surface
	Material of primary surface
	Seasonal and high maintenance vegetation
	Year-round vegetation
	Water fountain
	Public art
	Historic structures or buildings
	Public attractions
Incivilities	General liter
	Alcohol use
	Other drugs
	Sex work
	Vandalism
	Noise
	Smells
Safety	Lighting
	Visibility from ground level
	Visibility form surrounding buildings
	Safety adaptations form cars
	Safety adaptations from bikes
	CCTV
Potential usage	Sports activities in courts
	Informal games
	Walking or running
	Children's play

	Conservation or biodiversity Enjoy landscape Dog walking Social activities Relaxing Cycling Water sports Fishing
Animal biodiversity	Rhopalocera (suborder) Blattodea (order) Rodentia (order) Chiroptera (order) Other mammals (class) Reptiles and amphibians (class)
Birds biodiversity	Aseriformes (order) Charadriiformes (order) Falconiformes and Accipitriformes (order) Palumbiformes (order) Psittaciformes (order) Strigiformes (order) Coraciiformes (order) Pisciformes (order) Paseriformes (order) Ciconiformes (order)

We assessed UGS in the city of Barcelona that (1) were within the municipal area, (2) had vegetation, (3) were public, (4) were mainly used for recreational activities, and (5) had a size of more than 1 hectare. Fieldworkers were trained for four days on how to use the tool and how to recognize the required biodiversity groups. Each UGS was visited by four fieldworkers at a time (randomly selected out of a team of eight fieldworkers) between 10 AM and 2 PM in nonrainy days. Based on these surveys, RECITAL had an overall intraclass correlation (ICC) of 0.84 and a Cronbach's alpha of 0.92. More details about RECITAL can be found elsewhere (Knobel *et al.*, submitted).

The residential address of each participant at the time of the Barcelona Health Survey interview was geocoded. We then generated two different quality scores for each participant (using PostgreSQL/PostGIS):

Mean quality: the average quality score of all UGSs within 300m buffer (van den Bosch *et al.*, 2016) around the participant's residential address (separately for the overall quality score as well as for each quality dimension)

Maximum quality: the quality score of highest scored UGS within 300m buffer around the participant's residential address (separately for the overall quality score as well as each quality dimension)

2.3.Outcome assessment

Physical activity

The physical activity level of participants was evaluated using the International Physical Activity Questionnaire (IPAQ-Short version) (Craig et al., 2003). This questionnaire assesses the time spent on walking and0 moderate and vigorous physical activity in the last seven days. Using IPAQ guidelines (IPAQ Research Committee, 2005), we divided the participants into two groups based on their physical activity level: (i) inactivity and low level of physical activity or (ii) moderate-to-vigorous physical activity levels. We considered inactivity or low physical activity level as the reference category. Therefore, a positive association between exposure and this variable could be interpreted as a higher likelihood of achieving moderate-to-vigorous physical activity level.

Overweight/obesity

Participants were asked to report their unclothed weight and barefoot height. We calculated Body Mass Index (BMI) as the weight of the participant (kg) divided by the square of the height (m^2). Participants were classified as overweight/obese if their BMI was higher than 25 (WHO, 2000). We considered those with a normal weight (BMI: < 25) as the reference category. Due to the small number of underweight and obese particpants, we pooled them together with normal and overweight ones, respectively. A negative association between exposure and this variable can be interpreted as a lower likelihood of being overweight/obese.

Urban green space use

Participants were asked "In the last 12 months and in a regular week: approximately how many days have you spent your free time in parks, gardens, fields or other green spaces as mountain or natural parks?" with possible answers being numbers between zero and seven days. We used this measure as a proxy of UGS use.

2.4. Statistical analyses

We developed logistic regression models with physical activity and overweight/obesity as outcomes (one at a time) and the mean and maximum UGS quality scores for the overall quality score as well as for each quality dimension as the predictor (one at a time). For the UGS use as the outcome, we constructed negative binomial regression models with the same set of aforementioned predictors. Estimates for negative binomial regression are reported as exponentiated regression coefficient (ERC). All these models were further adjusted for age (in years as a continuous variable), sex (female/male), and education level (no or primary, secondary, or university education). We reported the associations for one interquartile range (IQR) increase in each quality score to facilitate the comparison between our included quality dimensions. We performed all analyses using STATA v15 (Statacorp, 2017).

Sensitivity analyses

To explore the robustness of our findings to the selected set of covariates, we further adjusted our analyses for neighborhood illiteracy rate (continuous) (Ministerio de Fomento, 2015), country of birth (high-income country: yes/no), and marital status (living alone or else). We also performed sensitivity analyses by excluding participants who had lived less than one year in their current neighborhood and by excluding participants located within 300m from the city limits (separately). To further explore the robustness of our findings to our choice of 300m buffer size to assess participants' exposure to UGS quality, we abstracted our exposure measures across a buffer of 500m around the participants' residential address (instead of 300m used in the main analyses) and repeated our analyses for this alternative set of exposures for both UGS quality dimensions.

Stratified analyses

We evaluated the potential effect modification of our studied associations for the overall quality score by sex, age (more or less than 65 years old) and education level (no or primary, secondary, and university education) using likelihood ratio test comparing models with and without multiplicative interaction term between overall quality score and each of these potential effect modifiers (one at a time). We then stratified the analyses of the total quality score based on sex, age, and education.

Meditation analyses

We evaluated the potential mediation role of the use of UGS in the association between the overall quality scores and both physical activity and overweight/obesity. We also assessed the potential mediation role of physical activity in the association between the overall quality score and overweight/obesity. For each mediation process, we present the percentage of mediation and its percentile confidence interval obtained after bootstrapping.

3. *Results:*

The summary description of the exposures, sociodemographic characteristics, and the study outcomes of the 2053 participants is shown in Table 2. Participants were almost evenly distributed by sex (51.6% female), and almost half (47.0%) of the participants were between 18 and 45 years old. The majority of participants (37.3%) had no or primary education, 27.9% had secondary education, and 34.8% had a university education. Only about a quarter of the participants had moderate-to-vigorous physical activity (28.4%) and almost half (47.2%) were overweight or obese. Almost a third (32.4%) of the participants reported no weekly visits to UGS, 22.0% reported one weekly visit, and 18.0% reported they visit UGS every day of the week.

Table 2: The description of exposures[a], sociodemographic characteristics of the study participants[b] and their health outcomes[b].

Variable	Description
Sex	
Male	994 (48.4%)
Female	1059 (51.6%)
Age	
18 - 45 years	964 (47.0%)
46 – 65 years	649 (31.6%)
> 65 years	440 (21.4%)
Education	
No or primary	764 (37.3%)
Secondary	573 (27.9%)
University	716 (34.8%)
Physical activity	
Low	1469 (71.6%)
Moderate-to-vigorous	584 (28.4%)
BMI (kg/m^2)	
Continuous	25.3 (4.5)
< 25	1085 (52.8%)
≥ 25	968 (47.2%)
UGS weekly use (days per week)	
Zero	666 (32.4%)
One	452 (22.0%)
Two	276 (13.4%)
Three	152 (7.4%)
Four	51 (2.5%)
Five	76 (3.7%)
Six	11 (0.5%)
Seven	369 (18.0%)
Surroundings	
Maximum	2.31 (0.33)
Mean	2.21 (0.3)
Access	
Maximum	2.03 (0.53)
Mean	1.91 (0.49)
Facilities	
Maximum	1.62 (0.98)
Mean	1.47 (0.73)
Amenities	
Maximum	1.6 (0.42)
Mean	1.46 (0.34)
Aesthetics	

Maximum	2.12 (0.75)
Mean	1.88 (0.69)
Lack of Incivilities	
Maximum	3.64 (0.29)
Mean	3.56 (0.29)
Safety	
Maximum	2 (0.71)
Mean	1.94 (0.56)
Potential use	
Maximum	2 (0.43)
Mean	1.86 (0.36)
Animal biodiversity	
Maximum	0.06 (0.17)
Mean	0.04 (0.13)
Bird biodiversity	
Maximum	0.75 (0.27)
Mean	0.7 (0.25)
Overall quality	
Maximum	1.77 (0.26)
Mean	1.72 (0.23)

[a] Median (IQR)

[b] When categorical: Count (% of the total), and when Continuous: Mean (standard deviation).

3.1.UGS quality and physical activity

The mean overall quality score (OR:1.13 ; 95% CI: 1.0 – 1.31) as well as the dimension-specific mean quality scores of surroundings (OR: 1.19; 95% CI: 1.05 – 1.35). facilities (OR: 1.15; 95% CI: 1.01 – 1.3), amenities (OR:1.13 ; 95% CI: 1.0 – 1.28), absence of incivilities (OR: 1.19; 95% CI: 1.03 – 1.38), and bird biodiversity (OR: 1.15; 95% CI: 1.15) were associated with having a moderate-to-vigorous physical activity level. The maximum quality measure yielded similar results, but we did not find any statistically significant association for amenities and with physical activity (Table 3).

3.2.UGS quality and overweight/obesity

Mean quality score of surroundings (OR: 0.87 ; 95% CI: 0.78 – 0.98), amenities (OR: 0.88; 95% CI: 0.79 – 0.99), absence of incivilities(OR: 0.85; 95% CI: 0.74 – 0.97), bird biodiversity (OR: 0.88; 95% CI: 0.79 – 0.99), and overall quality score (OR: 0.88; 95% CI: 0.79 – 0.98) had a statistically significant protective association with overweight/obesity. For the maximum quality score, the association was present for surroundings and amenities (Table 3).

3.3.UGS quality and UGS use

Mean quality measure of access (ERC: 1.08; 95% CI; 1.01 – 1.16), aesthetics and attractions (ERC: 1.07; 95% CI; 1.0 – 1.15), safety (ERC: 1.07; 95% CI; 1.0 – 1.14), potential use (ERC: 1.07; 95% CI; 1.0 – 1.15), bird biodiversity(ERC: 1.11; 95% CI; 1.04 – 1.19), and overall quality (ERC: 1.08; 95% CI; 1.01 – 1.15) were statistically significantly and positively associated with the use of UGS. Maximum quality measures showed similar results, in addition, both facilities and amenities were positively associated with the UGS use (Table 3).

Table 3: Adjusted[a] odds ratios (95% confidence intervals (CIs)) for physical activity and overweight/obesity, and exponentiated regression coefficient (95% CI) for UGS use in association with IQR increases in quality dimensions of urban green spaces

	Physical activity		Overweight/obesity		UGS use	
Quality dimension	Mean quality (95% CI)	Maximum quality (95% CI)	Mean quality (95% CI)	Maximum quality (95% CI)	Mean quality (95% CI)	Maximum quality (95% CI)
Surroundings	1.19 (1.05-1.35) **	1.18 (1.05-1.33) **	0.87 (0.78-0.98) **	0.87 (0.78-0.97) **	1.0 (0.94-1.07)	1.04 (0.98-1.11)
Access	1.09 (0.96-1.24)	1.07 (0.95-1.21)	0.92 (0.82-1.03)	0.93 (0.84-1.04)	1.08 (1.01-1.16) **	1.1 (1.04-1.18) **
Facilities	1.15 (1.01-1.3) **	1.15 (0.99-1.34) *	0.94 (0.84-1.06)	0.95 (0.83-1.09)	1.03 (0.96-1.1)	1.07 (0.99-1.16) *
Amenities	1.13 (1.0-1.28) **	1.1 (0.97-1.25)	0.88 (0.79-0.99) **	0.88 (0.79-0.99) **	1.04 (0.97-1.11)	1.07 (1.0-1.15) **
Aesthetics and attractions	1.02 (0.9-1.16)	1.03 (0.9-1.17)	0.93 (0.82-1.04)	0.95 (0.84-1.07)	1.07 (1.0-1.15) **	1.09 (1.01-1.16) **
Absence Incivilities	1.19 (1.03-1.38) **	1.15 (1.0-1.32) **	0.85 (0.74-0.97) **	0.91 (0.8-1.03)	1.02 (0.94-1.1)	1.04 (0.97-1.12)
Safety	0.92 (0.82-1.03)	0.9 (0.79-1.04)	0.95 (0.85-1.05)	0.95 (0.84-1.07)	1.07 (1-1.14) **	1.1 (1.02-1.18) **
Potential use	1.13 (0.99-1.28) *	1.13 (1-1.29) **	0.95 (0.84-1.07)	0.93 (0.83-1.04)	1.07 (1-1.15) **	1.1 (1.03-1.18) **
Animal biodiversity	1.03 (0.96-1.12)	1.04 (0.97-1.12)	0.96 (0.89-1.03)	0.97 (0.9-1.03)	1.0 (0.96-1.04)	1.0 (0.96-1.04)
Bird biodiversity	1.15 (1.01-1.31) **	1.12 (1.0-1.26) **	0.88 (0.78-0.99) **	0.92 (0.83-1.02)	1.11 (1.04-1.19) **	1.12 (1.05-1.19) **
Overall quality	**1.13 (1.0-1.27) ** **	**1.08 (0.98-1.2) * **	**0.88 (0.79-0.98) ** **	**0.91 (0.83-1.0) * **	**1.08 (1.01-1.15) ** **	**1.08 (1.03-1.14) ** **

* p < 0.1. ** p< 0.05

[a] Adjusted for age, sex and education level.

3.4. Sensitivity analyses

In all sensitivity analyses, the direction of the associations was in line with those observed in the main analyses (Table S1). Nevertheless, some of the associations lost their statistical significance. For physical activity, the results became non-significant when models were further adjusted for neighborhood literacy rate, the country of origin or the marital status, when we excluded those living for less than a year in the neighborhood, and when we applied 500m buffer to assign quality scores to the participants. For overweight/obesity, the results became non-significant when further controling our analyses for neighborhood literacy rate and marital status. We did not observe any notable change in our associations for the use of green spaces in any of our sensitivity analyses.

3.5. Effect modification

We did not observe any statistically significant interaction between the overall quality score and age, sex, and education level for any of the health outcomes (p-values >0.10) (Table S2). However, after stratifying the analyses based on age, sex, and education level (Figure S1-S3, for the three different outcomes) we observed some suggestions for potentially stronger protective associations with overweight/obesity for females and those with higher education level.

3.6. Mediation

We observed that 9.3% (95% CI; 0.8% – 47%) of the association between the mean overall quality score and physical activity could be mediated by the UGS use (p-value = 0.04). Moreover, physical activity could explain 9.7% (95% CI; -1.3% – 42 95%) between the mean overall quality score and overweight/obesity; however the mediation did not attain statistical significance (p-value = .066) (Table 4).

Table 4: Percentage of mediation and its percentile confidence interval obtained after bootstrapping.

	% of mediation (95% CI)	**P -value**
Mediator role of UGs use in the UGS - physical activity association:		
Mean complete	9.3% (0.8,47)	0.042
Max complete	14.7% (-81.2, 115)	0.11
Mediator role of UGS use in the quality of UGS - overweight/obesity association:		
Mean complete	-0.1% (-10.7,9)	0.942
Max complete	-0.2 % (-18.2,18)	0.930
Mediator role of physical activity in the quality of UGs - overweight/obesity association:		
Mean complete	9.7% (-1.3,42)	0.066
Max complete	8.9% (-21,56)	0.158

4. Discussion:

To our knowledge, this is the first epidemiological study to simultaneously evaluate and compare the association of different UGS quality dimensions with physical activity, overweight/obesity, and UGS use. This study also adds to the scarce body of epidemiological evidence on the role of quality characteristics of UGS in their potential for exerting health benefits. We observed that the overall quality of UGS was associated with a higher likelihood of engaging in moderate-to-vigorous physical activity, lower risk of overweight/obesity, and increased use of UGS. For the quality dimensions, we observed different patterns of associations depending on the outcome; however, bird biodiversity and amenities (e.g. picknick tables or drinking fountains) seemed to be consistently relevant to all of our evaluated outcomes. Regarding the effect size, surroundings and absence of invincibilities were the most strongly associated dimensions with physical activity, surroundings with overweight/obesity, and bird biodiversity with the use of UGS. The stratified analyses for overweight/obesity suggested a stronger association in females and higher education levels. The mediation analysis suggested that UGS use mediates the association between quality and physical activity, while physical activity mediates the association between quality and overweight/obesity. The sensitivity analyses were consistent with those of the main analyses; however, for physical activity and overweight/obesity, some associations lost their statistical significance.

For almost all quality dimensions, mean quality measures were suggestive of a stronger beneficial association compared to maximum quality measures for our three outcomes. This observation suggests that the overall quality of the surrounding UGS could be more relevant than the quality of the highest quality UGS. In other words, instead of having a single very high quality UGS, it might be more beneficial to improve the quality of the majority, if not all, of UGS. Having a diverse average-to-high quality UGS in the surroundings of the residence has been reported to increase the number of places of interest in the neighboring area, which in turn could potentially increase the use of public spaces for recreational activities or physical activity (Sugiyama, Leslie, Giles-Corti, & Owen, 2009), and promote UGS visits. Given the stronger associations observed in the mean quality compared to the maximum quality, we will focus the discussion on the mean quality measures.

4.1. Interpretation of results

Amenities were strongly associated with all our evaluated outcomes. A previous study by Costigan *et al.* (2017) examining the relationship between amenities and physical activity concluded that amenities were important predictors of the use of UGS for physical activity across different demographic groups. Similarly, amenities have been suggested to be relevant for UGS use across all age groups (McCormack *et al.*, 2010). Other studies have also reported that the presence of specific amenities could be appealing for specific population groups. For example, Cutt *et al.* (2008) reported that dog-related amenities could increase the use of UGS by dog owners. Therefore, a well-equipped UGS is more likely to encourage physical activity and use by a broader segment of the population (Kaczynski *et al.*, 2008).

