The differences by sex and gender in the relationship between urban greenness and cardiometabolic health: a systematic review

Marta-Beatriz Fernández Núñez[a], Lia Campos Suzman[a], Roser Maneja Zaragoza[bcd], Albert Bach Pagés[bc], Oriol Marquet[d], Isabelle Anguelovski[ae] & Pablo Knobel[f].

a Environmental Science and Technology Institute (ICTA), Universitat Autònoma de Barcelona
b Forest Science and Technology Center of Catalonia, Ctra. de St. Llorenç de Morunys, km 2, Solsona 25280,
Spain Environmental Science and Technology Institute (ICTA), Universitat Autònoma de Barcelona
c Environment and Human Health Laboratory (EH2 Lab), Ctra. de St. Llorenç de Morunys, km 2, Solsona 25280, Spain Environmental Science and Technology Institute (ICTA), Universitat Autònoma de Barcelona
d Geography Department, Autonomous University of Barcelona, Spain
e ICREA, Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain
f Icahn School of Medicine at Mount Sinai, Department of Environmental Medicine and Public Health, New York, NY, U.S.A.

Corresponding author:
Email address: pablo.knobel@mssm.edu (Knobel, P)
Department of Environmental Medicine and Public Health
Icahn School of Medicine at Mount Sinai
1 Gustave L. Levy Place, Box 1057
New York, NY 10029

Highlights:

- Sex and gender-related terminology is misused in most of the articles.
- Urban greenness was found to be protective against cardiometabolic conditions.
- Urban greenness health benefits differ due to sex and gender.

Abstract:

In an increasingly urbanized world, where cardiometabolic issues in cities have raised public health concerns, urban greenness is known to be beneficial for some of the most common health issues. However, the examination of the contribution of sex and gender regarding the benefits of urban greenness for people's cardiometabolic health is lacking. For that reason, we conducted a systematic review of previous literature on the topic following the PRISMA methodology. Additionally, we assessed the quality of the included articles, which we found satisfactory as most papers were of very good or good quality. We explored the relationship between urban greenness exposure and cardiovascular risk factors, cardiovascular diseases, and mortality from cardiovascular diseases. Results suggest that urban greenness is protective against cardiovascular risk factors, diseases, and mortality. When stratifying results by sex and gender, findings point to urban greenness being more beneficial for women and females in stroke and cardiovascular risk factors, except for hypertension and lipid accumulation product. On the other hand, males were more protected by urban greenness in terms of cardiovascular diseases and CVD related mortality. Thus, proving that sex and gender health inequalities exist. Furthermore, looking towards the future, research needs to use the proper terminology for sex and gender and policy makers should design urban greenness with a gender perspective.

Keywords: urban greenness, sex differences, gender differences, cardiovascular risk factors, obesity.

1.- Introduction:

As of 2018, 55% of the world's population lived in urban settlements [1], with numbers expected to increase further [2]. With urbanization rising, so are health issues linked to urban life, such as cardiometabolic and respiratory diseases commonly related to air pollution, poor diet, and sedentary behaviours [3, 4, 5]. In response, urban greenness has been suggested to protect against health issues such as cardiometabolic diseases and premature mortality [6, 7, 8, 9]. Thus, their benefits have driven cities to integrate green spaces into their planning. Examples of it exist all over the Global North: Barcelona's ambitious 2021 Green Space Plan, San Francisco's and Seattle's green conversion of industrialized waterfronts, or the 55m^2 of green space per resident achieved in Nantes through the creation and maintenance of 100 parks and gardens [10].

Access to ecosystem services from urban greenness can be distributed unequally across the population [11]. Therefore, health inequalities must be researched to better design cities with particular attention to intersectionality across sociodemographic factors [12]. However, while associations between health inequalities across socioeconomic status and race, among others, have been found [13, 14], the literature on sex and gender differences is still scarce.

This article will consider both sex and gender in binary terms. These terms have been historically used interchangeably in the scientific literature, but they entail different indicators. Sex (either female or male) is determined through the biological characteristics of a person: their chromosomes, hormones, or reproductive organs. Gender (either women or men) refers to socially constructed characteristics people adopt as part of their identity and expression which can include norms or roles [15, 16, 17, 18].

Previous studies have found differences in the protection urban greenness provides depending on sex and gender. Astell-Burt found that in the case of obesity that urban greenness had stronger protective effects on women [19]. However, the opposite was found in the article by Kowaleski-Jones & Wen [20]. Contradicting results were also discovered in the case of mortality related to cardiovascular diseases. Richardson & Mitchell found urban greenness to be more protective towards men [21]; however, the opposite was found by Vienneau et al. [22]. Therefore, due to the different findings, we aim to perform a systematic review. This review aims to examine the relationship between urban greenness and cardiometabolic health and whether their effects are modified by sex and gender.

2.- Methods:

We followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (see Table S2).

2.1.- Search strategy:

For the systematic search, we used the electronic databases of Web of Science, Scopus, and PubMed. We chose these databases as Web of Science and Scopus are the most used for bibliometric analysis, and PubMed is the most used for its biomedical resources [23, 24]. The search was performed on the

8th of July 2021. We identified the articles using keywords for three thematic blocks (see Table S1). First, urban greenness: including terms referring to different kinds of greenness that can be found in a city. Second, sex/gender: including different combinations referring to interaction, stratification, and effect modification by sex or gender. Third, cardiometabolic health: including cardiometabolic diseases (e.g., cardiomyopathy, ischemic heart disease, and metabolic syndrome), risk factors and markers (e.g., obesity, hypertension, and stroke), and cardiometabolic mortality (e.g., heart failure and infraction). Finally, we obtained the articles by submitting a Boolean search phrase with syntax tailored to each electronic database.

2.2.- Eligibility criteria:

We only included original human-based research articles in English. Both cross-sectional and longitudinal studies were included. The papers had to relate urban greenness or urban green spaces to cardiometabolic health and research the possible differences across sex or gender. We excluded those that were based on rural or virtual environments, as those are beyond the aim of this review.

2.3.- Selection process:

We used Rayyan QCRI to select articles systematically. Rayyan QCRI is a webpage that streamlines the selection process making it easier for researchers to collaborate [25]. Two reviewers (MF & LC) blindly selected the relevant papers through titles and abstract screening. A third reviewer (PK) was consulted when in disagreement. All selected articles were read in full and included in the systematic review when they fulfilled the inclusion criteria.

2.4.- Data extraction:

We extracted the following information from each selected article: data about the study (e.g., author, year, and citation), the study sample characteristics (e.g., size, age, and focus group), the location (e.g., country), the usage of sex or gender (or both), the exposure assessment measure of greenness (e.g., the neighbourhood surrounding greenness or urban green spaces), the health mediators and outcomes measures and the results (both the overall and the tailored across sex/gender).

2.5.- Quality assessment of the studies

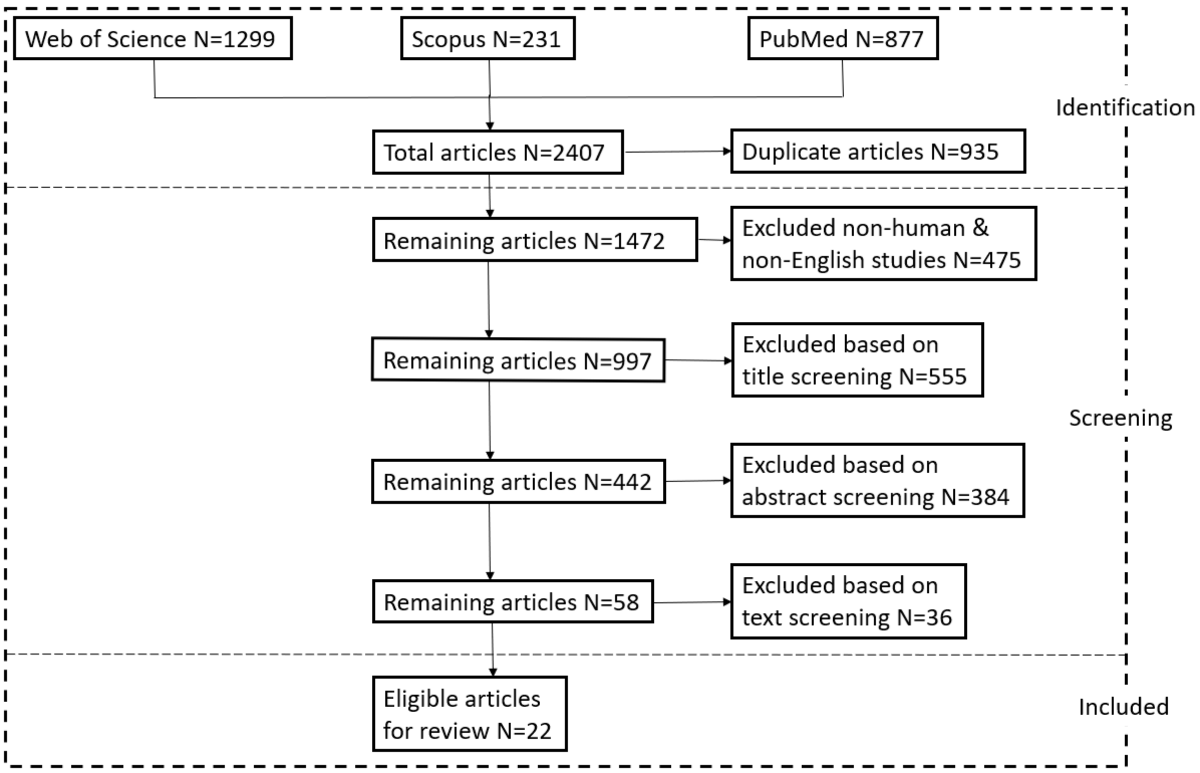
Modifying the quality assessment system from de Keijzer et al. [26] to fit for cardiometabolic health, we have been able to assess the quality of the articles (see Table S3 & S4). The tool utilises twelve quality criteria, and we assigned a score of 0, 1, or at times 2 points for each. The total points earned for every study's criteria were added and expressed as a percentage of the highest possible score. According to this proportion, the study's quality was rated as follows: 81 percent as very good quality, 61 to 80 percent as good quality, 41 to 60 percent as fair quality, 21 to 40 percent as poor quality, and 20 percent as very poor quality.

3.- Results:

3.1.- Article selection:

The initial 2,407 identified papers were trimmed down to 58 after removing duplicates, non-English literature, and screening titles and abstracts (see Figure 1). During the screening, we encountered papers that seemed to follow our eligibility criteria; however, in the end, they did not. One example was the articles that focused on mental health due to the inclusion of the keyword of stress [27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37]. Another example were those articles that did not stratify results through sex or gender; rather, they adjusted them through different models [38, 39, 40, 41, 42, 43]. In the end, a total of 22 papers were included in the review.

Fig 1 Selection process of the articles, starting with the identification phase, which includes the exclusion of the duplicates. Following with the screening phase, excluding the non-human, non-English articles, and screening the titles, abstracts, and titles of the papers. In the end, there remain the eligible articles



3.1.- Sample characteristics:

Table 1 summarises the sample characteristics of each study. The sample size varies from 408 to 28,6 million participants. Age ranged widely, but 68,2% of the studies focused on adults. Overall, Europe (45.5%), the U.S.A. (22.7%), and China (13.6%) were the main localizations.