Bird biodiversity was consistently associated with all of our selected outcomes. Most studies measuring biodiversity as a possible health predictor revolve around mental health, drawing associations between perceived and objective bird biodiversity with well-being measures (Aerts *et al.*,2018). However, possibly due to the complexity of its score

(Voigt, Kabisch, Wurster, Haase, & Breuste, 2014), bird biodiversity is overlooked in most UGS quality assessments for epidemiologic studies (Knobel *et al.*, 2019). The importance of bird biodiversity might be linked to their bioindicator function: bird biodiversity is related to other environmental factors, including plant biodiversity and soundscapes that are suggested also to be relevant to human health (Aerts *et al.*,2018).

We found an association between accessibility and UGS use. RECITAL measures qualitative elements of accessibility (e.g., entries or guiding signage), but accessibility to UGS is commonly measured with park proximity or other geospatial measures (McCormack *et al.* 2010). Coombes *et al.* (2010), for example, found that accessibility (defined through UGS proximity) is associated with physical activity, risk of overweight/obesity and UGS use. A previous study by Dadvand *et al*., (2016), using the 2011 edition of the Barcelona Health Survey, also included subjective measures of accessibility and found similar associations in physical activity for both subjective and objective measures. The differences between results when using raw proximity, subjective accessibility or quality measures of accessibility strongly suggest that access to UGS depends on more factors than proximity *per se* (Schipperijn *et al*., 2010)

Our observed association between facilities and physical activity is in line with previous studies (McCormack *et al.* 2010) showing that, similar to amenities, facilities are relevant for physical activity. However, we did not find any association between facilities and UGS use, which was reported by a previous study (Sugiyama et al., 2009). This inconsistency might be due to the differences in the definition of facility: RECITAL only considered facilities such as playgrounds or courts, and Sugiyama *et al.* (2009) additionally included other features such as beachfronts or riversides.

In our results safety positively influenced UGS use. Previous studies have found an association betweens safety and UGS use in both the general population (Calogiuri and Charni, 2014) and specific vulnerable groups such as adolescents (Ries *et al*., 2009), and African-American (Wilbur *et al.*, 2002) and Latino (Cronan *et al.*, 2008) women in the US.

The absence of incivilities positively influenced physical activity and overweight/obesity. UGS use has been described to mediate the association between the absence of incivilities and physical activity (Roberts et al., 2019). However, the absence of incivilities was not associated with UGS use.

We did not observe any association between animal biodiversity (non-bird animals) and our evaluated health outcomes, which might be due to the lack of variability in this indicator among UGSs included in our study. All UGSs had very low scores because the sighting of non-bird animals was rare, although we had carefully selected the animal species based on the city fauna inventories. Future studies that aim to delve into the relationship between animal biodiversity and health outcomes require more specialized methodologies such as the use of animal traps.

The positive associations of surroundings with physical activity, and the positive association between potential use and both physical activity and UGS haven't previously been reported in the literature.

Furthermore, our results regarding overweight/obesity are novel. To the best of our knowledge, there are no available studies directly assessing the association between UGS quality dimensions and overweight/obesity. The differences between quality dimensions could help explain the inconsistencies present in the existing literature (Lachowycz and Jones, 2010) and suggest the need for the inclusion of quality aspects of UGS in future studies of their effects on overweight/obesity.

4.2. Interpretation of stratification

Additionally, the stratified analyses for overweight/obesity suggested a stronger association in females and higher education levels. Similarly, in a recent study by O'Callaghan-Gordo *et al.*, (2019) in seven Spanish cities, the authors observed associations between UGS and obesity only in women. The reasons behind the difference in sociodemographic groups are still unknown.

4.3. Interpretation of mediation analysis

The association between overall quality score and physical activity is partially explained by use. At the same time, part of the association between quality and obesity could be partially explained by physical activity. The unmediated part of the association could be explained through some of the pathways between UGS and health described in the literature, such as: increased social contacts, reduced environmental exposure or restorative effects of UGS (Nieuwenhuijsen *et al.*, 2017). Better quality UGS could also motivate its neighbors to participate in more physical activity outside UGS by the beautification of the surrounding area or creating new landmarks (Sugiyama et al., 2009). Also, it is possible that UGSs could exert their positive effects without direct interaction with them. The viewing of UGS, for example, is suggested to be associated with positive health outcomes (Ulrich, 1984) and some pathways between UGS and human health (such as the reduction of environmental exposures or the biogenic or biodiversity hypothesis) theoretically do not require the UGS to be perceived to exert its positive effect

4.4. Study limitations

Some limitations should be considered when interpreting the results of this study. There was a two-year gap between the UGS quality assessment (2018) and the Barcelona Health Survey (2016) from which we extracted the health outcomes. However, given that we limited our UGS sample to those larger than one-hectare, we did not expect to have a considerable change in their quality characteristics during these two years. Less than one-hectare spaces could also affect our studied outcomes; however, van den Bosch *et al.* (2016) suggested that their effect might be minimal. The use of self-reporting questions for the health outcomes could have resulted in outcome misclassification due to recall bias and/or subjectivity. Nevertheless, the IPAQ has been reported to have acceptable validity and reliability to assess physical activity for the Spanish population (Roman-Viñas et al., 2010). Similarly, self-reported height and weight could have resulted in misclisification in BMI but previous studies have shown that the correlation between the self-reported and the objectively measured could be high (McAdams *et al.*, 2007). Additionally, the physical activity question was not directly aimed towards physical activity done in UGS. Similarly, our questionnaire on the use of UGS included other natural/green spaces than UGS, but we would assume that most visits of urban residents in a regular week would be to UGS as urban residents visit spaces that are closer to their residence more frequently (Kruize *et al.*, 2020).

5. *Conclusions:*

Our findings suggest that higher quality of UGS in the living environment of urban dwellers was associated with an increased likelihood of the use of these spaces and engaging in moderate-to-vigorous physical activity and lower risk of overweight/obesity. Moreover, we demonstrated how the relevance of different quality dimensions of UGS could vary depending on the health outcome of interest. An increase of physical activity is associated with the scores for surroundings facilities, amenities, absence of incivilities, bird biodiversity, and overall quality. A reduction of obesity is associated with the scores for surroundings, amenities, absence of incivilities, bird biodiversity, and overall quality. Use of UGS is associated with the scores for access, aesthetics and attractions, safety, potential use, bird biodiversity, and overall quality.

The novel results from this study could inform urban decision-makers about the relevant quality aspects of UGS that could be applied to increase the use of these spaces and maximize their potentials to promote physical activity and reduce the risk of overweight/obesity amongst citizens. Future longitudinal studies are required to replicate our findings in other settings with different climates, cultures, and urban designs while applying objective measures of our evaluated outcomes.

References:

Aerts, R., Honnay, O., & Van Nieuwenhuyse, A. (2018, September 1). Biodiversity and human health: Mechanisms and evidence of the positive health effects of diversity in nature and green spaces. *British Medical Bulletin*, Vol. 127, pp. 5–22. https://doi.org/10.1093/bmb/ldy021

Akaraci, S., Feng, X., Suesse, T., Jalaludin, B., & Astell-Burt, T. (2020, April 2). A systematic review and meta-analysis of associations between green and blue spaces and birth outcomes. *International Journal of Environmental Research and Public Health*, Vol. 17. https://doi.org/10.3390/ijerph17082949

Banay, R., Bezold, C., James, P., Hart, J., & Laden, F. (2017). Residential greenness:

current perspectives on its impact on maternal health and pregnancy outcomes. *International Journal of Women's Health*, *Volume 9*, 133–144. https://doi.org/10.2147/IJWH.S125358

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, *29*(2), 293–301. https://doi.org/10.1016/S0921-8009(99)00013-0

Costigan, S. A., Veitch, J., Crawford, D., Carver, A., & Timperio, A. (2017). A Cross-Sectional Investigation of the Importance of Park Features for Promoting Regular Physical Activity in Parks. *INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH*, *14*(11).

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., … Oja, P. (2003). International physical activity questionnaire: 12-Country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Dadvand, P., Hariri, S., Abbasi, B., Heshmat, R., Qorbani, M., Motlagh, M. E., … Kelishadi, R. (2019). Use of green spaces, self-satisfaction and social contacts in adolescents: A population-based CASPIAN-V study. *Environmental Research*, *168*, 171–177. https://doi.org/10.1016/j.envres.2018.09.033

Dadvand, P., Sunyer, J., Basagaña, X., Ballester, F., Lertxundi, A., Fernández-Somoano, A., … Nieuwenhuijsen, M. J. (2012). Surrounding Greenness and Pregnancy Outcomes in Four Spanish Birth Cohorts. *Environmental Health Perspectives*, *120*(10), 1481–1487. https://doi.org/10.1289/ehp.1205244

Dalton, A. M., Jones, A. P., Sharp, S. J., Cooper, A. J. M., Griffin, S., & Wareham, N. J. (2016). Residential neighbourhood greenspace is associated with reduced risk of incident diabetes in older people: a prospective cohort study. *BMC Public Health*, *16*(1), 1–10. https://doi.org/10.1186/s12889-016-3833-z

de Keijzer, C., Bauwelinck, M., & Dadvand, P. (2020). Long-Term Exposure to Residential Greenspace and Healthy Ageing: a Systematic Review. *Current Environmental Health Reports*, Vol. 7, pp. 65–88. https://doi.org/10.1007/s40572-020-00264-7

de Keijzer, C., Gascon, M., Nieuwenhuijsen, M. J., & Dadvand, P. (2016). Long-Term Green Space Exposure and Cognition Across the Life Course: a Systematic Review. *Current Environmental Health Reports*. https://doi.org/10.1007/s40572-016-0116-x

DEARBORN, D. C., & KARK, S. (2010). Motivations for Conserving Urban Biodiversity. *Conservation Biology*, *24*(2), 432–440. https://doi.org/10.1111/j.1523-1739.2009.01328.x

European Commission. (2015). *Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities*. https://doi.org/10.2777/765301

Gascon, M., Mas, M. T., Martínez, D., Dadvand, P., Forns, J., Plasència, A., &

Nieuwenhuijsen, M. J. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph120404354

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. J. (2016a). Residential green spaces and mortality: A systematic review. *Environment International*, *86*, 60–67. https://doi.org/10.1016/J.ENVINT.2015.10.013

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. J. (2016b). Residential green spaces and mortality: A systematic review. *Environment International*. https://doi.org/10.1016/j.envint.2015.10.013

Gidlow, C. J., Ellis, N. J., & Bostock, S. (2012). Development of the neighbourhood green space tool (NGST). *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2012.04.007

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., … Nieuwenhuijsen, M. J. (2018a). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333. Retrieved from https://www.sciencedirect.com/science/article/pii/S1618866717301917

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., … Nieuwenhuijsen, M. J. (2018b). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333. https://doi.org/10.1016/J.UFUG.2017.12.007

Goal 11 | Department of Economic and Social Affairs. (n.d.). Retrieved September 15, 2020, from https://sdgs.un.org/goals/goal11

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global Change and the Ecology of Cities. *Science*, *319*(5864), 756–760. https://doi.org/10.1126/science.1150195

Hystad, P., Davies, H. W., Frank, L., Loon, J. Van, Gehring, U., Tamburic, L., & Brauer, M. (2014). Residential Greenness and Birth Outcomes: Evaluating the Influence of Spatially Correlated Built-Environment Factors. *Environmental Health Perspectives*, *122*(10), 1095–1102. https://doi.org/10.1289/ehp.1308049

IPAQ Research Committee. (2005). Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ)-Short and Long Forms. *Http://Www.Ipaq.Ki.Se/Scoring.Pdf*.

Iyer, H. S., James, P., Valeri, L., Hart, J. E., Pernar, C. H., Mucci, L. A., … Rebbeck, T. R. (2020). The association between neighborhood greenness and incidence of lethal prostate cancer. *Environmental Epidemiology*, *4*(2), e091. https://doi.org/10.1097/ee9.0000000000000091

James, P., Banay, R. F., Hart, J. E., & Laden, F. (2015). A Review of the Health Benefits of Greenness. *Current Epidemiology Reports*, *2*(2), 131–142. https://doi.org/10.1007/s40471-015-0043-7

Kellert, S. R. (2006). Building for life: Designing and understanding the human-nature connection. *Renewable Resources Journal*, *24*(2).

Knobel, P., Dadvand, P., & Maneja-Zaragoza, R. (2019). A systematic review of multi-dimensional quality assessment tools for urban green spaces. *Health and Place*, *59*. https://doi.org/10.1016/j.healthplace.2019.102198

Kondo, M. C., Fluehr, J. M., McKeon, T., & Branas, C. C. (2018). Urban green space and its impact on human health. *International Journal of Environmental Research and Public Health*, Vol. 15. https://doi.org/10.3390/ijerph15030445

Maas, J., Verheij, R. A., De Vries, S., Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health*. https://doi.org/10.1136/jech.2008.079038

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., … Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research*, Vol. 158, pp. 301–317. https://doi.org/10.1016/j.envres.2017.06.028

Markevych, I., Tiesler, C. M. T., Fuertes, E., Romanos, M., Dadvand, P., Nieuwenhuijsen, M. J., … Heinrich, J. (2014). Access to urban green spaces and behavioural problems in children: Results from the GINIplus and LISAplus studies. *Environment International*, *71*, 29–35. https://doi.org/10.1016/j.envint.2014.06.002

McAdams, M. A., Van Dam, R. M., & Hu, F. B. (2007). Comparison of Self-reported and Measured BMI as Correlates of Disease Markers in U.S. Adults*. *Obesity*, *15*(1), 188–188. https://doi.org/10.1038/oby.2007.504

McCormack, G. R., Rock, M., Toohey, A. M., & Hignell, D. (2010). Characteristics of urban parks associated with park use and physical activity: A review of qualitative research. *Health and Place*, *16*(4), 712–726. https://doi.org/10.1016/j.healthplace.2010.03.003

Miralles-Guasch, C., Dopico, J., Delclòs-Alió, X., Knobel, P., Marquet, O., Maneja-Zaragoza, R., … Vich, G. (2019). Natural Landscape, Infrastructure, and Health: The Physical Activity Implications of Urban Green Space Composition among the Elderly. *International Journal of Environmental Research and Public Health*, *16*(20), 3986. https://doi.org/10.3390/ijerph16203986

Oliver-Smith, A. (2012). DEBATING ENVIRONMENTAL MIGRATION: SOCIETY, NATURE AND POPULATION DISPLACEMENT IN CLIMATE CHANGE. *Journal of International Development*, *24*(8), 1058–1070. https://doi.org/10.1002/jid.2887

Penuelas, J., & Boada, M. (2003). A global change-induced biome shift in the Montseny mountains (NE Spain). *Global Change Biology*, *9*(2), 131–140. https://doi.org/10.1046/j.1365-2486.2003.00566.x

Roberts, H., Kellar, I., Conner, M., Gidlow, C., Kelly, B., Nieuwenhuijsen, M., & McEachan, R. (2019). Associations between park features, park satisfaction and park use in a multi-ethnic deprived urban area. *Urban Forestry and Urban Greening*, *46*. https://doi.org/10.1016/j.ufug.2019.126485

Rojas-Rueda, D., Nieuwenhuijsen, M. J., Gascon, M., Perez-Leon, D., & Mudu, P. (2019). Green spaces and mortality: a systematic review and meta-analysis of cohort studies. *The Lancet Planetary Health*, *3*(11), e469–e477. https://doi.org/10.1016/S2542-5196(19)30215-3

Roman-Viñas, B., Serra-Majem, L., Hagströmer, M., Ribas-Barba, L., Sjöström, M., & Segura-Cardona, R. (2010). International physical activity questionnaire: Reliability and validity in a Spanish population. *European Journal of Sport Science*, *10*(5), 297–304. https://doi.org/10.1080/17461390903426667

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2009). Physical activity for recreation or exercise on neighbourhood streets: Associations with perceived environmental attributes. *Health and Place*, *15*(4), 1058–1063. https://doi.org/10.1016/j.healthplace.2009.05.001

Torres Toda, M., Anabitarte Riol, A., Cirach, M., Estarlich, M., Fernández-Somoano, A., González-Safont, L., … Dadvand, P. (2020). Residential Surrounding Greenspace and Mental Health in Three Spanish Areas. *International Journal of Environmental Research and Public Health*, *17*(16), 5670. https://doi.org/10.3390/ijerph17165670

Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science*, *224*(4647), 420–421. https://doi.org/10.1126/science.6143402

van den Berg, A. E., & van den Berg, C. G. (2011). A comparison of children with ADHD in a natural and built setting. *Child: Care, Health and Development*, *37*(3), 430–439. https://doi.org/10.1111/j.1365-2214.2010.01172.x

Voigt, A., Kabisch, N., Wurster, D., Haase, D., & Breuste, J. (2014). Structural diversity: a multi-dimensional approach to assess recreational services in urban parks. *Ambio*, *43*(4), 480–491. https://doi.org/10.1007/s13280-014-0508-9

Wheeler, B. W., Lovell, R., Higgins, S. L., White, M. P., Alcock, I., Osborne, N. J., … Depledge, M. H. (2015). Beyond greenspace: An ecological study of population general health and indicators of natural environment type and quality. *International Journal of Health Geographics*, *14*(1). https://doi.org/10.1186/s12942-015-0009-5

World Urbanization Prospects - Population Division - United Nations. (n.d.). Retrieved August 4, 2020, from https://population.un.org/wup/DataQuery/

Zhan, Y., Liu, J., Lu, Z., Yue, H., Zhang, J., & Jiang, Y. (2020, May 20). Influence of residential greenness on adverse pregnancy outcomes: A systematic review and dose-response meta-analysis. *Science of the Total Environment*, Vol. 718, p. 137420. https://doi.org/10.1016/j.scitotenv.2020.137420

Zijlema, W. L., Triguero-Mas, M., Cirach, M., Gidlow, C., Kruize, H., Grazuleviciene, R., … Litt, J. S. (2020). Understanding correlates of neighborhood aesthetic ratings: A European-based Four City comparison. *Urban Forestry and Urban Greening*, *47*, 126523. https://doi.org/10.1016/j.ufug.2019.126523

Zijlema, Wilma L., Triguero-Mas, M., Smith, G., Cirach, M., Martinez, D., Dadvand, P., … Julvez, J. (2017). The relationship between natural outdoor environments and cognitive functioning and its mediators. *Environmental Research*, *155*, 268–275. https://doi.org/10.1016/j.envres.2017.02.017

Supplementary material

Table S1: sensitivity analysis summary. Odds ratios (95% confidence intervals (CIs)) for physical activity and overweight/obesity, and exponentiated regression coefficient (95% CI) adjusted separatelt for potential confunders.

	Quality measure	Physical activty	Overweight/obesity	UGS use
Main analysis[a] + neighborhood illiteracy rate	Mean	1.11 (0.99-1.25) *	0.91 (0.82-1.02)	1.09 (1.03-1.16) **
	Max	1.08 (0.97-1.19)	0.93 (0.85-1.03)	1.09 (1.04-1.15) **
Main analysis[a] + Country of origin	Mean	1.12 (0.99-1.26) *	0,89 (0,8-0,99) **	1,08 (1,02-1,15) **
	Max	1.08 (0.97-1.19)	0,92 (0,84-1,01) *	1,09 (1,03-1,15) **
Main analysis[a] + Marital status	Mean	1.12 (1-1.26) *	0,9 (0,81-1) *	1,08 (1,02-1,15) **
	Max	1.09 (0.98-1.2)	0,92 (0,84-1,01) *	1,09 (1,03-1,15) **
Main analysis[a] excluding less than one year in the neighborhood	Mean	1.12 (0.99-1.26) *	0,87 (0,78-0,97) **	1,08 (1,01-1,15) **
	Max	1.08 (0.97-1.19)	0,92 (0,83-1,01) *	1,09 (1,03-1,15) **
Manin analysis[a] exluding respondets within 300m of municiapal limits	Mean	1.13 (1.0,1.28) **	0.89 (0.80,1.0) **	1.08 (1.02,1.16) **
	Max	1.09 (0.98,1.21) *	0.91 (0.83,1.01) *	1.09 (1.03,1.16) **
Main analysis[a] with 500m buffer	Mean	1,11 (1.0-1,24) *	0,83 (0,74-0,94) **	1,07 (1,01-1,14) **
	Max	1,07 (0,95-1,19)	0,92 (0,84-1) *	1,08 (1,02-1,15) **

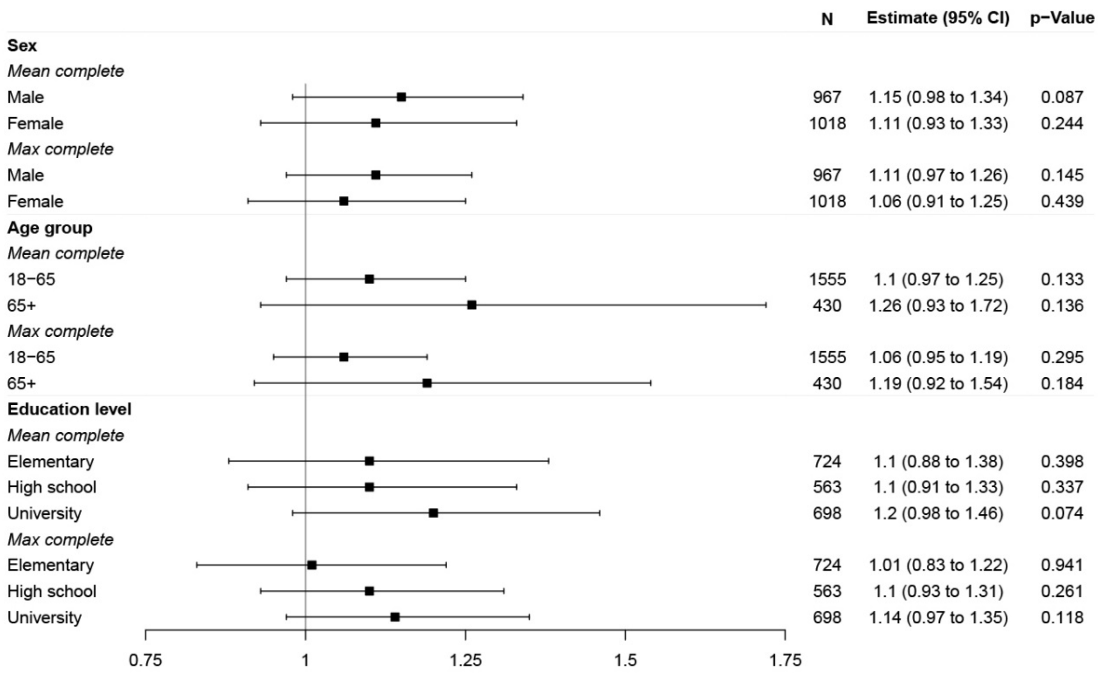
* $p < 0.1$. ** $p < 0.05$

[a] Adjusted for age, sex and education level.

Table S2: p-values of likelihood ratios of main models and models including interaction by sex, age and education level (separately).

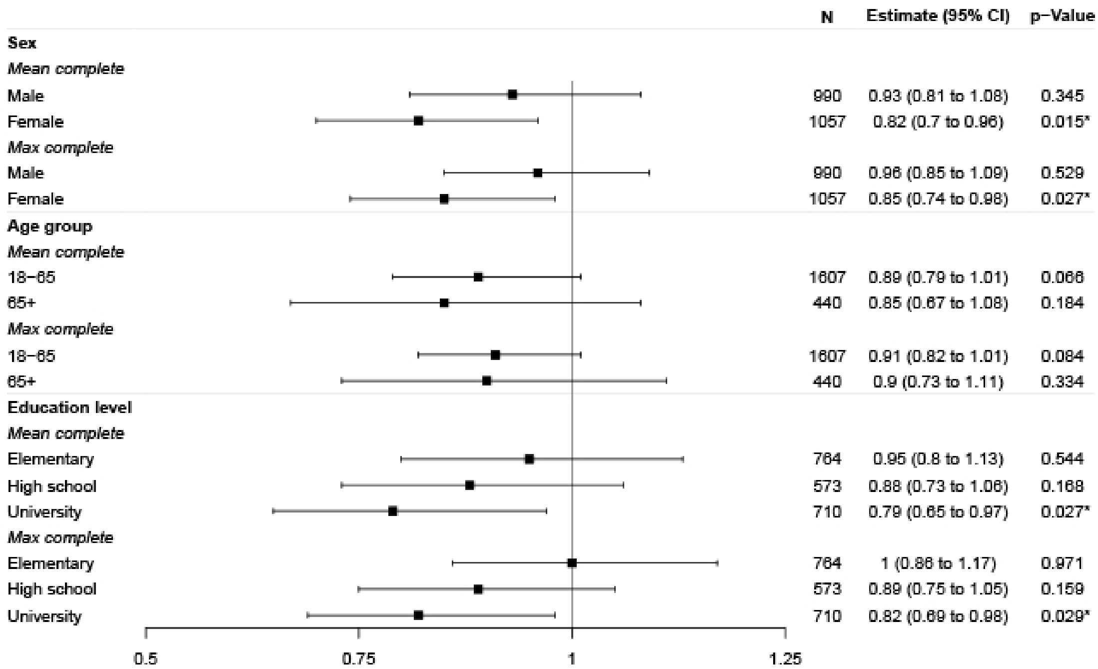
	Sex		**Age**		**Education level**	
	Mean overall	Maximum overall	Mean overall	Maximum overall	Mean overall	Maximum overall
Physical Activity	0.88	0.77	0.29	0.31	0.82	0.70
Overweight/obesity	0.14	0.12	0.64	0.91	0.51	0.25
UGS use	0.71	0.85	0.53	0.80	0.88	0.98

Figure S1: Physical activity odds ratio, 95% CI and p-values stratified by sex, age and education level



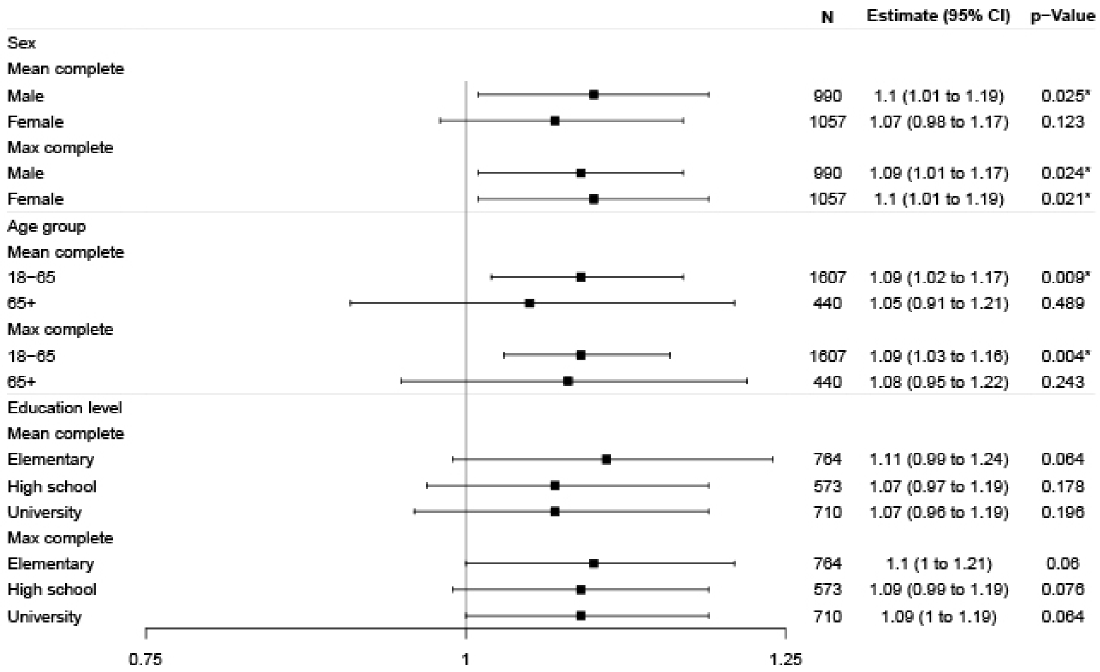
* $p < 0.05$

Figure S2: Overweight/obesity odds ratio, 95% CI and p-values stratified by sex, age and education level



* $p < 0.05$

Figure S3: UGS use incidence rate ratio, 95% CI and p-values stratified by sex, age and education level



* $p < 0.05$

Associations of urban green spaces with cardiometabolic risk factors: comparing metrics with an ecological study in Philadelphia

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Abstract: Mounting scientific evidence suggests that urban green is associated with improvement in a wide range of health outcomes across all age groups. Including relevant risk factors to predict CVD events, like reduced risk of being overweight, having high blood pressure, or having type 2 diabetes. Most research thus far on links between green space and health have used the normalized difference vegetation index (NDVI) as a cumulative exposure metric. However, the use of unique urban green metrics seems to play a role in the findings regarding the associations between urban green and cardiometabolic health. Moreover, there is some evidence of heterogeneity of effects of green space by sociodemographic groups. We compared the association between four different green space measures (tree cover, overall green space, NDVI and perceived access) and three of the most relevant cardiovascular risk factors (overweight, high blood pressure, and diabetes) using data from the Southeastern Pennsylvania Household Health Survey (SEPAHH). Additionally, we used stratified analysis to unveil the potential effect modification by neighborhood socioeconomic status and population density. In our analysis, associations with perceived access were stronger than with objective measures of green space, and among the objective measures, associations were strongest with tree canopy cover. When stratifying, objective green space measures protective association disappeared for tracts with a high proportion of population below the poverty line, a high proportion of the non-Hispanic black population, or high density. On the contrary, perceived access had a stronger protective association in these tracts. These results suggest that if urban decision-makers want to influence the cardiometabolic risk factors

of urban dwellers using urban green, it is not sufficient to increase the raw amount of greenness. They also need to consider typology, accessibility, and socioeconomic context.

Abstract accepted to special issue in *International Journal of Environmental Research and Public Health*

1. Introduction

Cardiovascular disease (CVD) is the leading cause of mortality worldwide (GBD collaborators *et al*., 2017). Overweight, high blood pressure, and diabetes are amongst the most relevant risk factors for CVD events (Damen *et al*., 2016). These three risk factors are themselves associated with modern urban lifestyle through different pathways, such as sedentarism (Medina *et al*., 2017), poor diet (Becerra-Tomás *et al*., 2020), air pollution (Bhatnagar, 2006), noise (Swinburn *et al*., 2015), and urban sprawl (Chandrabose *et al*., 2018). However, there is one feature of urban settings that has been beneficially associated with CVD risk factors: green space (GS). Although in many cities GS is relegated to small isolated areas, mounting scientific evidence suggests that GS is associated with some beneficial effects in a wide range of health outcomes across all age groups. These include reduced risk of being overweight (Muller *et al*., 2018), of having high blood pressure (Tamosiunas *et al*., 2014), or of having type 2 diabetes (Muller *et al*., 2018).

Most research thus far on links between GS and health have used the remote sensing-based indices as a cumulative exposure metric. It is easily accessible across the world and has a relatively high temporal resolution, thus allowing for its use in extensive, multi-site, population-based studies. However, the reliance on this measure leads to a homogenization of GS, as it fails to capture differences in type of GS (Reid, Clougherty, Shmool, & Kubzansky, 2017). The type of GS seems to play a role in the associations between GS and health outcomes. Reid *et al*. (2017), for example, found differences between the associations of tree cover, grass cover, and overall vegetation with self-reported health. Moreira *et al*. (2020) found differences when comparing the associations of street trees and parks with hypertension. Additionally, some studies suggest that perceived GS measures might be better predictors for specific health outcomes. Dadvand *et al*. (2016), for example, found associations between perceived access to greenspace with perceived general health, mental health, physical activity, social cohesion. Nevertheless, few studies have compared associations of cardiometabolic indicators both with perceived GS measures and specific GS types.

Moreover, there is some evidence of heterogeneity of effect of GS by sociodemographic group. For instance, Knobel *et al.* (*under revision*) found that GS was more protective against obesity for participants with a high education level. Such an analysis is critical for informing policy and planning interventions about optimal GS types for health promotion, tailored to population-specific characteristics.

With the present study, we aimed to evaluate and compare the associations of four different indicators of GS (overall green space, tree cover, NDVI and perceived access) with three of the most relevant CVD risk factors (overweight, high blood pressure, and diabetes). Additionally, we explored the potential modification of these associations by neighborhood socioeconomic status and population density.

2. *Methods*

2.1. Study setting and population

This ecologic study was mainly based on data from the 2013 Southeastern Pennsylvania Household Health Survey (SEPAHH) conducted in Philadelphia, PA. SEPAHH is a biennial telephone survey administered by the Public Health Management Corporation and is conducted in five counties in southeastern Pennsylvania (Bucks, Chester, Delaware, Montgomery, and Philadelphia) (PHMC, 2015). Data is collected through random digit dialing, with oversampling of people ages 60 and over. We used data on adult residents (ages 18+) from the surveys conducted in the years 2012 and 2014/2015; we assigned the average of the values from these two years as the value for the year 2013. The unit of observation was the census tract (CT), and all data were aggregated to the 2010 CT boundaries. CTs are administrative units, defined by the U.S. Census Bureau. In Philadelphia, CTs are densely populated. Exact SEPAHH questions, responses and codification of the included variables can be found in Table S1.

2.2. Exposure measures

Our assessment of exposure to GS included three objective (NDVI, overall green cover, and tree canopy cover) and one subjective (perceived access to GSs) indicators of this exposure

NDVI

We used images from the Moderate-resolution Imaging Spectroradiometer (MODIS) of NASA's Terra satellite (MOD13Q1, Version 6 product) to derive normalized difference vegetation index (NDVI) estimates (Carroll, DiMiceli, Sohlberg, & Townshend, 2004). The NDVI is a quantitative measure of greenness density, ranging in value from -1 to 1 with higher values indicating more photosynthetically active land cover. It is calculated based on the reflectance properties of vegetated versus non-vegetated areas; healthy vegetation absorbs visible light but reflects near-infrared light. On the other hand, non-vegetated areas reflect more visible light and less near-infrared light. Negative NDVI values represent water, values close to zero represent areas without green (e.g., pavement in urban areas), and values close to one represent the most densely green areas. MODIS provides 250 m resolution images for 16-day periods. We used the extract function in the Raster package (Hijmans & van Etten, 2012) of the R software (version 3.5.1) to calculate the mean NDVI value for each CT,. We then calculated the mean NDVI for the year of 2013 within each CT. We did not exclude any NDVI values; therefore, any values that were zero or negative would have been included in the calculation.

Overall green cover and tree canopy cover

We used very high-resolution (30.5 cm × 30.5 cm) orthophotography and Light Detection and Ranging (LiDAR) based land cover data to calculate proportion tree canopy and low vegetation (grass/shrubs) cover within each CT. The land cover assessments assigned each pixel ten mutually exclusive categories, which we used to calculate the different GS types. Proportions were defined as the total area covered by either GS type divided by total area in each CT (km2). Two land cover assessments were conducted for Philadelphia County; one was conducted in 2008 and the other in the year 2018 (O'Neil-Dunne &

Grove, 2011; O'Neil-Dunne, MacFaden, Royar, & Pelletier, 2013). We used values from these two assessments and linear interpolation to assign values to the year 2013.

Perceived access to green space

The specific question on perceived GS access was the following: "Is there a park or other outdoor space in your neighborhood that you are comfortable visiting during the day?" Therefore, the park access measure represented the proportion of all residents in a CT, ages 18 years and older, who reported that they have a park or outdoor space in their neighborhood that they felt comfortable visiting during the day.