Table 1 Key characteristics of the articles

Citations	Unit of analysis*	Country	Use of sex or gender	Greenness exposure measure	Health outcome	Protection**
Asri et al., 2020	183 countries	Worldwide	Gender	NDVI	Stroke	Stronger effect found in men
					Ischemic heart disease	Stronger effect found in women
Bauwelinck et al., 2020	14,000	Spain & Belgium	Sex	NDVI, MSAVI2 (100m, 300m, and 500m buffers), access to green spaces (300m and 500m) & distance to nearest green space	Hypertension	Stronger effect found in males
Bauwelinck et al., 2021	2,185,170	Belgium	Sex	NDVI, MSAVI2 (300m, 500m and 1000m buffers) & Green space proportion within buffer zone	Cardiovascular disease (CVD) mortality	Stronger effect found in males
Bell et al., 2008	3,831	U.S.A.	Gender	NDVI (1km buffer)	Obesity	Stronger effect found in men
Cummins & Fagg, 2011	42,177	UK	Sex	Green space area proportion in each district	Obesity	Stronger effect found in females

de Keijzer et al., 2019	6,076	U.K.	Sex	NDVI & VCF (500m and 1000m buffers)	Metabolic syndrome	Stronger effect found in females
Huang et al., 2020	24,845	China	Gender	NDVI & SAVI (500m and 1000m buffers)	Obesity	Stronger effect found in women
Liu et al., 2021	2,100	China	Gender	NDVI (1,000m, 1,500m, and 2,000m buffers)	Pulse pressure	Stronger effect found in women
					Lipid accumulation product	Stronger effect found in men
					Cardiovascular disease	Stronger effect found in men
Persson et al., 2018	5,126	Sweden	Sex	NDVI (100m, 250 and 500m buffers)	Obesity	Stronger effect found in females
Plans et al., 2019	1,720	Spain	Gender	NDVI (300m, 500m, 1000m and 1500m buffers)	Obesity	No association between urban greenness and obesity was found
					Hypertension	Stronger effect found in men
					Diabetes	Stronger effect found in women
					Hypercholesterolemia	Stronger effect found in women

Prince et al., 2011	3,383	Canada	Sex	Green space access	Obesity	Stronger effect found in females
O'Callaghan-Gordo et al., 2020	2,354	Spain	Sex	NDVI (300m buffer) and access to green space	Obesity	Stronger effect found in females
Richardson & Mitchell, 2010	6,432 urban wards	U.K.	Gender	Green space access	CVD mortality	Stronger effect found in men
Sanders et al., 2015	4,423	Australia	Gender	Green space access	Obesity	Stronger effect found in boys
Sarkar, 2017	333,183	U.K.	Sex	NDVI (500m and 800m buffers)	Obesity	Stronger effect found in women Stronger effect found in men for the waist circumference
Seo et al., 2019	351,409	Korea	Sex	Green space area proportion in each district	CVD	Stronger effect found in males
Vienneau et al., 2017	4,284,680	Switzerland	Sex	NDVI (150m and 500m buffer)	CVD mortality	Stronger effect found in females
Wall et al., 2015	2,682	U.S.A.	Gender	NDVI (1600 buffers)	Obesity	Stronger effect found in girls
White et al., 2021	8,282	U.S.A.	Sex	Green space presence (400m buffer)	Obesity	Stronger effect found in females
Xu et al., 2017	199 Tertiary Planning Unit	China	Gender	NDVI	CVD mortality	Stronger effect found in men

Yang et al., 2018	41,283	U.S.A.	Gender	Distance to nearest park	Obesity	Stronger effect found in girls
Yeager et al., 2018	408	U.S.A.	Sex	NDVI (250m and 1000m buffers)	Stress	Stronger effect found in females

*When no unit of analysis is given, the unit are individuals.
**The use of the terminology is according to whether the papers used sex or gender. It is not necessarily the same as what they use in their papers to refer to the participants.

3.2.- Usage of sex or gender:

Regarding sex and gender, 54.5% of the studies stratified results according to sex, but only 22,7% of the articles focused mainly on sex and gender when performing the study [21, 52, 54, 58, 62]. However, the terms surrounding sex and gender were used interchangeably. More than 90% of the studies talk about sex but refer to the participants as women and men or vice versa; they refer to participants as females and males but talk about gender [21, 22, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61]. Additionally, a few studies use both the terms of sex and gender interchangeably [49, 53]. Only the papers by Sanders et al. and White et al. were consistent with the terminology (9,1%) [62, 63].

3.3.- Exposure assessment measure of greenness:

Most papers (68.2%) assessed residential or neighbourhood surrounding greenness, while a minority studied urban green spaces such as parks and sports fields. The measure used for the residential surrounding greenness was mainly the Normalized Difference Vegetation Index (NDVI) [22, 44, 45, 47, 48, 49, 50, 51, 52, 54, 55, 57, 58, 59, 60]. Other measures were also used, such as the Modified Soil-adjusted Vegetation Index 2 (MSAVI2) [45, 46], the Vegetation Continuous Field (VCF) [37], and the Soil Adjusted Vegetation Index (SAVI) [49]. In contrast, those used for urban green spaces accounted for the access [21, 54, 55, 62, 63], the proportion of green space in each district [46, 48, 57] or the distance to the nearest green space [45, 61].

3.4.- Quality assessment of the studies

Out of the 22 included articles, the majority qualified as good quality (50%), 36,4% qualified as very good quality and the rest as fair quality (13,6%) with no paper of poor or very poor quality. All studies performed well within the quality criteria of potential bias, greenspace data source, covariates, statistics, and effect size. However, there were some problematic quality criteria which were related to the assessment of the greenness. None of the articles assessed the quality of greenness. Additionally, only one paper included the usage of urban greenness in their study [54]. Furthermore, only 18,2% of the papers included different greenness indicators to measure it within the study [45, 46, 49, 64]. In terms of sex and gender, out of the papers that qualified as very good quality, 57% pointed to urban greenness being overall more protective towards males/men [46, 47, 57, 62]. However, 72,7% of those that qualified as good quality urban greenness was more protective towards females/women [49, 53, 54, 55, 56, 58, 61, 63]. Additionally, two of the three articles that qualified as fair quality found results of urban greenness being more protective towards males/men [21,59].

3.5.- Cardiometabolic risk factors:

Obesity was the most common health outcome assessed in these studies (50%), followed by cardiometabolic mortality (18%).