2.2. Outcome assessment

Survey-based measures

The survey-based measures of diabetes and high blood pressure were based on questions asking if a doctor or medical professional had ever told them that they had either of these conditions outside pregnancy. Obesity was determined based on self-reported height and weight. To account for the uncertainty that comes from using survey data to derive CT-level estimates, we used proportions that were smoothed using Bayesian hierarchical models that simultaneously account for spatial, temporal, and between race/ethnic dependence structures. The methods used to derive these smoothed estimates have been reported in detail elsewhere. (Quick, Terloyeva, Wu, Moore, & Roux, 2020)

2.3. Covariates

Census-based covariate measures

Data on CT-level population density, the proportion of the population unemployed, the proportion with a Bachelor's degree or higher, and proportion of the population living below the poverty line were based on American Community Survey data for years 2011-2015 ("US Census Bureau American community survey (ACS)," n.d.).

Air pollution measures

We estimated the mean average concentration of particulate matter < 2.5 μ/m^3 (PM$^{2.5}$) in each CT in the year 2013. Data on $PM_{2.5}$ concentrations were derived from the EPA's Downscaler model (Berrocal, Gelfand, & Holland, 2010b, 2010a).

Violent crime

CT-level rates of violent crime per 10,000 population were calculated using daily crime data from the Philadelphia Police Department, available from Philadelphia's Open Data portal ("OpenDataPhilly," n.d.), and population data from the U.S.Census.

2.4. Statistical analysis

Main analysis

We developed 12 general linear models (GLM), including the proportion of the adult population in the CT who had been diagnosed with obesity, high blood pressure, and diabetes as outcome (one at a time) and CT-level measures of proportion tree canopy cover, overall green space (tree canopy and grass/shrub), NDVI, and perceived park access as exposures (one at a time). Given that some of our evaluated associations were not linear, we categorize our exposure variables based on their tertiles and used this categorical variable in our models. We considered the first tertile as the reference category; as such our estimates represented the percentage change in the health outcome for moving from the first to the second or the first to the third tercile. Our models were adjusted for the percent of the population below poverty, percent of non-Hispanic black population, and population density. We selected these variables *a priori*, based on hypotheses that they might confound associations between GS and cardiometabolic indicators.

Effect modification

We assessed potential modification of our evaluated associations by the following variables: percent below poverty line, percent non-Hispanic black population, and population density. We explored effect modification by stratifying our data by tertiles of these variables.

Sensitivity analysis

To test the robustness of our findings to the selected set of covariates, we further adjusted our analyses by adding the following covariates one-by-one (in terciles): prevalence of current smokers, the proportion of the adult population with a Bachelor's degree or higher, the prevalence of the population reporting having access to fresh fruit and vegetables, the proportion of the population who were unemployed, violent crime rates, and annual concentration of $PM_{2.5}$. To account for residual confounding due to spatial autocorrelation across CT boundaries, we also repeated the analyses using spatial lag models.

We performed all our analyses using R statistical software. We used the package spdep (Bivand *et al*., 2015) to run the spatial lag models.

3. Results

3.1. Descriptive statistics

Socioeconomic covariates showed considerable variability with average values of 7390 inhabitants/km^2 (range 0 – 25800 inhabitants/km^2), 42.3% (range 0.0 – 99.6) for percent non-Hispanic black population, and 26.4% (range 0.0 – 74.4%) for percent of population below poverty line. Objective measures of GS exposures had substantial variability across the CTs. The average value of NDVI was 0.29 (range 0.06 – 0.63%), of overall green space was 35.1% (range 4.6 – 92.7%), and of tree cover was 15.4% (range 0.8 – 80.4%). Compared to objective measures, reported perceived access to parks had higher average value and less variability, with 75.2% (range 46.4 – 95.0%). On average, less than half of the residents by CT were obese (31.5%, range 16.9 – 41.0%) or had high blood pressure (33.4%, range 20.5 – 42.1%). Compared to the other health outcomes, diabetes prevalence average was notably lower, with less than one-fifth of the population (12.4%, range 4.5 - 17.5%). (TABLE 1)

Table 1: summary statistics of exposure measures, outcomes and covariates.

Variable	N = 384
Population density (hab/km2)	
Mean (SD)	7390 (4490)
Median [min,max]	6760 [0, 25800]
Proportion of non-Hispanic black	
Mean (SD)	0.423 (0.350)
Median [min,max]	0.296 [0, 0.996]
Missing	7 (1.8%)
Proportion of population below the poverty line	
Mean (SD)	0.264 (0.157)
Median [min,max]	0.248 [0, 0.744]
Missing	7 (1.8%)
NDVI	
Mean (SD)	0.290 (0.118)
Median [min,max]	0.270 [0.0597, 0.637]
Proportion overall green space	
Mean (SD)	0.351 (0.169)
Median [min,max]	0.315 [0.0462, 0.927]
Proportion tree canopy cover	
Mean (SD)	0.154 (0.114)
Median [min,max]	0.123 [0.00825, 0.804]
Perceived access to GS	
Mean (SD)	0.752 (0.0905)
Median [min,max]	0.753 [0.464, 0.950]
Obesity prevalence	
Mean (SD)	0.315 (0.0580)
Median [min,max]	0.324 [0.169, 0.410]
High blood pressure prevalence	
Mean (SD)	0.334 (0.0533)
Median [min,max]	0.339 [0.205, 0.421]
Diabetes prevalence	
Mean (SD)	0.124 (0.0299)
Median [min,max]	0.132 [0.0454, 0.175]

All objective GS measures were highly correlated: with correlation coefficients higher than 0.8. Perceived access had a lower correlation with the objective measures: 0.32 for tree cover, 0.21 for overall green space, and 0.12 for NDVI. Health outcomes were highly correlated with one another; correlation coefficients were higher than 0.9. Amongst covariates, proportions non-Hispanic black and proportion of the population living below the poverty line were relatively highly correlated (correlation coefficient:0.41). (FIGURE S1)

3.2. Main analysis

Results from models of the association between proportion tree canopy cover, overall green space, NDVI, and perceived access with the proportion of the adult population who were obese, with high blood pressure, and with diabetes are presented in Figure 1 (and Table S2) . All three outcomes follow similar patterns, with stronger protective associations for obesity, then high blood pressure, and, finally, diabetes. Associations with the intermediate exposure tertile were null or borderline null for all exposures and outcomes. For the highest exposure tertile, tree cover and perceived access had a protective association with obesity, high blood pressure, and diabetes, while NDVI and overall green space associations remained null.

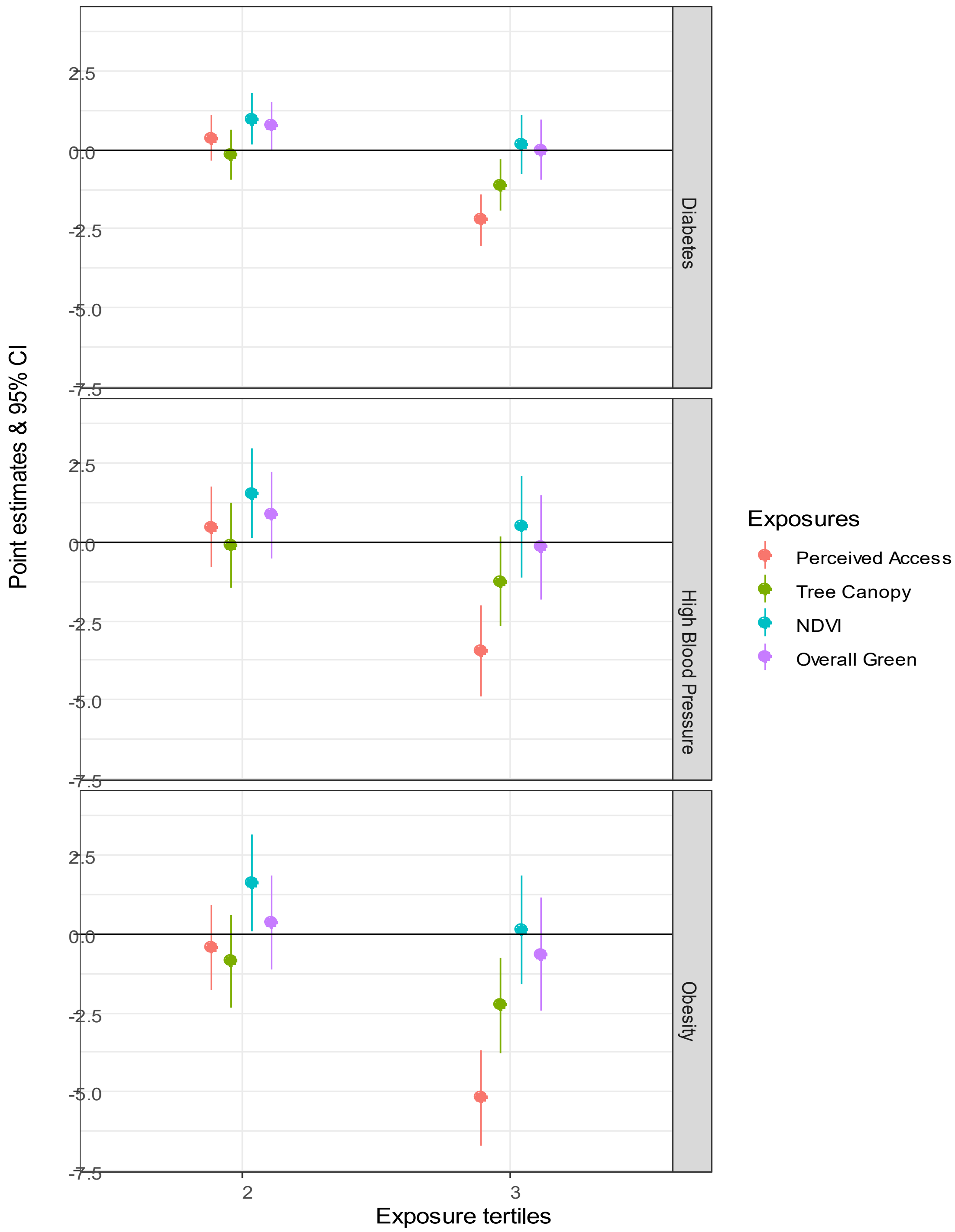

Figure 3: Estimates of association between NDVI, overall green space, tree canopy cover, and perceived access with the proportion of the adult population who were obese, with high blood pressure, and with diabetes, derived from generalized linear regression models adjusted for CT population density, proportion non-Hispanic black, and proportion of the population living below the poverty line.

3.3. Stratified analysis

When we stratified our analyses based on terciles of the CT proportion of population below the poverty line, a potential effect modification became apparent for some of exposure measures (Figure 2). Divergent trends could be seen in perceived access and objective measures, while similar trends can be seen across health outcomes. In CTs with the lowest proportions of the population living in poverty, the protective association of perceived access disappeared, even becoming pernicious for the intermediate exposure tercile. CTs with a medium and high proportion of the population living below the poverty line saw the protective association restored, with stronger associations for the high poverty CTs. Objective measures followed a different pattern, with small protective associations for the low poverty CTs (null for NDVI) and trends that suggest a disappearance of the association in the medium and high poverty CTs.

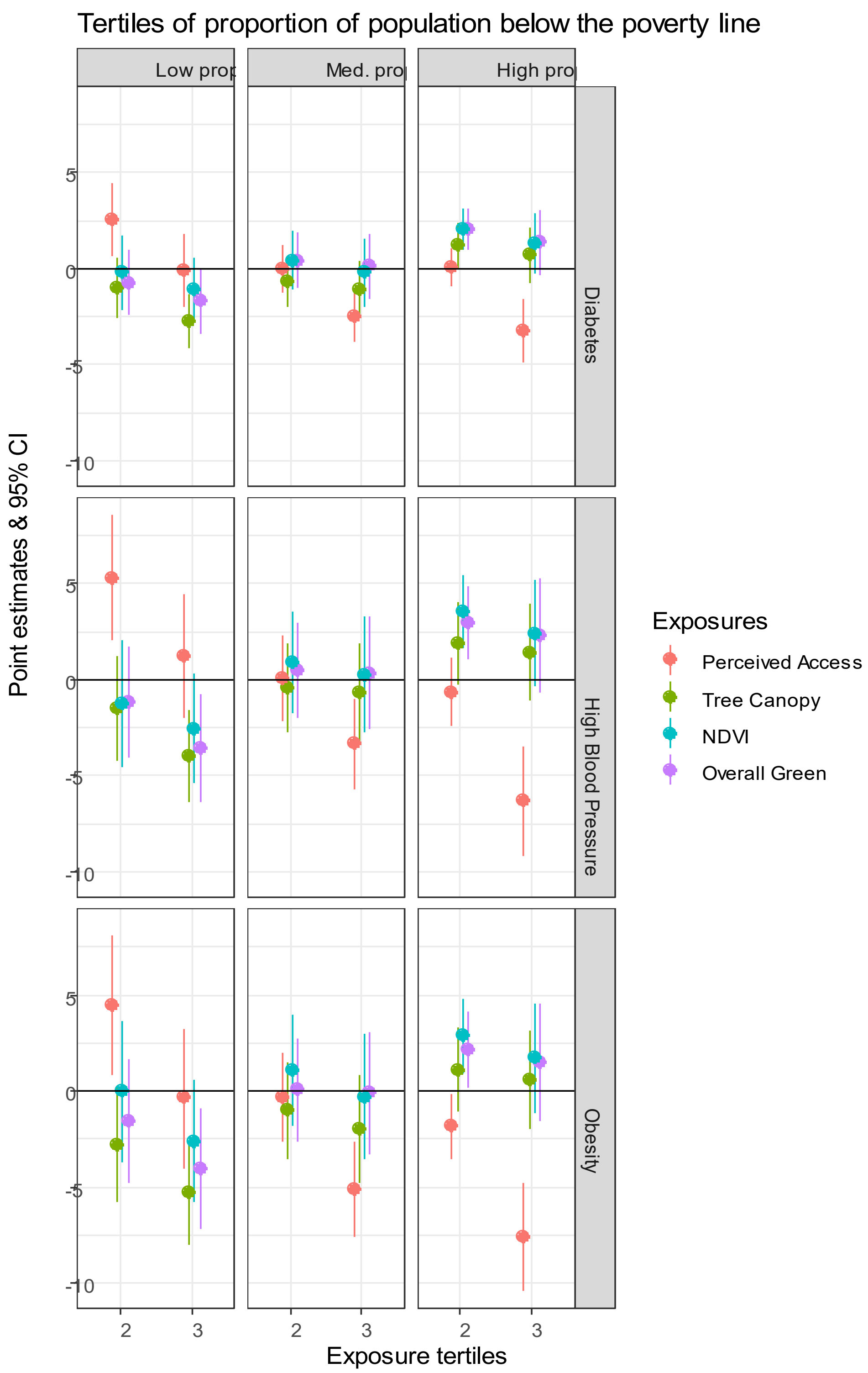

Figure 4: Estimates of association between NDVI, overall green space, tree canopy cover, and perceived access with the proportion of the adult population who were obese, with high blood pressure, and with diabetes. Derived from generalized linear regression models adjusted for CT level population density and proportion non-Hispanic black and stratified for the proportion of the population living below the poverty line.

Stratification by percent non-Hispanic black population also suggested a potential effect modification. Distinct trends could be observed in perceived access to GSs and objective measures, while similar trends can be seen across health outcomes. Negative associations with perceived access remained present through all terciles. However, CTs with an intermediate proportion of non-Hispanic black populations seem to have a stronger association. Objective measures have a protective association for the CTs with a low proportion of the non-Hispanic black population (Null for NDVI), this association disappear for the CTs with a medium proportion of the non-Hispanic black population, and is suggestive of a pernicious association of NDVI and overall green space for CTs with a high proportion of the non-Hispanic black population (Figure 3).

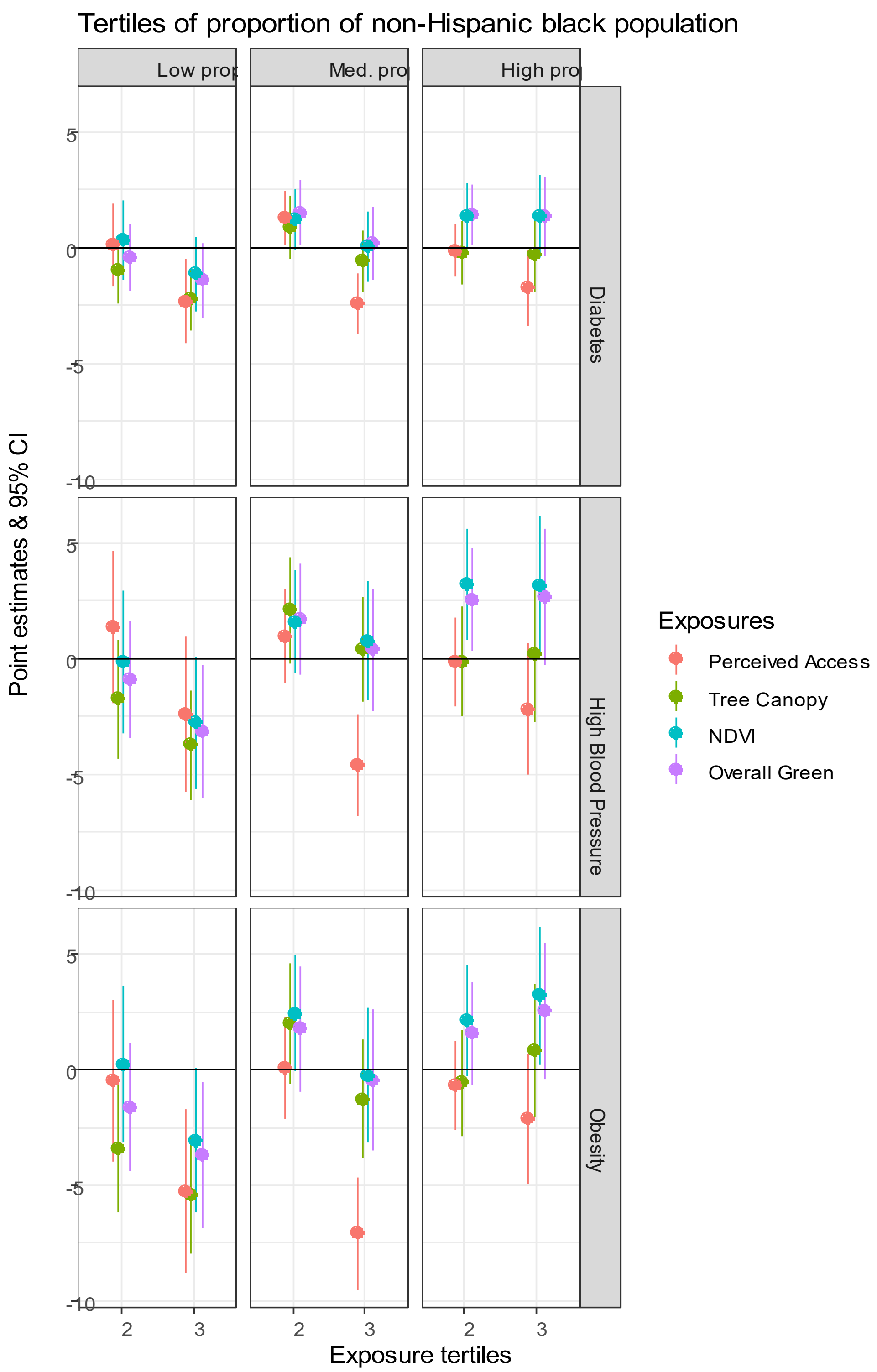

Figure 5: Estimates of association between NDVI, overall green space, tree canopy cover, and perceived access with the proportion of the adult population who were obese, with high blood pressure and with diabetes. Derived from generalized linear regression models adjusted for CT level population density and proportion of the population living below the poverty line, and stratified for proportion non-Hispanic black.

Stratification by percent non-Hispanic black population also suggested a potential effect modification. All exposures seemed to have a protective association in the CTs with the lowest population density. Tree canopy and overall green space move towards the null in denser CTs. In comparison, perceived access strengthens its protective association, and NDVI changes direction into a strong pernicious association for the denser CTs (Figure 4).

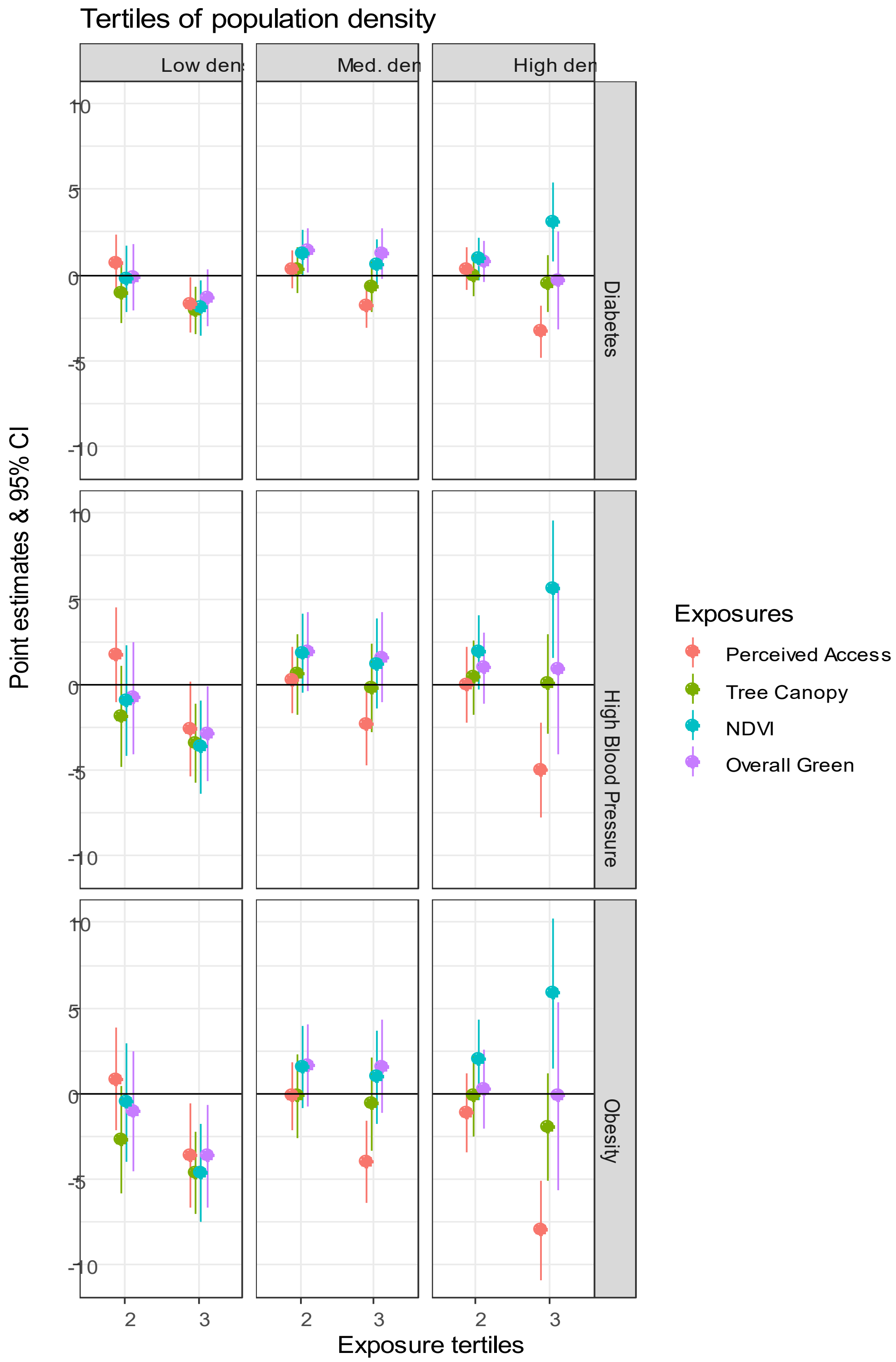

Figure 6: Estimates of association between NDVI, overall green space, tree canopy cover, and perceived access with the proportion of the adult population who were obese, with high blood pressure, and with diabetes. Derived from generalized linear regression models adjusted for CT level proportion non-Hispanic black and proportion of the population living below the poverty line, and stratified for population density.

3.4. Sensitivity analyses

We did not observe any notable changes in the direction and strength of associations after further adjusting our analyses for the proportion of the CT's adult population with a Bachelor's degree or higher, the prevalence of the population reporting having access to fresh fruit and vegetables, the proportion of the CT's population who were unemployed, CT-level violent crime rates, and annual concentration of PM_{25}. (Table S3).

4. Discussion

To our knowledge, this is the first study to compare the magnitude and direction of estimates of associations of different GS measures, including a measure of perceived access to GS, with cardiometabolic risk factors. Previous studies have analyzed the different exposures independently or have been limited to mental health indicators and overall self-reported health measures. In our analysis, associations with perceived access were stronger than with objective measures of GS, and among the objective measures, associations were strongest with tree canopy cover. When stratifying, objective green space measures protective association disappeared for CTs with a high proportion of population below the poverty line, a high proportion of the non-Hispanic black population, or high density. On the contrary, perceived access had a stronger protective association in these high poverty, high non-hispanic black or high density CTs.

4.1. Differences amongst exposure measures:

The low correlation between perceived and objective green space exposure measures concurs with previous research. Orsad *et al*. (2017) reviewed the agreement between objective and perceived green space metrics in physical activity studies, and 72.1% of the studies showed only slight-to-poor agreement (kappa = .00 - .40). Our stronger association of perceived access to greenspaces compared to objective measures also concurs with the results of Orstad *et al*. (2917): they found that studies using perceived measures had higher odds of finding significative asociaitons between green space and physical activity. There are several potential explanations for the poor correlation between objective and perceived measures. The disagreement could be due to faulty question design: the questionnaires used to build perceived green space measures are yet to be fully developed. They could potentially be improved to be closer to the objective measures (Orsad *et al*., 2017). The second, and more plausible option, is that objective and perceived measures capture different aspects of the green space. Social cohesion, for example, can be measured by perceived measures and not by objective measures, at least in a reliable way (Zhang, Zhou, & Kwan, 2019). Moreover, personal opinions and depictions of urban green space are constructed though a combination of both objective measures and personal perceptions (Lackey 2009) Therefore, perceived and objective measures should not aim to be interchangeable and compared as equals (Leslie *et al*., 2008). However, the aspects captured by each one might be relevant for different pathways between green space and human health.

Objective green space measures tend to be highly correlated, which could lead to the idea that including a single measure in a study is enough (Reid *et al*., 2017). However, our objective measures where highly correlated and still showed substantial association strength differences in relation to our evaluated outcomes, with only tree cover showing a substantial association with our selected health outcomes. The association of tree cover is in line with existing literature: Ulmer *et al*. (2016) delved into the effects of trees independently and found associations with overall health that were mediated by a reduction in overweight, diabetes, high blood pressure, and asthma. Similar to the perceived-objective comparison, differences in associations with different GS types might be a consequence of how one acts upon health. Amongst others, trees have been linked to reduced crime (Kondo *et al*., 2017), reduced environmental exposures (like noise) (Fang *et al*., 2005), an increased presence of potentially beneficial biogenic compounds (Bach *et al*., *in revision*), and provision of many other ecosystem services (like thermal comfort) (Sanusi *et al*. 2016). Although with different levels of confidence, all these improvements have been linked underlying mechanisms that positively influence cardiometabolic health, including the biogenics hypothesis, reduction of environmental exposure, promote physical activity, reduce stress, promote social contacts and the biodiversity hypothesis (Nieuwenhuijsen, Khreis, Triguero-Mas, Gascon, & Dadvand, 2017). Considering this, improved study design would test mechanisms by which GS affects the health outcome of interest to find the best fit exposure-wise. As an example: GS's positive effect on air quality does not require for the GS to be seen or used, as it exerts its positive effect directly by its presence. Objective measures are ideal in this case. On the other hand, physical activity requires GS to be perceived as usable, accessible, or safe to have a positive effect. Therefore, perceived measures would be a better fit in this case. Moreover, perceived and objective metrics can, and maybe should be used as complementary measures (Moore *et al*., 2008), especially when studying less explored pathways and outcomes.

4.2.Effect modification:

Literature regarding the modification of the CVD effects of GSs link is not consistent. Some studies have shown that people from lower socioeconomic status could benefit more from GSs regarding obesity (Sharkar, 2017) and insulin resistance (Thiering *et al*,. 2016), while others have not found such a difference between income levels in obesity (Browning *et al*., 2018). Our findings for the perceived access to GS were in line with the hypothesis that lower socioeconomic status groups could benefit more from GS. Contrarily, CTs with a low proportion of the population below the poverty line are protected by objective measures, and detrimentally associated with perceived access. One possible source for disagreement is that perceived measures are, by definition, perceived by the participants, with some perceptions such as safety could be influenced by the socioeconomic status (Weiman *et al*., 2017). Therefore, CTs with similar levels of objective GS might have very different perceived GS values depending on the characteristics of those who live in them.

Similarly, literature regarding differences in GS and human health associations by race/ethnicity is scarce and inconsistent. When looking at pregnant women, Dadvand *et al*. (2014) found a positive association between GS and birth outcomes only for white females, but not for the Pakistani origin mothers. Contrarily, McEachan *et al*. (2016) found no differences between ethnic groups regarding the association between GSs and depression during pregnancy. Our results suggest that GS has a protective role in CTs with a low proportion of the non-Hispanic black population. This association disappeared and even became pernicious for the CTs with a high proportion of the black population. The health impact of objective measures of exposure to GS might also be mediated by personal perceptions, such as connectedness to GS, which could, by itself, be associated with sociodemographic variables such as age, gender, ethnicity, or socioeconomic status (Shanahan *et al*., 2016). Therefore, the association between GS and human health might be substantially different between CTs with similar levels of objective GS but with different sociodemographic profile.

Population density is often incorporated in composite measures of urban sprawl and walkability. Both measures have been linked to obesity (Chandrabose *et al*. 2019). However, literature regarding its potential modifier role between GS and human health is scarce and inconsistent. Richardson *et al*. (2011) found that the amount of urban sprawl modified the relation between GS and all-cause mortality. Browning *et al*. (2018) did not find such a pattern regarding the association of GS with obesity and mental health. We only found substantial differences in the NDVI estimates, from a beneficial association in lower density, to a detrimental one in the highest. This is the only instance where NDVI and overall green space had differentiated patterns.

4.3.Strengths and limitations:

We acknowledge the limitations derived from this study being a cross-sectional ecological study, which, is prone to the ecological bias and as such, has a limited capability to establish causality. However, Philadelphia's small and dense CTs might have reduced the extend of such a bias. Moreover, we could not rule out reverse causation or self-selection bias, especially regarding perceived access to greenspace in that healthy people might have fewer requirements to define something as accessible or might move into greener areas. We tried to reduce residual confounding by controlling for race, poverty, and population density and conducting several sensitivity analyses, however, like any other observational study, we could not rule out the potential for residual confounding.

The question we used ("Is there a park or other outdoor space in your neighborhood that you are comfortable visiting during the day?") make use of a broad definition of GS and accessibility. Participants might be referring to non-green public open space instead of GS. On the other hand, this question allows for the capture of accessibility to spaces that are not defined as gardens or parks. Similarly, the definition of access is not limited to physical access, as it includes the concept of comfort. Comfort is a construct that might include many factors, such as safety, maintenance, or a specific set of amenities.

5. *Conclusions:*

Our results suggest that if urban decision-makers are willing to influence the cardiometabolic health of urban dwellers using GS, it is not sufficient to increase the raw amount of greenness. Trees and also perceived access to GSs could have essential roles in the potential of greenspace in improving the cardiometabolic health of the citizens. Strategies might consider not only relying on increasing the green area but also making it more accessible, safe, and usable. Moreover, it is critical to consider the socioeconomic context when developing GS and cardiometabolic health strategies. Our results reinforce the idea that the effects of greenery are heterogeneous amongst income and race groups. Choosing the best option between increasing the among of green or facilitating access to the exiting one might depend on the socioeconomic context.

Further research must deepen into the specific differences between socioeconomic groups and try to disentangle how the socioeconomic factors interact with the salutogenic pathways. It is also essential to unravel the associations with specific health outcomes using study designs that allow for appropriate mediation analysis.

References:

Berrocal, V. J., Gelfand, A. E., & Holland, D. M. (2010a). A bivariate space-time downscaler under space and time misalignment. *The Annals of Applied Statistics*, *4*(4), 1942.

Berrocal, V. J., Gelfand, A. E., & Holland, D. M. (2010b). A spatio-temporal downscaler for output from numerical models. *Journal of Agricultural, Biological, and Environmental Statistics*, *15*(2), 176–197.

Bivand, R., Altman, M., Anselin, L., Assunção, R., Berke, O., Bernat, A., & Blanchet, G. (2015). Package 'spdep.' *See Ftp://Garr. Tucows. Com/Mirrors/CRAN/Web/Packages/Spdep/Spdep. Pdf (Accessed 9 December 2015)*.

Carroll, M. L., DiMiceli, C. M., Sohlberg, R. A., & Townshend, J. R. G. (2004). 250m MODIS normalized difference vegetation index. *University of Maryland, College Park, Maryland*.

Hijmans, R. J., & van Etten, J. (2012). *raster: Geographic analysis and modeling with raster data. R package version 2.0–12*.

Nieuwenhuijsen, M. J., Khreis, H., Triguero-Mas, M., Gascon, M., & Dadvand, P. (2017, January). Fifty shades of green. *Epidemiology*, Vol. 28, pp. 63–71. https://doi.org/10.1097/EDE.0000000000000549

O'Neil-Dunne, J., & Grove, J. M. (2011). A report on the City of Philadelphia's existing and possible tree canopy. *USDA Forest Service: Washington, DC, USA*.

O'Neil-Dunne, J. P. M., MacFaden, S. W., Royar, A. R., & Pelletier, K. C. (2013). An object-based system for LiDAR data fusion and feature extraction. *Geocarto International*, *28*(3), 227–242.

OpenDataPhilly. (n.d.). Retrieved August 17, 2020, from https://www.opendataphilly.org/

PHMC. (2015). Public Health Management Corporation Community Health Data Base's Southeastern Pennsylvania Household Health Survey. Retrieved from http://www.chdbdata.org/..

Quick, H., Terloyeva, D., Wu, Y., Moore, K., & Roux, A. V. D. (2020). Trends in Tract-Level Prevalence of Obesity in Philadelphia by Race-Ethnicity, Space, and Time. *Epidemiology*, *31*(1), 15–21.

Reid, C., Clougherty, J., Shmool, J., & Kubzansky, L. (2017). Is All Urban Green Space the Same? A Comparison of the Health Benefits of Trees and Grass in New York City. *International Journal of Environmental Research and Public Health*, *14*(11), 1411. https://doi.org/10.3390/ijerph14111411

US Census Bureau American community survey (ACS). (n.d.). Retrieved from https://www.census.gov/programs-surveys/acs/

Zhang, L., Zhou, S., & Kwan, M. P. (2019). A comparative analysis of the impacts of objective versus subjective neighborhood environment on physical, mental, and social health. *Health and Place*, *59*, 102170. https://doi.org/10.1016/j.healthplace.2019.102170

Berrocal, V. J., Gelfand, A. E., & Holland, D. M. (2010a). A bivariate space-time downscaler under space and time misalignment. *The Annals of Applied Statistics*, *4*(4), 1942.

Berrocal, V. J., Gelfand, A. E., & Holland, D. M. (2010b). A spatio-temporal downscaler for output from numerical models. *Journal of Agricultural, Biological, and Environmental Statistics*, *15*(2), 176–197.