3.5.1.- Obesity:

All 11 studies that measured obesity, adiposity, and overweight did so through the body mass index (B.M.I.) [47, 48, 49, 52, 53, 54, 55, 56, 58, 61, 62, 63], but some also used additional measures such as waist circumference (W.C.) [49, 52, 56], waist to hips ratio (W.H.R.) [55], weight gain (in a longitudinal study) [52] and whole-body fat [56]. The overall results (58,3% of the articles) point to a protective effect of urban greenness [47, 49, 55, 56, 58, 62, 63]. Authors such as Bell et al. and Sanders et al. assessed that physical activity is the apparent mediator between the association between obesity and urban greenness [48, 62].

In terms of sex and gender, 63.6% of the papers found that urban greenness was more beneficial to females than males and women than men [48, 52, 54, 55, 56, 58, 63]. However, results were not always consistent through all indicators of weight. For instance, Persson and colleagues found that the beneficial effects of urban greenness in females only reduced the increase in W.C. from the baseline; this did not happen with weight gain or B.M.I. [52]. Alternatively, Sarkar performed in the U.K. to adults aged 38 to 73 [56]. The study found the beneficial effects of urban greenness more pronounced in the male population when doing waist circumference measurements. Two other studies assessing obesity in children using longitudinal designs found urban greenness to be more protective towards males [48, 62].

3.5.2.- Hypertension:

Two studies assessed the relationship between urban greenness and hypertension. Both found no significant association between the two factors. In terms of sex and gender, the same lack of significance was found [45, 53].

3.5.3.- Metabolic syndrome:

The only study including metabolic syndrome was that of Keijzer and colleagues, who conducted a longitudinal study in the U.K, with the population being between 45 and 69 years old at baseline [50]. The study findings were coherent with existing results on obesity and found that people exposed to higher levels of residential surrounding greenspace had lower risks of developing metabolic syndrome. In addition, in terms of sex, stronger protective effects of urban greenness were found in females.

3.5.4.- Stress:

Yeager and colleagues measured urinary epinephrine to capture stress results to understand CVD risk when residents are surrounded by urban greenness in the US [60]. Their overall results showed that residents who lived closer to greener surroundings had lower stress levels. Moreover, when stratifying results by sex, the protective association between greenness and stress was found in both sexes, with females more protected in this association than males.

3.5.5.- Diabetes & hypercholesterolemia:

Plans and colleagues assessed different risk factors of CVD in Madrid, Spain. For hypercholesterolemia, the results were clear, the closer to green space, the lower the odds of having high cholesterol. However, for diabetes, results were mixed as they were only significant for the second quartile of the density of green spaces. In that quartile, the odds of diabetes went up, meaning the less density of green spaces, the higher the odds of diabetes. In terms of gender, women were the only ones affected by the density of green spaces; thus, the lower the density, the higher the odds of having high cholesterol. Again, in the case of diabetes, results were mixed. The relation was only observed for women, and results were unclear about the relationship both factors had [53].

3.5.7.- Pulse pressure & lipid accumulation product:

Liu and colleagues assessed both pulse pressure and lipid accumulation product in China as risk factors for CVD. For pulse pressure, urban greenness was identified as having a protective effect on the population: For the buffer of 1500m in the NDVI in the second tertile, they found: -2.99: 95% CI: -4.43, -0.15, while for the third tertile: -4.00; 95% CI: -6.53, -1.47. Thus, they demonstrated the inverse relation between urban greenness and pulse pressure. However, for the case of lipid accumulation, results were more mixed. If we look at the same buffer, in the second tertile the authors found: -10.02; 95% CI: -16.08, -3,96, however in the third tertile: -3.72, 95% CI: -10.85, -3.41. Therefore, the more urban greenness is still better than the reference base but not more protective than having a small amount of urban greenness. In terms of gender, they found that urban greenness was especially protective for pulse pressure among women (-1.216; 95% CI: -1.982, -0.450), whereas greenness was associated with fewer lipid accumulation among men (-0.803; 95% CI: -3.535, 1.929) [51].

3.6.- Stroke:

Arsi and colleagues performed a study around 183 countries and found urban greenness to have a protective impact on the overall population in terms of stroke incidence. The benefits were statistically significant for both women and men, but they were more pronounced in women (with coefficient estimates of -2.62; p-value < 0.01) than in men (with coefficient estimates of -1.84; p-value < 0.05) [7].

3.7.- Ischemic heart disease:

Ischemic heart disease was one of the two CVDs that appeared in the articles from our system research. Asri and colleagues found urban greenness to be protective (−11.245; 95% CI: −16.770, −5.720; p-value < 0.001). In terms of gender, the relation was more pronounced in men (-6.39; p-value <0.001) than in women (-5.18; p-value <0.001) [7].

3.8.- Cardiovascular disease:

Only Liu et al. and Seo et al. have studied the relationship between urban greenness and cardiovascular disease [51, 57]. Both papers found urban greenness to be protective; however, males and men had more pronounced results, especially in the paper by Liu et al. with men: 0.768, 95% CI 0.663, 0.890, p=0.017; and women: 0.906, 95% CI 0.805,1.020, p=0.017 [51].

3.9.- Cardiometabolic mortality:

Mortality was the second most common topic assessed through the articles (18%). All studies found a protective effect from urban greenness concerning mortality. The overall results showed that age mediated the association between mortality and urban green space protection. Younger subjects were more protected than older ones [22, 46, 48].

Results stratified by sex and gender indicated a protective effect on males and men in CVD, diabetes, and cerebrovascular mortality [21, 46, 59]. However, results were mixed when looking into ischemic heart disease as only two studies assessed it, and each found contradicting results. Vienneau et al. found a more protective effect on females, while Bauwelinck et al. found a protective impact on males [22, 46]. Finally, Vienneau and colleagues found that females were more protected by urban greenness than males regarding hypertension-related [22].

4.- Discussion:

This systematic review mostly pointed to urban greenness as having a protective effect against cardiometabolic risk factors and diseases. However, when stratifying results by sex and gender, findings suggest that urban greenness is more beneficial for females in stroke and cardiovascular risk factors, except for hypertension and lipid accumulation. On the other hand, males were more protected by urban greenness in terms of cardiovascular diseases and mortality.