Bivand, R., Altman, M., Anselin, L., Assunção, R., Berke, O., Bernat, A., & Blanchet, G. (2015). Package 'spdep.' *See Ftp://Garr. Tucows. Com/Mirrors/CRAN/Web/Packages/Spdep/Spdep. Pdf (Accessed 9 December 2015)*.

Carroll, M. L., DiMiceli, C. M., Sohlberg, R. A., & Townshend, J. R. G. (2004). 250m MODIS normalized difference vegetation index. *University of Maryland, College Park, Maryland*.

Hijmans, R. J., & van Etten, J. (2012). *raster: Geographic analysis and modeling with raster data. R package version 2.0–12*.

Nieuwenhuijsen, M. J., Khreis, H., Triguero-Mas, M., Gascon, M., & Dadvand, P. (2017, January). Fifty shades of green. *Epidemiology*, Vol. 28, pp. 63–71. https://doi.org/10.1097/EDE.0000000000000549

O'Neil-Dunne, J., & Grove, J. M. (2011). A report on the City of Philadelphia's existing and possible tree canopy. *USDA Forest Service: Washington, DC, USA*.

O'Neil-Dunne, J. P. M., MacFaden, S. W., Royar, A. R., & Pelletier, K. C. (2013). An object-based system for LiDAR data fusion and feature extraction. *Geocarto International*, *28*(3), 227–242.

OpenDataPhilly. (n.d.). Retrieved August 17, 2020, from https://www.opendataphilly.org/

PHMC. (2015). Public Health Management Corporation Community Health Data Base's Southeastern Pennsylvania Household Health Survey. Retrieved from http://www.chdbdata.org/..

Quick, H., Terloyeva, D., Wu, Y., Moore, K., & Roux, A. V. D. (2020). Trends in Tract-Level Prevalence of Obesity in Philadelphia by Race-Ethnicity, Space, and Time. *Epidemiology*, *31*(1), 15–21.

Reid, C., Clougherty, J., Shmool, J., & Kubzansky, L. (2017). Is All Urban Green Space the Same? A Comparison of the Health Benefits of Trees and Grass in New York City. *International Journal of Environmental Research and Public Health*, *14*(11), 1411. https://doi.org/10.3390/ijerph14111411

US Census Bureau American community survey (ACS). (n.d.). Retrieved from https://www.census.gov/programs-surveys/acs/

Zhang, L., Zhou, S., & Kwan, M. P. (2019). A comparative analysis of the impacts of objective versus subjective neighborhood environment on physical, mental, and social health. *Health and Place*, *59*, 102170. https://doi.org/10.1016/j.healthplace.2019.102170

Supplementary material

TABLE S1: Survey questions, responses and codification derived from the Southeastern Pennsylvania Household Health Survey (SEPAHH).

Variable	Question	Responses	Codification
Perceived access to GS	Is there a park or other outdoor space in your neighborhood that you're comfortable visiting during the day?	1=Yes	1=Yes
		2=No	0=No
High blood pressure	Have you EVER been told by a doctor or other health professional that you have high blood pressure or hypertension?	1=Yes	1=Yes
		2=No 3=Only during pregnancy	0=No
Diabetes	Have you EVER been told by a doctor or other health professional that you have or had any of the following conditions: Diabetes	1=Yes	1=Yes
		2=No 7=Only during pregnancy	0=No
Smoking	Do you NOW smoke cigarettes every day, some days, or not at all?	1=Everyday 2=Some days	1=Yes
		3=Not at all 4=Never smoked	0=No
Find fruit	How easy or difficult is it for you to find fruits and vegetables in your neighborhood? Would you say that it is very easy, easy, difficult, or very difficult?	1=Very easy 2=Easy	1=Easy
		3=Difficult 4=Very difficult	0=Difficult

TABLE S2: Estimates of association between NDVI, overall green space, tree canopy cover, and perceived access with the proportion of the adult population who were obese, with high blood pressure, and with diabetes, derived from generalized linear regression models adjusted for the CT population density, proportion non-Hispanic black, and proportion of the population living below the poverty line.

		Outcomes	**Obesity**		**High Blood Pressure**		**Diabetes**	
Exposures		Tercile Range	Estimate (95% CI)	p-value	Estimate (95% CI)	p-value	Estimate (95% CI)	p-value
NDVI	Tertile 1	(0.06 -0.23)	Ref.		Ref.		Ref.	
	Tertile 2	(0.23 - 0.33)	1.62(0.10, 3.15)	0.038	1.55(0.13, 2.97)	0.032	0.98(0.17, 1.79)	0.019
	Tertile 3	(0.33 - 0.63)	0.15(-1.57, 1.88)	0.864	0.50(-1.10, 2.10)	0.541	0.18(-0.74, 1.10)	0.707
Proportion Overall green space (trees, Grass, and shrubs)	Tertile 1	(0.05 - 0.27)	Ref.		Ref.		Ref.	
	Tertile 2	(0.27 - 0.39)	0.36(-1.13, 1.84)	0.638	0.88(-0.50, 2.25)	0.212	0.76(-0.03, 1.55)	0.059
	Tertile 3	(0.39 - 0.92)	-0.64(-2.41, 1.14)	0.483	-0.17(-1.82, 1.47)	0.836	0.00(-0.94, 0.95)	0.996
Proportion Tree canopy cover	Tertile 1	(0.01 - 0.09)	Ref.		Ref.		Ref.	
	Tertile 2	(0.10 - 0.16)	-0.85(-2.31, 0.61)	0.253	-0.10(-1.47, 1.26)	0.882	-0.15(-0.93, 0.63)	0.711
	Tertile 3	(0.16 - 0.80)	-2.25(-3.78, -0.73)	0.004	-1.25(-2.68, 0.17)	0.085	-1.12(-1.94, -0.31)	0.007
Perceived Access to parks	Tertile 1	(0.45 - 0.72)	Ref.		Ref.		Ref.	
	Tertile 2	(0.72 - 0.79)	-0.41(-1.75, 0.92)	0.544	0.47(-0.80, 1.74)	0.471	0.38(-0.34, 1.10)	0.300
	Tertile 3	(0.79 - 0.94)	-5.19(-6.71, -3.67)	0.000	-3.44(-4.89, -1.99)	0.000	-2.21(-3.03, -1.39)	0.000

TABLE S3: Estimates of association between proportion NDVI, overall green space, tree canopy cover, and perceived access with the proportion of the adult population who were obese, with high blood pressure, and with diabetes. Derived from generalized linear regression models. MAIN model adjusted at CT level for population density, proportion non-Hispanic black, and proportion of the population living below the poverty line. Other models adjusted with the same covariates plus an additional covariate, one-by-one. Last model using spatial lag regression.

			RAW model	MAIN model	MAIN + Smoking	MAIN + education	MAIN + find fruit	MAIN + unemployment	MAIN + crime	MAIN + pm25	MAIN - spatial lag
Outcome	Exposure	Tercile	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate
Obesity	Tree canopy cover	2	-0.25(-1.65,1.14)	-0.85(-2.31,0.61)	0.49(-0.87,1.85)	-0.58(-1.98,0.82)	-0.54(-1.89,0.82)	-0.38(-1.86,1.1)	-0.3(-1.81,1.21)	-0.35(-1.75,1.05)	-0.88(-3.57,1.8)
	Tree canopy cover	3	-2.51(-3.9,-1.11) *	-2.25(-3.78,-0.73) *	-0.12(-1.59,1.36)	-1.22(-2.71,0.28)	-1.2(-2.63,0.23)	-1.72(-3.27,-0.16)	-1.32(-3,0.35)	-1.12(-2.67,0.44)	-2.3(-4.46,-0.15)*
	Overall green space	2	1.16(-0.25,2.57)	0.36(-1.13,1.84)	1.66(0.32,3.01) *	0.22(-1.19,1.62)	0.72(-0.64,2.08)	0.65(-0.82,2.12)	0.97(-0.53,2.47)	0.46(-0.93,1.85)	-0.53(-3.44,2.38)
	Overall green space	3	-1.06(-2.47,0.34)	-0.64(-2.41,1.14)	1.89(0.22,3.55) *	-0.54(-2.22,1.15)	0.83(-0.84,2.5)	-0.29(-2.05,1.48)	0.79(-1.12,2.69)	-0.53(-2.24,1.18)	-1.97(-4.42,0.49)
	NDVI	2	2.31(0.91,3.7) *	1.62(0.1,3.15) *	2.7(1.34,4.06) *	1.09(-0.38,2.56)	1.81(0.41,3.2) *	1.64(0.13,3.14) *	1.92(0.41,3.43) *	1.37(-0.09,2.82) .	0.71(-2.26,3.68)
	NDVI	3	-0.45(-1.84,0.95)	0.15(-1.57,1.88)	2.7(1.1,4.3) *	0.06(-1.59,1.7)	2.07(0.43,3.71) *	0.37(-1.34,2.08)	1.55(-0.3,3.4)	-0.03(-1.72,1.67)	-0.84(-3.09,1.41)
	Perceived acesss	2	-0.68(-1.95,0.6)	-0.41(-1.75,0.92)	0.17(-1.03,1.37)	-0.11(-1.45,1.22)	0.45(-0.83,1.73)	-0.31(-1.68,1.07)	-0.34(-1.68,1.01)	0(-1.33,1.33)	1.37(-1.27,4.01)
	Perceived acesss	3	-5.78(-7.06,-4.51) *	-5.19(-6.71,-3.67) *	-4.16(-5.53,-2.78) *	-3.9(-5.55,-2.26) *	-3.92(-5.36,-2.47) *	-4.9(-6.54,-3.26) *	-4.88(-6.42,-3.34) *	-3.71(-5.31,-2.11) .	-1.34(-3.88,1.19)
High blood preasure	Tree canopy cover	2	0.46(-0.83,1.76)	-0.1(-1.47,1.26)	1.05(-0.26,2.36)	0.06(-1.29,1.41)	0.19(-1.08,1.45)	0.07(-1.32,1.46)	0.31(-1.1,1.72)	0.08(-1.28,1.44)	-0.56(-3.22,2.11)
	Tree canopy cover	3	-1.34(-2.64,-0.04) *	-1.25(-2.68,0.17) .	0.56(-0.85,1.98)	-0.69(-2.14,0.75)	-0.29(-1.63,1.05)	-1.08(-2.54,0.39)	-0.6(-2.16,0.97)	-0.89(-2.4,0.62)	-2.48(-4.62,-0.34)*
	Overall green space	2	1.51(0.21,2.8) *	0.88(-0.5,2.25)	1.97(0.67,3.26) *	0.81(-0.54,2.16)	1.2(-0.07,2.47) .	1.05(-0.33,2.43)	1.34(-0.05,2.74) .	0.88(-0.47,2.23)	-0.75(-3.65,2.15)

	Overall green space	3	-0.42(-1.71,0.87)	-0.17(-1.82,1.47)	1.91(0.31,3.5) *	-0.13(-1.75,1.49)	1.14(-0.41,2.7)	-0.07(-1.72,1.59)	0.83(-0.95,2.6)	-0.31(-1.97,1.34)	-2.23(-4.68,0.22).
	NDVI	2	2.05(0.76,3.33) *	1.55(0.13,2.97) *	2.44(1.13,3.75) *	1.28(-0.13,2.69) *	1.72(0.42,3.02) *	1.61(0.19,3.03) *	1.82(0.41,3.23) .	1.31(-0.11,2.73) .	-0.18(-3.15,2.79)
	NDVI	3	0.06(-1.23,1.35)	0.5(-1.1,2.1)	2.59(1.05,4.13) *	0.43(-1.15,2.01)	2.24(0.71,3.77) *	0.56(-1.05,2.16)	1.49(-0.24,3.21) .	0.2(-1.44,1.85)	-1.37(-3.63,0.88)
	Perceived acesss	2	0.13(-1.09,1.35)	0.47(-0.8,1.74)	0.95(-0.24,2.13)	0.56(-0.74,1.85)	1.31(0.09,2.53) *	0.43(-0.89,1.74)	0.5(-0.79,1.78)	0.54(-0.76,1.84)	1.55(-1.08,4.18)
	Perceived acesss	3	-4.12(-5.34,-2.91) *	-3.44(-4.89,-1.99) *	-2.59(-3.94,-1.23) *	-2.94(-4.53,-1.35) *	-2.22(-3.6,-0.84) *	-3.57(-5.13,-2) *	-3.27(-4.74,-1.8) *	-2.91(-4.47,-1.34) *	-1.44(-3.96,1.09)
Diabetes	Tree canopy cover	2	-0.15(-0.93,0.63)	0.05(-0.67,0.77)	0.45(-0.3,1.2)	-0.04(-0.8,0.73)	0(-0.73,0.74)	-0.03(-0.83,0.76)	0.04(-0.77,0.84)	0.06(-0.69,0.82)	-0.47(-2.01,1.07)
	Tree canopy cover	3	-1.12(-1.94,-0.31) *	-1.06(-1.79,-0.34) *	-0.17(-0.98,0.65)	-0.72(-1.54,0.1) .	-0.63(-1.41,0.15)	-0.99(-1.83,-0.16) *	-0.84(-1.73,0.06) .	-0.66(-1.5,0.19)	-1.38(-2.62,-0.15)*
	Overall green space	2	0.76(-0.03,1.55)	0.96(0.24,1.69) *	1.38(0.64,2.12) *	0.71(-0.06,1.48) .	0.93(0.2,1.67) *	0.86(0.08,1.65) *	1.02(0.23,1.82) *	0.8(0.05,1.55) *	-0.08(-1.75,1.59)
	Overall green space	3	0(-0.94,0.95)	-0.12(-0.84,0.61)	1.19(0.28,2.1) *	0.04(-0.88,0.96)	0.7(-0.2,1.6)	0.07(-0.87,1.02)	0.58(-0.43,1.6)	0.02(-0.91,0.94)	-1.09(-2.5,0.32)
	NDVI	2	0.98(0.17,1.79)*	1.09(0.37,1.82) *	1.47(0.71,2.22) *	0.77(-0.03,1.58) .	1.07(0.31,1.83) *	1.01(0.2,1.83) *	1.13(0.32,1.94) *	0.84(0.05,1.63) *	0.34(-1.38,2.05)
	NDVI	3	0.18(-0.74,1.1)	-0.03(-0.75,0.7)	1.34(0.46,2.22) *	0.13(-0.77,1.03)	1.08(0.18,1.97) *	0.22(-0.7,1.14)	0.7(-0.3,1.69)	0.05(-0.87,0.97)	-0.51(-1.81,0.79)
	Perceived acesss	2	0.38(-0.34,1.1)	0.38(-0.3,1.06)	0.65(-0.02,1.31) .	0.48(-0.25,1.21)	0.83(0.13,1.53) *	0.32(-0.42,1.07)	0.38(-0.35,1.1)	0.57(-0.15,1.29)	0.41(-1.1,1.93)
	Perceived acesss	3	-2.21(-3.03,-1.39) *	-2.19(-2.87,-1.51) *	-1.74(-2.5,-0.97) *	-1.76(-2.66,-0.86) *	-1.58(-2.37,-0.79) *	-2.31(-3.19,-1.43) *	-2.13(-2.97,-1.3) *	-1.52(-2.39,-0.65) *	-1.24(-2.69,0.22).

. p-value <0.10
* p-value <0.05

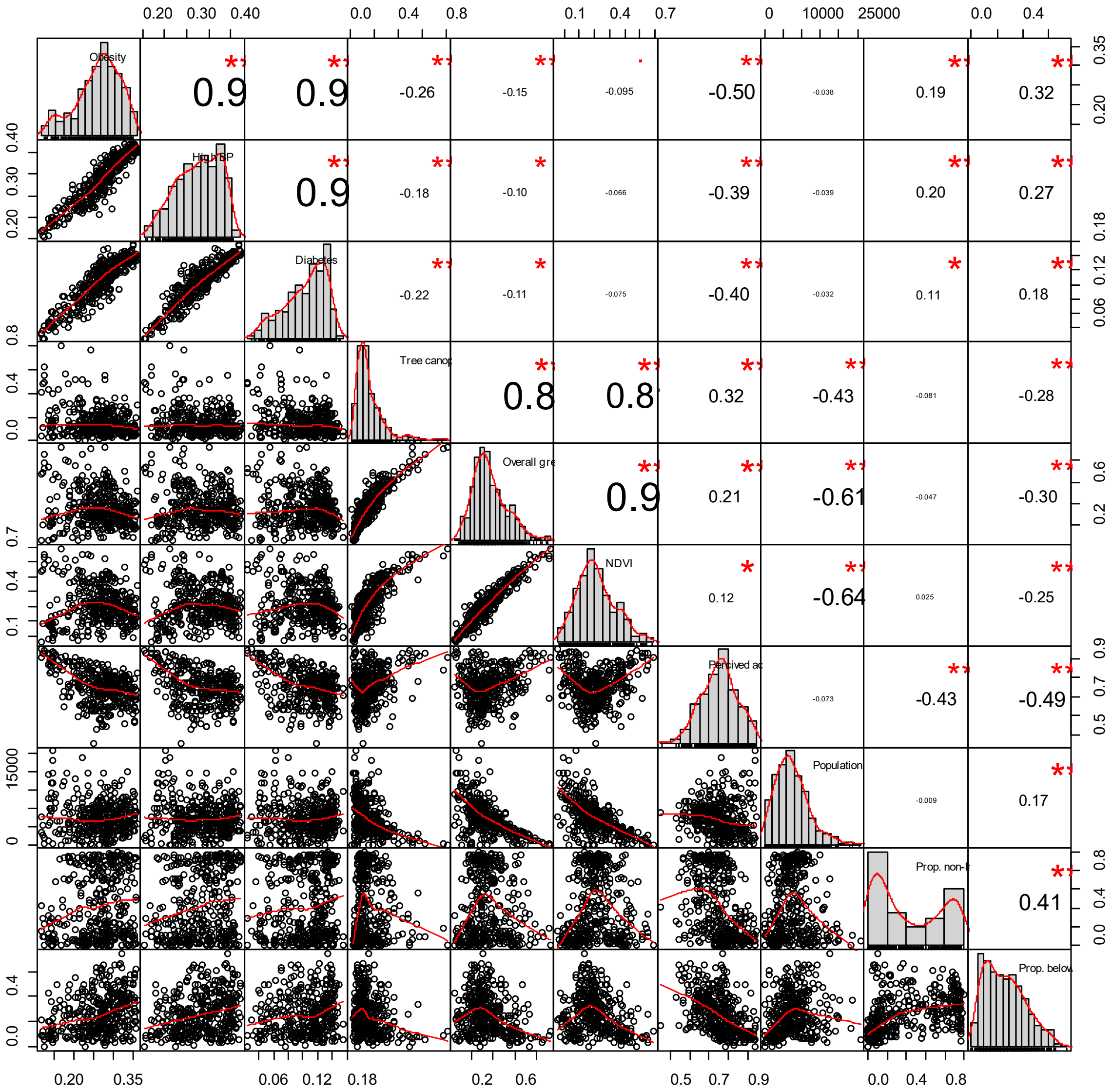

Figure S1: correlation chart of outcomes, exposures and covariables.

4. Discussion

Main findings

In Paper I, I reviewed the currently available urban green space quality assessment tools. I observed that, although the number of tools is increasing, there is a substantial heterogeneity between the quality dimensions assessed. While some dimensions are almost always present, others are systematically underrepresented. Moreover, I found that there is a shortage of tools that comprehensively include the dimensions relevant to the mechanisms underlying the effects of exposure to greenspaces on human health. Such tools are essential for the epidemiological studies evaluating these effects. Moreover, I detected a lack of a standardized definition of urban green space between tools. In many cases, tools used a broad definition that was unclear about what typology of spaces it is including.

In paper II, I built upon the lessons learned in Paper I and developed, implemented, and tested the reliability of a multidimensional quality assessment tool: the RECITAL. The tool was developed with the help of an interdisciplinary team and was implemented in the city of Barcelona by a team of specially trained fieldworkers. This tool including total of 90 items divided into 11 quality dimensions was applied to assess the quality of 147 urban green spaces that showed good-to-excellent overall reliability. The RECITAL encompasses a broad diversity of quality dimensions relevant to human health that allow for exploring previously underrepresented quality dimensions while comparing their effects with regards to human health. Additionally, the urban green spaces were selected systematically with a clear and defined selection process and criteria.

In paper III, I applied the RECITAL quality measures for the urban green spaces in Barcelona in combination with the health data from a representative sample of Barcelona residents to analyze the associations of the different quality dimensions of these spaces with the use of these space, physical activity, and overweight/obesity. The findings suggested that higher quality of UGS in the living environment of urban dwellers was associated with an increased likelihood of the use of these spaces, lower risk of overweight/obesity, and increased likelihood of engaging in moderate-to-vigorous physical activity. These effects of specific quality dimensions varied depending on the health outcome of interest, with only overall quality and bird biodiversity having significant associations with the three health outcomes. I also observed some suggestions for a potential modification of these associations by sex and education level (as an indicator of socioeconomic status (SES))

In paper IV, I used a different perspective towards greenspace exposure. I compared the associations of four different greenspace measures (tree cover, overall greenspace, residential surrounding greenness (measured as the average of normalized difference vegetation index (NDVI), and perceived access) and three of the most relevant cardiometablic risk factors (i.e. overweight, high blood pressure, and diabetes) in an ecological study in Philadelphia, US. The results suggested that perceived access might have more impact on the outcomes compared to objective measures, and the only objective measure that had an association with my evaluated outcones was the tree canopy cover. Additionally, I observed some indications for a potential modification of these associations by stratifying by SES, race, and population density.

Future research

Study setting

The results of this thesis are grounded in two cities: Barcelona (paper III) and Philadelphia (paper IV). The results found in stratified models build upon the existing literature regarding the potential effect modification role of demographic and socioeconomic characteristics of the participants and their contexts. Therefore, my findings need to be replicated in other settings with not only different social, demographic, economic, and cultural characteristics, but also different climates and vegetation types.

Study design

My study of the association between quality dimensions of green spaces and human health had cross-sectional design. Cross-sectional studies have a limited capability to establish causality, mainly because they cannot ensure the precedent of exposure to the outcome and also because they are prone to self-selection bias. There is therefore a need for longitudinal studies that, by design, could overcome these important limitations. Additionally, the life-course interaction between greenspace and humans might have effects beyond health: the quality of the green spaces around the childhood residence, for example, might affect the perception and affiliation to green spaces later in life.

Natural experiments can also provide strong evidence for causality. In natural experiments, it is possible to evaluate the effects of changes in the built environment (e.g. adding new street trees or remodeling a park) on the health and wellbeing of the affected people. This type of interventional studies has two key advantages. First, by comparing the same participants before and after the intervention, it can minimize the residual confounding due to SES, lifestyle, or demographic characteristics. Moreover, it reduces potential self-selection bias caused by healthy (or ill) participants having residential preferences. Second, it allows for a straightforward translation of the results for urban decision-makers by providing them with the cost-benefit analysis by showing how the investment in these interventions have been paid off the the improvement in the health and wellbeing of residents and its consequent saving of the healthcare costs.

Exposure assessment

In paper II, I established and implemented a selection process for urban green spaces. The results in both papers II and III suggested that our selection criteria were a good fit for the city of Barcelona. Barcelona has a highly dense and mixed urban structure, with a wide presence of street trees and relatively sparse parks and gardens. My selection criteria might be useful to other cities with similar structures, especially those surrounding the Mediterranean. However, my definition might not be successfully implementable in other cities such northern European cities with very large parks or American cities with large urban sprawls. Using and presenting a clear definition of green space is critical for future studies. First, the article readers must be able to clearly understand what kind of green space is included in the study. While this might seem a simple task for people that know the city context, it is complicated for outsiders. Second, my results suggest that differences in the characteristics of green space might have a meaningful impact on its health effects. Therefore, the same study with different green space selection criteria might lead to different results.

Future studies might want to incorporate various exposure measures, as I did in Paper IV, by including high-resolution data on tree canopy, overall green and perceived greenspace. The use of various exposure measures showcases the bigger picture of the association between exposure to greenspace and health and can capture details that using a single measure would have missed. In a scenario where we only used overall green for Paper IV, we would have missed the importance of trees and might have ended up suggesting that greenspace and cardiovascular risk factors were not associated.

On top of using various objective measures, studies must reflect on the possible use of perceived measures. Perception of green space is a combination of many elements, including personal factors such as affinity for nature or biodiversity expertise, objective green space characteristics such as the presence of green space or accessibility, and contextual factors such safety or culture. The inclusion of perceived measures of greenspace could complement the picture provided by objective measures and, in time, might unveil differences between sociodemographic groups.

Some specific quality dimensions such as bird biodiversity are gaining traction and attention. The results of Paper III suggest that bird biodiversity is a relevant quality dimension regarding overweight, physical activity, and park use. However, in Paper I I observed that bird biodiversity is currently underrepresented in urban green space quality assessment tools. Future studies must consider the inclusion of quality measures, especially in studies regarding health outcomes, which available literature has inconsistent results. Particular attention must be paid to the dimensions that are relevant to the potential underlying mechanisms specific to the selected health outcome.

Many studies, including the ones in this thesis, rely on the residential address to carry out exposure assessment, only considering the greenspace surrounding the participants' residence. While this might be an acceptable proxy of real greenspace exposure, future studies can add additional relevant exposure microenvironments such as school, workplace, or commuting route. Moreover, questionnaires about green space use and

GPS-tracking devices can be used to have an even better picture of the participant's exposure to greenspace. Visual access to greenspace is another aspect of exposure to greenspace that has been understudied. Future studies can collect data on visual access to greenspace through questionnaires, obtaining photos from the windows of the home, school, or workplace of participants, or using high-resultion 3D maps of vegetations surrounding the aforemention microenvironments.

Health outcomes

The use of questionnaire-based health measures was one of the limitations of this thesis. These kinds of measures are useful for proof-of-concept studies, as they are accessible and tend to have large samples, and for self-reported wellbeing studies, as they capture the participants' perception. Future studies are recommended to incorporate objectively measured markers of health or risk factors (e.g. blood or urine biomarkers, measured blood pressure, measured physical activity levels, etc.) or diagnosis of diseases by clinicians or other healthcare professionals such as psychologists.

Future studies are also recommended to evaluate other health outcomes as well as other sub-populations (e.g. elderly, children, pregnant women) than the ones covered by this thesis. Finding different relevant quality dimensions for each health outcome in each sub-population could suggest that each outcome and each sub-population might benefit from its own set of quality dimensions.

Mechanisms

Future studies are encouraged to shed light on the mechanisms underlying the greenspace – human health association they want to explore. As the mechanisms underlying the health effects of greenspace are yet to be established, researchers could hypothesize what are the potential mechanisms relevant to their evaluated outcome. In doing so, they will be able to better select which exposure metrics and quality dimentions better fit their needs. For example, if the health outcome of interest is linked to direct contact with green, then it might be more interesting to employ green space use or perceived access to green spaces rather than objective measures. Participants might have green space nearby but not interact with them. This can also be applied to quality dimensions, reflecting on the underlying mechanism that might facilitate the selection of relevant quality dimensions.

Statistical analysis

Studies that rely on administrative boundaries are especially susceptible to spatial autocorrelation: greener areas are often clustered through the city. Additionally, the use of administrative boundaries could lead to the separation of areas that are unequivocally influencing each other. An example of this is Central Park in New York (US) when using census tract data: The Central Park would not be captured as exposure to most neighboring participants because Central Park has its own census tract. Spatial regression can mitigate this issue by accounting for the dependencies amongst neighboring areas.

Effect modification

Paper III suggested that the beneficial health effect of exposure to greenspace might be more substantial for females than for males. Paper IV suggested that the protective effects of greenspace exposure could be modified by socioeconomic status, race, and population density. In some cases, they were even opposite direction of the associations across the strata of the evaluated potential effect modifiers. The results from this thesis build upon the existing literature suggesting personal and contextual demographic and socioeconomic characteristics could modify the association between greenspace exposure and human health. As such, future studies are recommended to explore the possibility that social, demographic and economic differences could influence the health effects of exposure to greenspace. On top of gathering the required data on the variables of interest, future studies can tackle this issue in two different ways. On the one hand, researchers can aim towards a large sample size that allows for stratification by different variables without having underpowered analyses. On the other, researchers can rely on study designs that maximises the contrast regarding the interested effect modifier.

5. Conclusions

Urban green spaces have the potential to exert beneficial health effects on urban dwellers. However, the results of this thesis suggest that to enjoy the health benefits from an urban green space it is not enough to live nearby. Particularly it highlights the importance of quality aspects of these spaces in exerting such benefits. Some other factors including demographic and socioeconomic stauts characteristics could also play an important role in these benefits.

Take home messages:

- Green spaces quality and how green space is measured could have an impotant role in the association between urban green spaces and human health.
- Each health outcome is linked to its own set of green space quality dimensions and measures.
- Social, demographic and economic factors could modify the association between green spaces and human health.

References

Aerts, R., Honnay, O., & Van Nieuwenhuyse, A. (2018, September 1). Biodiversity and human health: Mechanisms and evidence of the positive health effects of diversity in nature and green spaces. *British Medical Bulletin*, Vol. 127, pp. 5–22. https://doi.org/10.1093/bmb/ldy021

Akaraci, S., Feng, X., Suesse, T., Jalaludin, B., & Astell-Burt, T. (2020, April 2). A systematic review and meta-analysis of associations between green and blue spaces and birth outcomes. *International Journal of Environmental Research and Public Health*, Vol. 17. https://doi.org/10.3390/ijerph17082949

Banay, R., Bezold, C., James, P., Hart, J., & Laden, F. (2017). Residential greenness: current perspectives on its impact on maternal health and pregnancy outcomes. *International Journal of Women's Health*, *Volume 9*, 133–144. https://doi.org/10.2147/IJWH.S125358

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, *29*(2), 293–301. https://doi.org/10.1016/S0921-8009(99)00013-0

Costigan, S. A., Veitch, J., Crawford, D., Carver, A., & Timperio, A. (2017). A Cross-Sectional Investigation of the Importance of Park Features for Promoting Regular Physical Activity in Parks. *INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH*, *14*(11).

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., … Oja, P. (2003). International physical activity questionnaire: 12-Country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Dadvand, P., Hariri, S., Abbasi, B., Heshmat, R., Qorbani, M., Motlagh, M. E., … Kelishadi, R. (2019). Use of green spaces, self-satisfaction and social contacts in adolescents: A population-based CASPIAN-V study. *Environmental Research*, *168*, 171–177. https://doi.org/10.1016/j.envres.2018.09.033

Dadvand, P., Sunyer, J., Basagaña, X., Ballester, F., Lertxundi, A., Fernández-Somoano, A., … Nieuwenhuijsen, M. J. (2012). Surrounding Greenness and Pregnancy Outcomes in Four Spanish Birth Cohorts. *Environmental Health Perspectives*, *120*(10), 1481–1487. https://doi.org/10.1289/ehp.1205244

Dalton, A. M., Jones, A. P., Sharp, S. J., Cooper, A. J. M., Griffin, S., & Wareham, N. J. (2016). Residential neighbourhood greenspace is associated with reduced risk of incident diabetes in older people: a prospective cohort study. *BMC Public Health*, *16*(1), 1–10. https://doi.org/10.1186/s12889-016-3833-z

de Keijzer, C., Bauwelinck, M., & Dadvand, P. (2020). Long-Term Exposure to

Residential Greenspace and Healthy Ageing: a Systematic Review. *Current Environmental Health Reports*, Vol. 7, pp. 65–88. https://doi.org/10.1007/s40572-020-00264-7

de Keijzer, C., Gascon, M., Nieuwenhuijsen, M. J., & Dadvand, P. (2016). Long-Term Green Space Exposure and Cognition Across the Life Course: a Systematic Review. *Current Environmental Health Reports*. https://doi.org/10.1007/s40572-016-0116-x

DEARBORN, D. C., & KARK, S. (2010). Motivations for Conserving Urban Biodiversity. *Conservation Biology*, *24*(2), 432–440. https://doi.org/10.1111/j.1523-1739.2009.01328.x

European Commission. (2015). *Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities*. https://doi.org/10.2777/765301

Gascon, M., Mas, M. T., Martínez, D., Dadvand, P., Forns, J., Plasència, A., & Nieuwenhuijsen, M. J. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph120404354

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. J. (2016a). Residential green spaces and mortality: A systematic review. *Environment International*, *86*, 60–67. https://doi.org/10.1016/J.ENVINT.2015.10.013

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. J. (2016b). Residential green spaces and mortality: A systematic review. *Environment International*. https://doi.org/10.1016/j.envint.2015.10.013

Gidlow, C. J., Ellis, N. J., & Bostock, S. (2012). Development of the neighbourhood green space tool (NGST). *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2012.04.007

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., … Nieuwenhuijsen, M. J. (2018a). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333. Retrieved from https://www.sciencedirect.com/science/article/pii/S1618866717301917

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., … Nieuwenhuijsen, M. J. (2018b). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333. https://doi.org/10.1016/J.UFUG.2017.12.007

Goal 11 | Department of Economic and Social Affairs. (n.d.). Retrieved September 15, 2020, from https://sdgs.un.org/goals/goal11

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs,

J. M. (2008). Global Change and the Ecology of Cities. *Science*, *319*(5864), 756–760. https://doi.org/10.1126/science.1150195

Hystad, P., Davies, H. W., Frank, L., Loon, J. Van, Gehring, U., Tamburic, L., & Brauer, M. (2014). Residential Greenness and Birth Outcomes: Evaluating the Influence of Spatially Correlated Built-Environment Factors. *Environmental Health Perspectives*, *122*(10), 1095–1102. https://doi.org/10.1289/ehp.1308049

IPAQ Research Committee. (2005). Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ)-Short and Long Forms. *Http://Www.Ipaq.Ki.Se/Scoring.Pdf*.

Iyer, H. S., James, P., Valeri, L., Hart, J. E., Pernar, C. H., Mucci, L. A., … Rebbeck, T. R. (2020). The association between neighborhood greenness and incidence of lethal prostate cancer. *Environmental Epidemiology*, *4*(2), e091. https://doi.org/10.1097/ee9.0000000000000091

James, P., Banay, R. F., Hart, J. E., & Laden, F. (2015). A Review of the Health Benefits of Greenness. *Current Epidemiology Reports*, *2*(2), 131–142. https://doi.org/10.1007/s40471-015-0043-7

Kellert, S. R. (2006). Building for life: Designing and understanding the human-nature connection. *Renewable Resources Journal*, *24*(2).