4.1.- Focusing on sex and gender:

The terminology around sex and gender has been a key issue during this systematic review as terms were used interchangeably. The fact that papers claimed they were analysing gender differences but used females and males to refer to the participants may show a misunderstanding of the term gender and careless use of the terminology. In addition, it confuses to readers who become uncertain about what the authors refer to, either sex or gender.

Additionally, none of the reviewed papers explained how the authors assess sex and gender, define it, and most importantly, why they use either one of them and not both [64]. In reality, observed differences and inequalities in greenness protective effects might not be only attributable to sex only, but also to gender roles and norms our world dictates [65]. Thus, both should be thoroughly examined [66]. Moreover, the misuse of the terminology directly affects those who do not identify themselves within the binary system, those who reject gender norms, as they are probably misread in research and thus, not accounted for [67].

4.2.- Type of greenness and sex and gender:

This review attempted to uncover specific sex and gender differences in various types of urban greenness. We found that those papers that measured greenness through NDVI generally found the greenness to be more protective of females and women across all health indicators (57,1%) [22, 49, 50, 53, 55, 56, 60]. However, for other exposure types such as green access, green proportion in the district, and distance to the nearest park, the results are mixed [21, 45, 46, 48, 54, 58, 61, 62, 63]. Mechanisms that could be involved with the health outcomes and types of exposure studied are a combination of indirect and direct contact with the greenness. Even though it would be interesting to differentiate the mechanisms involved for each exposure type, we cannot fully do so as we cannot differentiate the uses completely (proximity, view, usage). The lack of inclusion of the use of greenness within the papers has been one of the factors that has lowered the quality of the reviewed papers, indicating a gap within the research. Thus, we were not able to draw any clear conclusions due to a lack of evidence. However, some efforts to establish the mechanisms can be seen, with the mechanism being mitigation, restoration, and instoration [68, 69]. The mechanism of mitigation -reducing harm through greenness- includes different factors that can be mitigated, such as noise or air pollution. Mitigation within the included papers has been studied regarding CVD [21], mortality [22,46], and obesity [52,55,56] assessing the levels of air pollution in the environment as a confounding factor. This mechanism could be argued to be the most detected when using NDVI as a measure of greenness, as it is a vegetation index, and it is not accounting for the usage of the greenness but rather for its presence. The same could be argued for the measure of the greenness of distance to the nearest park. The mechanism of restoration delves into the restorative effect greenness can have on people's psychological wellbeing. The study by Yeager et al. studied the levels of stress as a risk factor for CVD risk [60]. The mechanism of instoration includes the building of capacities either physical or social through greenness. Within the studies, physical activity has been studied in some articles that assessed obesity [49,52,55], and in one regarding CVD [51]. Both the mechanisms of restoration and instoration could be argued to be detected when using the measure of access to greenness, as these mechanisms are more dependent on the use of greenness.

From previous studies, we know that women might be more reluctant to access green spaces if they are not perceived as safe, which directly influences how much women interact with their surrounding greenness, even from a young age [71, 72, 73,74, 75]. For instance, multiple environmental and social factors shape people's perception of safety. Social disorder and serious crime help shape the fear of crime perceived by women within their neighbourhood. Thus, factors such as these aid in the understanding of the gendered nature of perception of safety [76]. Additionally, even when there is an interaction between both sexes and genders, these might differ. For example, women typically visit parks following their assigned role of childcaring, while men tend to be more physically active [75, 77].

4.3.- Quality of the studies:

As the quality of the papers has proven to be good, the results presented here can be understood to be of high quality as well. Results show no correlation between the quality of the articles and the protection of urban greenness through sex and gender, pointing to unbiased researchers and results.

Even though the quality of the articles included was overall good, none of the articles assessed the quality of greenness, which is a substantial gap. Park quality has been studied in the literature, and authors found sex and gender differences, pointing to women being more affected by their surroundings than men [79]. Additionally, only one paper assessed the usage of greenness, which hinders the possibility of understanding which mechanisms are involved in the relationship between the use of greenness and cardiometabolic health.

4.4.- Contextualizing benefits for females and women:

As observed, most greenness effects on cardiometabolic risk factors were more beneficial for females or women. An explanation could be that women interact more with greenness as they might surround themselves more with urban greenness due to enduring childcare and housekeeping obligations [39, 49, 53]. Thus, the availability of green space seems particularly critical for women's health [80]. Prince and colleagues point to the lack of specificity of the use of urban green spaces (such as having designated areas for different sports) to be what made men be unmotivated to use them and be physically active in them [54]. This was coherent with results found by many authors [77, 78, 81, 82, 83, 84]. They point to men being more likely to be observed in more active informally and formally organised activities, such as playing soccer in sports or grass fields. At the same time, women are seen walking, jogging on walking trails, or dancing and doing aerobics. These gendered differences can even be seen during childhood and adolescence [85].

Additionally, because the relationship between urban greenness and cardiometabolic health is complex, other factors may also mediate it. For example, Wall et al. and Yang et al. found unhealthy food availability through fast-food restaurants more predictive of girls' obesity than urban greenness [58, 61]. This difference is possibly explained by the modification of socioeconomic level in women, making them more vulnerable to obesity, as they might not be able to afford healthier food [80, 55]. Stress may also play an important role in obesity, as some studies found restorative effects from urban greenness, which probably contributed to the participants' weight loss [53, 57].

4.5.- Contextualizing benefits for males and men:

Urban greenness has proved to be more protective for males and men regarding cardiovascular diseases and mortality. Bell et al. and Sander et al. studied childhood obesity in specificity and found men more protected by urban greenness [47, 62]. These results are in accordance with those found by Wolch and colleagues, who also assessed childhood obesity [85]. Sanders and colleagues point to gender as a possible mediator as boys have more independence to move around the neighbourhood, allowing them to be more physically active in other spaces [62]. Marquet et al. further hypothesise that this trend can be due to parents engaging in gendered avoidance behaviour when they perceive threats to security, such as crime [71, 87].

Contrary to what authors that found better results for females and women suggest about their interaction with urban greenness, Richardson & Mitchell point to a possible underrepresentation of women in urban green spaces such as parks due to the value women put into the quality of these spaces [21]. As mentioned before, a sense of safety and crime can also explain why women might be less likely to access urban greenness [72]. Consequently, Liu and colleagues believe that men are more likely to use urban green spaces [51]. Xu and colleagues further argue that this use may be due to their occupations, either because more males work outdoors near where they live or because they are exposed to them in their commute [59].

Other authors who did not relate CVD to urban greenness remind us that these better results for men may be due to the possible late or wrongful diagnosis of CVD in women. For example, Hyung and colleagues discovered that women attending primary healthcare services in Australia were less likely to be examined for CVD risk factors [86]. Mauvais-Jarvis et al. further add that women are more likely to die because of coronary heart disease, potentially because of undiagnosed ischemic heart disease [89].

4.6.- Strengths and limitations:

This review has many strengths and has faced some limitations. First, our study offers a critical view of the use of sex and gender, through which we identified the misuse of the terminology in the epidemiologic research field. Additionally, we conducted a rigorous systematic review using the PRISMA methodology at all stages. We ran the systematic search with a second blind reviewer to confirm that we were not disregarding any articles relevant to our study.

However, we encountered some limitations. The exclusion of all non-English articles might have led to the concentration of the cases in Europe and the US., meaning there is a need for further research of other parts of the world to increase global knowledge as results may vary across countries. At the same time, studies analysing the differences by sex and gender used different terminology and structures, which complicated the systematic search. We focused our search on articles relating urban greenness and sex and gender through interaction, stratification, and effect modification. Both these factors might have influenced the number of papers reviewed; however, we used a comprehensive search to avoid missing any relevant articles. Additionally, the wrongful use of the terminology challenged the understanding of the results.

4.7.- Future research:

Future research should aim to better understand health differences by sex and gender and the terminology around these terms, as most reviewed studies used them wrongfully and interchangeably. At the same time, future research should purposely examine both sex and gender when relating to urban greenness and health. Additionally, none of the included papers that considered gender discussed the entire gender spectrum or, at least, tried to have a section on non-binary people and the effects that urban greenness had on their health. In these articles, a part of today's society was ignored or possibly misread. Thus, denoting the need for inclusivity in this research field.

Aside from inclusiveness, the literature still lacks the intersectionality of sex and gender with other socio-cultural and demographic aspects (e.g., class, race, ethnicity, etc.) regarding urban greenness and health. Intersectionality will be essential to outline the factors that lead to health inequalities. In terms of intersectionality, future research should also assess people's perceptions of urban greenness to understand how they interact. Thus, future research would benefit from the inclusion of qualitative research. It would also benefit from further exploring the possible late or misdiagnosis that women suffer in cardiometabolic issues. For this reason, we also need better-prepared physicians; therefore, there is a need to incorporate a gender perspective in their curriculums. Additionally, articles need to include the assessment of different criteria related to urban greenness, especially the quality, usage and measurements of greenness.

4.8.- Policy implications:

Planning for green space should integrate a gender perspective. Urban green spaces need to be safe and welcoming spaces where women can access them without fear, apprehension, and discomfort. In addition, women need to have the possibility of being physically active. As mentioned, women tend to have competing responsibilities either within the household or with their children. Duties take up time and energy, impeding them from having the possibility or the time to go to urban green spaces to be physically active for themselves and their health with no other purpose than self-care.

Some interventions might make urban green spaces more appealing and accessible to women. For example, Casper and colleagues suggested having childcare facilities in parks so mothers can exercise while their young kids are taken care of [76]. Additionally, Mitchell and colleagues pointed to the need for programmed and supervised activities for adolescents and young girls, so their parents will let them participate in outdoor activities [90]. Barcelona is an example of a city placing care at the centre of city planning. With the Ciutat Cuidadora (City of Care) model, the town council aims to recognise the importance of care and ensure that everyone can be cared for through fair and equitable conditions [91]. The municipality is integrating care into green space planning, including the pedestrianised and green Superblocks which are being developed throughout the city. Only through care and justice-centred policies that account for women and females' intersectional needs and responsibilities can a green city be a just city for all.

5.- Conclusions:

Results suggest urban greenness is protective against cardiometabolic risk factors and diseases. However, in terms of sex and gender, women are more protected by urban greenness in cardiovascular risk factors, except for hypertension and lipid accumulation product. On the other hand, urban greenness benefited men more for cardiovascular diseases and mortality. There are several possible explanations, one of the main ones being that women and men pattern of use of urban greenness may differ. These findings could be used to help ease certain health inequalities regarding sex and gender.

Additionally, this review has also shown that literature on the topic of urban greenness protection across sex and gender to people's cardiometabolic health is still an under-examined field. In turn, this limits the conclusions that can be extracted from the data.

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7.- Supplementary material:

Table S1. Search design for each database:

PubMed	(green*[Title/Abstract] OR "natural environment"[Title/Abstract] OR tree*[Title/Abstract] OR "urban environment*"[Title/Abstract] OR "urban nature"[Title/Abstract] OR "nature area"[Title/Abstract] OR "natural area*"[Title/Abstract] OR "open space*"[Title/Abstract] OR "public space*"[Title/Abstract] OR "vegetated space*"[Title/Abstract] OR "natural outdoors environment"[Title/Abstract] OR playground[Title/Abstract] OR (park*[Title/Abstract] NOT parkinson[Title/Abstract]) OR NDVI[Title/Abstract]) AND (("male-female"[Title/Abstract] OR "female-male"[Title/Abstract] OR "women-men"[Title/Abstract] OR "men-women"[Title/Abstract] OR "boy-girl"[Title/Abstract] OR "girl-boy"[Title/Abstract]) OR ((gender[Title/Abstract] OR sex[Title/Abstract]) AND (differences[Title/Abstract] OR specific[Title/Abstract] OR stratif*[Title/Abstract] OR "effect modification"[Title/Abstract] OR interaction[Title/Abstract]))) AND (cardiovascular*[Title/Abstract] OR cardiomyopathy*[Title/Abstract] OR myocarditis[Title/Abstract] OR "atrial fibrillation"[Title/Abstract] OR "atrial flutter*"[Title/Abstract] OR "aortic aneurysm"[Title/Abstract] OR endocarditis[Title/Abstract] OR hypertension[Title/Abstract] OR dyslipidaemia[Title/Abstract] OR hyperlipidaemia[Title/Abstract] OR "vascular disorder*"[Title/Abstract] OR migraine*[Title/Abstract] OR "tension type headache*"[Title/Abstract] OR h*moglobinopath*[Title/Abstract] OR haemolytic an*mia*[Title/Abstract] OR "endocrine disorder*"[Title/Abstract] OR "blood disorder*"[Title/Abstract] OR “congenital heart”[Title/Abstract] OR hypertension[Title/Abstract] OR stroke*[Title/Abstract] OR ictus[Title/Abstract] OR "heart rate variability"[Title/Abstract] OR "blood pressure"[Title/Abstract] OR stress[Title/Abstract] OR "ischaemic heart disease"[Title/Abstract] OR hdlc*[Title/Abstract] OR cvd[Title/Abstract] OR "heart failure"[Title/Abstract] OR "heart disease"[Title/Abstract] OR infarction*[Title/Abstract] OR diabet*[Title/Abstract] OR HbA1c[Title/Abstract] OR insulin[Title/Abstract] OR "blood glucose"[Title/Abstract] OR obes*[Title/Abstract] OR overweight*[Title/Abstract] OR adipos*[Title/Abstract] OR bmi[Title/Abstract] OR “body mass index”[Title/Abstract] OR "metabolic syndrome"[Title/Abstract] OR "metabolic diseases"[Title/Abstract] OR "sudden cardiac death*"[Title/Abstract] OR mortalit*[Title/Abstract] OR morbidit*[Title/Abstract] OR "salivary cortisol"[Title/Abstract])
Scopus	TITLE-ABS(green* OR "natural environment" OR tree* OR "urban environment*" OR "urban nature" OR "nature area" OR "natural area*" OR "open space*" OR "public space*" OR "vegetated space*" OR "natural outdoors environment" OR playground OR (park* AND NOT parkinson) OR NDVI) AND TITLE-ABS(("male-female" OR "female-male" OR "women-men" OR "men-women" OR "boy-girl" OR "girl-boy") OR ((gender OR sex) AND (difference OR specific OR stratif* OR "effect modification" OR interaction))) AND TITLE-ABS(cardiovascular* OR cardiomyopathy* OR myocarditis OR "atrial fibrillation" OR "atrial flutter*" OR "aortic aneurysm" OR endocarditis OR hypertension OR dyslipidaemia OR hyperlipidaemia OR "vascular disorder*" OR migraine* OR "tension type headache*" OR h*moglobinopath* OR haemolytic an*mia* OR "endocrine disorder*" OR "blood disorder*" OR “congenital heart” OR hypertension OR stroke* OR ictus OR "heart rate variability" OR "blood pressure" OR stress OR "ischaemic heart disease" OR hdlc* OR cvd OR "heart failure" OR "heart disease" OR infarction* OR diabet* OR HbA1c OR insulin OR "blood glucose" OR obes*

	OR overweight* OR adipos* OR bmi OR “body mass index” OR "metabolic syndrome" OR "metabolic diseases" OR "sudden cardiac death*" OR mortalit* OR morbidit* OR "salivary cortisol")
Web of science	(TI=(green* OR "natural environment" OR tree* OR "urban environment*" OR "urban nature" OR "nature area" OR "natural area*" OR "open space*" OR "public space*" OR "vegetated space*" OR "natural outdoors environment" OR playground OR (park* NOT parkinson) OR NDVI) OR AB= (green* OR "natural environment" OR tree* OR "urban environment*" OR "urban nature" OR "nature area" OR "natural area*" OR "open space*" OR "public space*" OR "vegetated space*" OR "natural outdoors environment" OR playground OR (park* NOT parkinson) OR NDVI)) AND (TI=(("male-female" OR "female-male" OR "women-men" OR "men-women" OR "boy-girl" OR "girl-boy") OR ((gender OR sex) AND (difference OR specific OR stratif* OR "effect modification" OR interaction))) OR AB=(("male-female" OR "female-male" OR "women-men" OR "men-women" OR "boy-girl" OR "girl-boy") OR ((gender OR sex) AND (difference OR specific OR stratif* OR "effect modification" OR interaction)))) AND (TI=(cardiovascular* OR cardiomyopathy* OR myocarditis OR "atrial fibrillation" OR "atrial flutter*" OR "aortic aneurysm" OR endocarditis OR hypertension OR dyslipidaemia OR hyperlipidaemia OR "vascular disorder*" OR migraine* OR "tension type headache*" OR h*moglobinopath* OR haemolytic an*mia* OR "endocrine disorder*" OR "blood disorder*" OR “congenital heart” OR hypertension OR stroke* OR ictus OR "heart rate variability" OR "blood pressure" OR stress OR "ischaemic heart disease" OR hdlc* OR cvd OR "heart failure" OR "heart disease" OR infarction* OR diabet* OR HbA1c OR insulin OR "blood glucose" OR obes* OR overweight* OR adipos* OR bmi OR “body mass index” OR "metabolic syndrome" OR "metabolic diseases" OR "sudden cardiac death*" OR mortalit* OR morbidit* OR "salivary cortisol") OR AB=(cardiovascular* OR cardiomyopathy* OR myocarditis OR "atrial fibrillation" OR "atrial flutter*" OR "aortic aneurysm" OR endocarditis OR hypertension OR dyslipidaemia OR hyperlipidaemia OR "vascular disorder*" OR migraine* OR "tension type headache*" OR h*moglobinopath* OR haemolytic an*mia* OR "endocrine disorder*" OR "blood disorder*" OR “congenital heart” OR hypertension OR stroke* OR ictus OR "heart rate variability" OR "blood pressure" OR stress OR "ischaemic heart disease" OR hdlc* OR cvd OR "heart failure" OR "heart disease" OR infarction* OR diabet* OR HbA1c OR insulin OR "blood glucose" OR obes* OR overweight* OR adipos* OR bmi OR “body mass index” OR "metabolic syndrome" OR "metabolic diseases" OR "sudden cardiac death*" OR mortalit* OR morbidit* OR "salivary cortisol"))