Knobel, P., Dadvand, P., & Maneja-Zaragoza, R. (2019). A systematic review of multi-dimensional quality assessment tools for urban green spaces. *Health and Place*, *59*. https://doi.org/10.1016/j.healthplace.2019.102198

Kondo, M. C., Fluehr, J. M., McKeon, T., & Branas, C. C. (2018). Urban green space and its impact on human health. *International Journal of Environmental Research and Public Health*, Vol. 15. https://doi.org/10.3390/ijerph15030445

Maas, J., Verheij, R. A., De Vries, S., Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health*. https://doi.org/10.1136/jech.2008.079038

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., … Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research*, Vol. 158, pp. 301–317. https://doi.org/10.1016/j.envres.2017.06.028

Markevych, I., Tiesler, C. M. T., Fuertes, E., Romanos, M., Dadvand, P., Nieuwenhuijsen, M. J., … Heinrich, J. (2014). Access to urban green spaces and behavioural problems in children: Results from the GINIplus and LISAplus studies. *Environment International*, *71*, 29–35. https://doi.org/10.1016/j.envint.2014.06.002

McAdams, M. A., Van Dam, R. M., & Hu, F. B. (2007). Comparison of Self-reported and Measured BMI as Correlates of Disease Markers in U.S. Adults*. *Obesity*, *15*(1), 188–188. https://doi.org/10.1038/oby.2007.504

McCormack, G. R., Rock, M., Toohey, A. M., & Hignell, D. (2010). Characteristics of urban parks associated with park use and physical activity: A review of qualitative research. *Health and Place*, *16*(4), 712–726. https://doi.org/10.1016/j.healthplace.2010.03.003

Miralles-Guasch, C., Dopico, J., Delclòs-Alió, X., Knobel, P., Marquet, O., Maneja-Zaragoza, R., … Vich, G. (2019). Natural Landscape, Infrastructure, and Health: The Physical Activity Implications of Urban Green Space Composition among the Elderly. *International Journal of Environmental Research and Public Health*, *16*(20), 3986. https://doi.org/10.3390/ijerph16203986

Oliver-Smith, A. (2012). DEBATING ENVIRONMENTAL MIGRATION: SOCIETY, NATURE AND POPULATION DISPLACEMENT IN CLIMATE CHANGE. *Journal of International Development*, *24*(8), 1058–1070. https://doi.org/10.1002/jid.2887

Penuelas, J., & Boada, M. (2003). A global change-induced biome shift in the Montseny mountains (NE Spain). *Global Change Biology*, *9*(2), 131–140. https://doi.org/10.1046/j.1365-2486.2003.00566.x

Roberts, H., Kellar, I., Conner, M., Gidlow, C., Kelly, B., Nieuwenhuijsen, M., & McEachan, R. (2019). Associations between park features, park satisfaction and park use in a multi-ethnic deprived urban area. *Urban Forestry and Urban Greening*, *46*. https://doi.org/10.1016/j.ufug.2019.126485

Rojas-Rueda, D., Nieuwenhuijsen, M. J., Gascon, M., Perez-Leon, D., & Mudu, P. (2019). Green spaces and mortality: a systematic review and meta-analysis of cohort studies. *The Lancet Planetary Health*, *3*(11), e469–e477. https://doi.org/10.1016/S2542-5196(19)30215-3

Roman-Viñas, B., Serra-Majem, L., Hagströmer, M., Ribas-Barba, L., Sjöström, M., & Segura-Cardona, R. (2010). International physical activity questionnaire: Reliability and validity in a Spanish population. *European Journal of Sport Science*, *10*(5), 297–304. https://doi.org/10.1080/17461390903426667

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2009). Physical activity for recreation or exercise on neighbourhood streets: Associations with perceived environmental attributes. *Health and Place*, *15*(4), 1058–1063. https://doi.org/10.1016/j.healthplace.2009.05.001

Torres Toda, M., Anabitarte Riol, A., Cirach, M., Estarlich, M., Fernández-Somoano, A., González-Safont, L., … Dadvand, P. (2020). Residential Surrounding Greenspace and Mental Health in Three Spanish Areas. *International Journal of Environmental Research and Public Health*, *17*(16), 5670. https://doi.org/10.3390/ijerph17165670

Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science*, *224*(4647), 420–421. https://doi.org/10.1126/science.6143402 van den Berg, A. E., & van den Berg, C. G. (2011). A comparison of children with ADHD in a natural and built setting. *Child: Care, Health and Development*, *37*(3), 430–439. https://doi.org/10.1111/j.1365-2214.2010.01172.x

Voigt, A., Kabisch, N., Wurster, D., Haase, D., & Breuste, J. (2014). Structural diversity: a multi-dimensional approach to assess recreational services in urban parks. *Ambio*, *43*(4), 480–491. https://doi.org/10.1007/s13280-014-0508-9

Wheeler, B. W., Lovell, R., Higgins, S. L., White, M. P., Alcock, I., Osborne, N. J., … Depledge, M. H. (2015). Beyond greenspace: An ecological study of population general health and indicators of natural environment type and quality. *International Journal of Health Geographics*, *14*(1). https://doi.org/10.1186/s12942-015-0009-5

World Urbanization Prospects - Population Division - United Nations. (n.d.). Retrieved August 4, 2020, from https://population.un.org/wup/DataQuery/

Zhan, Y., Liu, J., Lu, Z., Yue, H., Zhang, J., & Jiang, Y. (2020, May 20). Influence of residential greenness on adverse pregnancy outcomes: A systematic review and dose-response meta-analysis. *Science of the Total Environment*, Vol. 718, p. 137420. https://doi.org/10.1016/j.scitotenv.2020.137420

Zijlema, W. L., Triguero-Mas, M., Cirach, M., Gidlow, C., Kruize, H., Grazuleviciene, R., … Litt, J. S. (2020). Understanding correlates of neighborhood aesthetic ratings: A European-based Four City comparison. *Urban Forestry and Urban Greening*, *47*, 126523. https://doi.org/10.1016/j.ufug.2019.126523

Zijlema, Wilma L., Triguero-Mas, M., Smith, G., Cirach, M., Martinez, D., Dadvand, P., … Julvez, J. (2017). The relationship between natural outdoor environments and cognitive functioning and its mediators. *Environmental Research*, *155*, 268–275. https://doi.org/10.1016/j.envres.2017.02.017

Aerts, R., Honnay, O., & Van Nieuwenhuyse, A. (2018, September 1). Biodiversity and human health: Mechanisms and evidence of the positive health effects of diversity in nature and green spaces. *British Medical Bulletin*, Vol. 127, pp. 5–22. https://doi.org/10.1093/bmb/ldy021

Akaraci, S., Feng, X., Suesse, T., Jalaludin, B., & Astell-Burt, T. (2020, April 2). A systematic review and meta-analysis of associations between green and blue spaces and birth outcomes. *International Journal of Environmental Research and Public Health*, Vol. 17. https://doi.org/10.3390/ijerph17082949

Banay, R., Bezold, C., James, P., Hart, J., & Laden, F. (2017). Residential greenness: current perspectives on its impact on maternal health and pregnancy outcomes. *International Journal of Women's Health*, *Volume 9*, 133–144. https://doi.org/10.2147/IJWH.S125358

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological Economics*, *29*(2), 293–301. https://doi.org/10.1016/S0921-8009(99)00013-0

Costigan, S. A., Veitch, J., Crawford, D., Carver, A., & Timperio, A. (2017). A Cross-Sectional Investigation of the Importance of Park Features for Promoting Regular Physical Activity in Parks. *INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH*, *14*(11).

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., … Oja, P. (2003). International physical activity questionnaire: 12-Country reliability and validity. *Medicine and Science in Sports and Exercise*, *35*(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Dadvand, P., Hariri, S., Abbasi, B., Heshmat, R., Qorbani, M., Motlagh, M. E., … Kelishadi, R. (2019). Use of green spaces, self-satisfaction and social contacts in adolescents: A population-based CASPIAN-V study. *Environmental Research*, *168*, 171–177. https://doi.org/10.1016/j.envres.2018.09.033

Dadvand, P., Sunyer, J., Basagaña, X., Ballester, F., Lertxundi, A., Fernández-Somoano, A., … Nieuwenhuijsen, M. J. (2012). Surrounding Greenness and Pregnancy Outcomes in Four Spanish Birth Cohorts. *Environmental Health Perspectives*, *120*(10), 1481–1487. https://doi.org/10.1289/ehp.1205244

Dalton, A. M., Jones, A. P., Sharp, S. J., Cooper, A. J. M., Griffin, S., & Wareham, N. J. (2016). Residential neighbourhood greenspace is associated with reduced risk of incident diabetes in older people: a prospective cohort study. *BMC Public Health*, *16*(1), 1–10. https://doi.org/10.1186/s12889-016-3833-z

de Keijzer, C., Bauwelinck, M., & Dadvand, P. (2020). Long-Term Exposure to Residential Greenspace and Healthy Ageing: a Systematic Review. *Current Environmental Health Reports*, Vol. 7, pp. 65–88. https://doi.org/10.1007/s40572-020-00264-7

de Keijzer, C., Gascon, M., Nieuwenhuijsen, M. J., & Dadvand, P. (2016). Long-Term Green Space Exposure and Cognition Across the Life Course: a Systematic Review. *Current Environmental Health Reports*. https://doi.org/10.1007/s40572-016-0116-x

DEARBORN, D. C., & KARK, S. (2010). Motivations for Conserving Urban Biodiversity. *Conservation Biology*, *24*(2), 432–440. https://doi.org/10.1111/j.1523-1739.2009.01328.x

European Commission. (2015). *Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities*. https://doi.org/10.2777/765301

Gascon, M., Mas, M. T., Martínez, D., Dadvand, P., Forns, J., Plasència, A., & Nieuwenhuijsen, M. J. (2015). Mental health benefits of long-term exposure to residential green and blue spaces: A systematic review. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph120404354

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. J. (2016a). Residential green spaces and mortality: A systematic review. *Environment International*, *86*, 60–67. https://doi.org/10.1016/J.ENVINT.2015.10.013

Gascon, M., Triguero-Mas, M., Martínez, D., Dadvand, P., Rojas-Rueda, D., Plasència, A., & Nieuwenhuijsen, M. J. (2016b). Residential green spaces and mortality: A systematic review. *Environment International*. https://doi.org/10.1016/j.envint.2015.10.013

Gidlow, C. J., Ellis, N. J., & Bostock, S. (2012). Development of the neighbourhood green space tool (NGST). *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2012.04.007

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., … Nieuwenhuijsen, M. J. (2018a). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333. Retrieved from https://www.sciencedirect.com/science/article/pii/S1618866717301917

Gidlow, C., van Kempen, E., Smith, G., Triguero-Mas, M., Kruize, H., Gražulevičienė, R., … Nieuwenhuijsen, M. J. (2018b). Development of the natural environment scoring tool (NEST). *Urban Forestry & Urban Greening*, *29*, 322–333. https://doi.org/10.1016/J.UFUG.2017.12.007

Goal 11 | Department of Economic and Social Affairs. (n.d.). Retrieved September 15, 2020, from https://sdgs.un.org/goals/goal11

Grimm, N. B., Faeth, S. H., Golubiewski, N. E., Redman, C. L., Wu, J., Bai, X., & Briggs, J. M. (2008). Global Change and the Ecology of Cities. *Science*, *319*(5864), 756–760. https://doi.org/10.1126/science.1150195

Hystad, P., Davies, H. W., Frank, L., Loon, J. Van, Gehring, U., Tamburic, L., & Brauer, M. (2014). Residential Greenness and Birth Outcomes: Evaluating the Influence of Spatially Correlated Built-Environment Factors. *Environmental Health Perspectives*, *122*(10), 1095–1102. https://doi.org/10.1289/ehp.1308049

IPAQ Research Committee. (2005). Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ)-Short and Long Forms. *Http://Www.Ipaq.Ki.Se/Scoring.Pdf*.

Iyer, H. S., James, P., Valeri, L., Hart, J. E., Pernar, C. H., Mucci, L. A., … Rebbeck, T. R. (2020). The association between neighborhood greenness and incidence of lethal prostate cancer. *Environmental Epidemiology*, *4*(2), e091. https://doi.org/10.1097/ee9.0000000000000091

James, P., Banay, R. F., Hart, J. E., & Laden, F. (2015). A Review of the Health Benefits of Greenness. *Current Epidemiology Reports*, *2*(2), 131–142. https://doi.org/10.1007/s40471-015-0043-7

Kellert, S. R. (2006). Building for life: Designing and understanding the human-nature connection. *Renewable Resources Journal*, *24*(2).

Knobel, P., Dadvand, P., & Maneja-Zaragoza, R. (2019). A systematic review of multi-dimensional quality assessment tools for urban green spaces. *Health and Place*, *59*. https://doi.org/10.1016/j.healthplace.2019.102198

Kondo, M. C., Fluehr, J. M., McKeon, T., & Branas, C. C. (2018). Urban green space and its impact on human health. *International Journal of Environmental Research and Public Health*, Vol. 15. https://doi.org/10.3390/ijerph15030445

Maas, J., Verheij, R. A., De Vries, S., Spreeuwenberg, P., Schellevis, F. G., & Groenewegen, P. P. (2009). Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health*. https://doi.org/10.1136/jech.2008.079038

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., … Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research*, Vol. 158, pp. 301–317. https://doi.org/10.1016/j.envres.2017.06.028

Markevych, I., Tiesler, C. M. T., Fuertes, E., Romanos, M., Dadvand, P., Nieuwenhuijsen, M. J., … Heinrich, J. (2014). Access to urban green spaces and behavioural problems in children: Results from the GINIplus and LISAplus studies. *Environment International*, *71*, 29–35. https://doi.org/10.1016/j.envint.2014.06.002

McAdams, M. A., Van Dam, R. M., & Hu, F. B. (2007). Comparison of Self-reported and Measured BMI as Correlates of Disease Markers in U.S. Adults*. *Obesity*, *15*(1), 188–188. https://doi.org/10.1038/oby.2007.504

McCormack, G. R., Rock, M., Toohey, A. M., & Hignell, D. (2010). Characteristics of urban parks associated with park use and physical activity: A review of qualitative research. *Health and Place*, *16*(4), 712–726. https://doi.org/10.1016/j.healthplace.2010.03.003

Miralles-Guasch, C., Dopico, J., Delclòs-Alió, X., Knobel, P., Marquet, O., Maneja-Zaragoza, R., … Vich, G. (2019). Natural Landscape, Infrastructure, and Health: The Physical Activity Implications of Urban Green Space Composition among the Elderly. *International Journal of Environmental Research and Public Health*, *16*(20), 3986. https://doi.org/10.3390/ijerph16203986

Oliver-Smith, A. (2012). DEBATING ENVIRONMENTAL MIGRATION: SOCIETY, NATURE AND POPULATION DISPLACEMENT IN CLIMATE CHANGE. *Journal of International Development*, *24*(8), 1058–1070. https://doi.org/10.1002/jid.2887

Penuelas, J., & Boada, M. (2003). A global change-induced biome shift in the Montseny mountains (NE Spain). *Global Change Biology*, *9*(2), 131–140. https://doi.org/10.1046/j.1365-2486.2003.00566.x

Roberts, H., Kellar, I., Conner, M., Gidlow, C., Kelly, B., Nieuwenhuijsen, M., & McEachan, R. (2019). Associations between park features, park satisfaction and park use in a multi-ethnic deprived urban area. *Urban Forestry and Urban Greening*, *46*. https://doi.org/10.1016/j.ufug.2019.126485

Rojas-Rueda, D., Nieuwenhuijsen, M. J., Gascon, M., Perez-Leon, D., & Mudu, P. (2019). Green spaces and mortality: a systematic review and meta-analysis of cohort studies. *The Lancet Planetary Health*, *3*(11), e469–e477. https://doi.org/10.1016/S2542-5196(19)30215-3

Roman-Viñas, B., Serra-Majem, L., Hagströmer, M., Ribas-Barba, L., Sjöström, M., & Segura-Cardona, R. (2010). International physical activity questionnaire: Reliability and validity in a Spanish population. *European Journal of Sport Science*, *10*(5), 297–304. https://doi.org/10.1080/17461390903426667

Sugiyama, T., Leslie, E., Giles-Corti, B., & Owen, N. (2009). Physical activity for recreation or exercise on neighbourhood streets: Associations with perceived environmental attributes. *Health and Place*, *15*(4), 1058–1063. https://doi.org/10.1016/j.healthplace.2009.05.001

Torres Toda, M., Anabitarte Riol, A., Cirach, M., Estarlich, M., Fernández-Somoano, A., González-Safont, L., … Dadvand, P. (2020). Residential Surrounding Greenspace and Mental Health in Three Spanish Areas. *International Journal of Environmental Research and Public Health*, *17*(16), 5670. https://doi.org/10.3390/ijerph17165670

Ulrich, R. S. (1984). View through a window may influence recovery from surgery. *Science*, *224*(4647), 420–421. https://doi.org/10.1126/science.6143402

van den Berg, A. E., & van den Berg, C. G. (2011). A comparison of children with ADHD in a natural and built setting. *Child: Care, Health and Development*, *37*(3), 430–439. https://doi.org/10.1111/j.1365-2214.2010.01172.x

Voigt, A., Kabisch, N., Wurster, D., Haase, D., & Breuste, J. (2014). Structural diversity: a multi-dimensional approach to assess recreational services in urban parks. *Ambio*, *43*(4), 480–491. https://doi.org/10.1007/s13280-014-0508-9

Wheeler, B. W., Lovell, R., Higgins, S. L., White, M. P., Alcock, I., Osborne, N. J., … Depledge, M. H. (2015). Beyond greenspace: An ecological study of population general health and indicators of natural environment type and quality. *International Journal of Health Geographics*, *14*(1). https://doi.org/10.1186/s12942-015-0009-5

World Urbanization Prospects - Population Division - United Nations. (n.d.). Retrieved August 4, 2020, from https://population.un.org/wup/DataQuery/

Zhan, Y., Liu, J., Lu, Z., Yue, H., Zhang, J., & Jiang, Y. (2020, May 20). Influence of residential greenness on adverse pregnancy outcomes: A systematic review and dose-response meta-analysis. *Science of the Total Environment*, Vol. 718, p. 137420. https://doi.org/10.1016/j.scitotenv.2020.137420

Zijlema, W. L., Triguero-Mas, M., Cirach, M., Gidlow, C., Kruize, H., Grazuleviciene, R., … Litt, J. S. (2020). Understanding correlates of neighborhood aesthetic ratings:

A European-based Four City comparison. *Urban Forestry and Urban Greening*, *47*, 126523. https://doi.org/10.1016/j.ufug.2019.126523

Zijlema, Wilma L., Triguero-Mas, M., Smith, G., Cirach, M., Martinez, D., Dadvand, P., … Julvez, J. (2017). The relationship between natural outdoor environments and cognitive functioning and its mediators. *Environmental Research*, *155*, 268–275. https://doi.org/10.1016/j.envres.2017.02.017