Table S2. PRISMA Checklist:

Section and Topic	Ite m #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	3
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	4
Information sources	6	Specify all databases, registers, websites, organizations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	S1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	4
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	4
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	4
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	4
Study risk of	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how	N.A.

bias assessment		many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	N.A.
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	NA
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	N.A.
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	6-7
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	N.A.
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	N.A.
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	N.A.
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	N.A.
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NA
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	5
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	5
Study characteristics	17	Cite each included study and present its characteristics.	8-11
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	N.A.
Results of individual	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	N.A.

studies			
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	NA
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	N.A.
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	N.A.
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	N.A.
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	N.A.
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NA
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	11
	23b	Discuss any limitations of the evidence included in the review.	13
	23c	Discuss any limitations of the review processes used.	13
	23d	Discuss implications of the results for practice, policy, and future research.	14
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	NA
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	N.A.
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	15
Competing interests	26	Declare any competing interests of review authors.	15
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	15

Table S3. Quality criteria.

SD	Study design	0 = ecological, 1 = cross-sectional, 2 = longitudinal
PB	Potential bias	0 = evidence of bias (other than due to cross-sectional or ecological study design), 1 = no evidence of bias
OA	Outcome assessment	0 = self-reported in questionnaires, 1 = questionnaire or scale to assess cardiometabolic health, 2 = objectively measured outcome at a clinic visit or retrieved by medical records or other
GD	Greenspace data source	0 = subjective measured: perceived green, 1 = subjectively measured: expert assessment (audit) or objectively measured, but source not sufficiently described, 2= objectively measured: using satellite image, land use map, etc.
GQ	Quality of greenspace	0 = not measured or not included in the analysis as effect modifier or confounder, 1= measured and included in the analysis
GU	Use of greenspace	0 = not measured or not included in the analysis, 1=measured and included in the analysis
GT	Type of greenspace	0 = one greenspace indicator (e.g. one vegetation index or one type or composition of land use) assessed, 1 = two or more greenspace indicators (e.g. vegetation indices and/or types or compositions of land use) assessed
EM	Exposure misclassification	0 = exposure measured at ecological level, 1 = exposure measured at individual level
RH	Residential history	0 = residential history was not taken into account, 1 = residential history was taken into account or green space exposure was assessed repeatedly over the study period
CO	Covariates	0 = no confounding factors considered, 1 = confounding factors considered but some key confounders omitted, 2 = key confounders included in the analyses
ST	Statistics	0 = flaws in or inappropriate statistical testing or interpretation of statistical tests that may have affected results, 1 = appropriate statistical testing and interpretation of tests
ES	Effect size	0 = incomplete information, 1 = complete information (estimate and standard error or confidence interval)

Modified from de Keijzer, Bauwelinck, & Dadvand (2020).

Table S4. Quality assessment results.

	SD	PB	OA	GD	GQ	GU	GT	EM	RH	CO	ST	SE	Score	%	Quality*
Asri et al. (2020)	0	1	2	2	0	0	0	0	0	2	1	1	9	56,25%	F
Bauwelinck et al. (2020)	1	1	0	2	0	0	1	1	0	2	1	1	10	62,50%	G
Bauwelinck et al. (2021)	2	1	2	2	0	0	1	1	1	2	1	1	14	87,50%	V
Bell (2008)	2	1	2	2	0	0	0	1	1	2	1	1	13	81,25%	V
Cummins & Fagg (2011)	2	1	2	2	0	0	0	1	1	2	1	1	13	81,25%	V
de **Keijzer et al. (2019)**	2	1	2	2	0	0	1	1	1	2	1	1	14	87,50%	V
Huang et al. (2020)	1	1	0	2	0	0	1	1	0	2	1	1	10	62,50%	G
Liu et al. (2021)	1	1	2	2	0	0	0	1	0	2	1	1	11	68,75%	G
Persson et al. (2018)	2	1	2	2	0	0	0	1	1	2	1	1	13	81,25%	V
Plans et al. (2019)	1	1	2	2	0	0	0	1	0	2	1	1	11	68,75%	G
Prince et al. (2011)	1	1	1	2	0	1	0	1	0	2	1	1	11	68,75%	G
O'Callaghan-Gordo et al. (2020)	1	1	2	2	0	0	0	1	0	2	1	1	11	68,75%	G
Richardson & Mitchell (2010)	0	1	2	2	0	0	0	0	0	2	1	1	9	56,25%	F
Sanders et al. (2015)	2	1	2	2	0	0	0	1	1	2	1	1	13	81,25%	V
Sarkar (2017)	1	1	1	2	0	0	0	1	0	2	1	1	10	62,50%	G
Seo et at. (2019)	2	1	2	2	0	0	0	1	1	2	1	1	13	81,25%	V
Vienneau et al. (2017)	2	1	2	2	0	0	0	1	1	2	1	1	13	81,25%	V
Wall et al. (2012)	1	1	0	2	0	0	0	1	0	2	1	1	9	56,25%	G
White et al. (2021)	2	1	2	2	0	0	0	1	1	1	1	1	12	75,00%	G
Xu et al. (2017)	0	1	2	2	0	0	0	0	0	1	1	1	8	50,00%	F

Yang et al. (2018)	1	1	2	2	0	0	0	1	0	2	1	1	11	68,75%	G
Yeager et al. (2021)	1	1	2	2	0	0	0	1	0	2	1	1	11	68,75%	G

* * The percentage was used to rate the overall quality of each study: V=very good (score ≥81%), G=good (score 61-80%), F=fair (score 41-60%), P=poor (score 21-40%), and VP=very poor (score ≤20%).