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Review of Key Findings and Future Directions for Assessing Equitable Cycling Usage

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Abstract

Research studies on mode shift toward sustainable transport, particularly cycling, have become more common in the last decade. Despite some success in increasing cycling usage, there exist many barriers, both environmental and societal. This study provides a review of the key equity findings to date in cycling usage and identifies knowledge gaps. Barriers to cycling from an equity perspective are examined from three perspectives: policy and planning, infrastructure and cycling facilities, and population groups. The review includes both peer-reviewed and grey papers. Using a systematic review process, out of 73 documents, 33 which met the scope of the study were carefully examined. The review showed that accessibility is the most common measure for bicycling equity. A key knowledge gap is the lack of robust measures to determine inequities in cycling and evaluate the distribution of benefits across population groups. This is attributed to the lack of measures to effectively evaluate a program or policy from an equity perspective. Consequently, this review emphasizes the need to develop and evaluate equity measures for effective policymaking, to ensure that the needs of different population groups are met. The paper concludes with recommendations for future research, given the identified knowledge gaps.

Although it is crucial to take equity into consideration in transport project planning and to implement equitable systems and infrastructure for everyone, it is rarely a key objective of projects and is often lacking entirely (*1*). However, there is an increasing trend in the literature to evaluate, understand and provide solutions for transportation equity-related issues (*1–7*). Equity in transportation has been defined as sharing of benefits and costs to all members of society in an equitable way (*1*). Transport equity can be discussed through different approaches including social equity, spatial equity, or a combination of both, and from other aspects (*5*). As stated by Thomopoulos et al., equity can have different aims: providing equal rights and benefits of a service or program for all, maximizing the whole welfare of a community, or improving the situation of more disadvantaged population groups (*8*). Critically, equity seeks fairness in society and this is the point of difference when compared with the concept of equality (*6, 9*). Equal access to facilities and infrastructure varies from an equity perspective as equal access does not consider the specific needs of different population groups.

Among transportation modes, active transportation, and in particular cycling, has become a priority for many countries to reduce single-occupant car usage. Bicycles can provide cost effective and flexible access to destinations, and reduce air pollution, traffic, fuel consumption and transportation costs, as well as improve health outcomes (*10*). Equitable bicycle infrastructure, bicycle sharing systems (BSSs), and dock-less bicycle sharing systems (DBSSs) can be achieved when they are accessible by different population groups with minimal barriers. An equitable system also provides access to key destinations for all, by distributing quality infrastructure fairly in a region. Reviewing literature focused on active transport equity, Lee et al. highlighted that studies commonly assess social and spatial equity but do not consider factors such as safety, quality of facilities, project funding, procedural equity, and the consideration of potential users (*5*). The study found that the main focus has been on pedestrian equity, with a paucity of research

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undertaken on bicycling equity. However, an understanding of equity in relation to access to bicycle infrastructure and facilities is important to provide better insights for planning. Consequently, this study provides a review of recent literature on bicycling equity, which includes both peer-reviewed and grey papers. The objectives of this study are as follows:

- Synthesize the key findings from studies focused on bicycling equity; and
- Identify knowledge gaps and suggest avenues for future research.

The review considers cycling systems, including private bicycles, BSS, and DBSS, and both leisure and utility cycling. The key findings and knowledge gaps are provided in sub-categories for ease of summarization. The subcategories were not defined prior but based on the papers included in the review. Findings from this review are expected to help direct future research in cycling equity so that practitioners and transportation policymakers can integrate equity into their planning procedures and policymaking.

Equity and its Application in Transportation

A key element of equity, justice, or fairness is the distribution of benefits and costs across population groups. How these benefits and costs are measured is a prerequisite to make a system more equitable. In transportation, equity is mainly discussed by considering accessibility. Discussing accessibility in transport equity typically relates to access to transport facilities/modes, or access to destinations by transportation modes (*1*). Studies used various measures for investigating accessibility, such as considering journey time, distance, travel cost, and travel destinations, as well as considering place-based or people-based accessibility (*11–14*). Affordability is another factor considered in transport equity and directly relates to different income levels. If transport services are relatively cheap, more people can afford them and will use them and affordable transportation is critical for low-income people, especially low-income workers (*15–17*). Socio-demographic characteristics of people, such as age, gender, income, employment status, educational level, and physical impairment differentiate population groups and can also affect transport equity. However, the influence of socio-demographic characteristics is not shaped by a single axis of social division and it is the "intersections of them" (the combination of multiple socio-demographic variables) that create differences among different population groups. It suggests that researchers should not characterize the population groups' behavior by considering one aspect of their identity (*18*). For example, it is not possible to describe "men's cycling behavior" and "women's cycling behavior" without taking into account other socio-demographic characteristics.

Method

The procedure adopted for the systematic review is explained step by step in this section. A mixed search strategy was used to combine database searches using keywords, forward snowballing (finding citations to papers), and backward snowballing (from the reference lists) similar to those used in previous studies (*19*, *20*). Mixing these methods, according to Jalali and Wohlin, results in a comprehensive list of relevant papers, although it is more time consuming (*19*). The process is illustrated in Figure 1 and the individual steps are described below. The papers were collected by the first author (steps 1–4) and then reviewed by all authors (steps 5–6).

1. The search process first involved identifying the keywords for database searches. Scopus, Google Scholar, and Transport Research International Documentation (TRID) were used as the target databases and only English language articles were considered for inclusion. The databases were searched using (combinations of) the following keywords: bike, bicycle, cycling, active, equity, equality, fairness, and justice. The terms equity, equality, fairness, and justice have been included because these terms are often used interchangeably. Restrictions were not applied to the year of publishing, but the oldest publication was found to originate in 2009.
2. Articles were evaluated for inclusion and exclusion. At this stage, all the titles found by searching the selected keywords through databases were checked for relevance. If the article title was relevant to equity/inequity in cycling, it was added to the extracted papers list (L). When it was not clear if the title was relevant to the scope of the study, it was included in the extracted papers list, to be looked at in detail at a later stage.
3. The next step involved forward and backward snowballing of each extracted paper. Initially, citations to all the papers, including the papers published in the selected databases, grey papers, theses/dissertations, books, book reviews, reports, editorials, and conference abstracts, were checked through using Google Scholar ($L = 59$). Next, all the references lists were scanned and potential papers extracted based on the titles. Through this step, 19 new papers were selected ($L = 78$). Forward snowballing and backward snowballing continued with each new paper identified and ended when there were no suitable papers in the

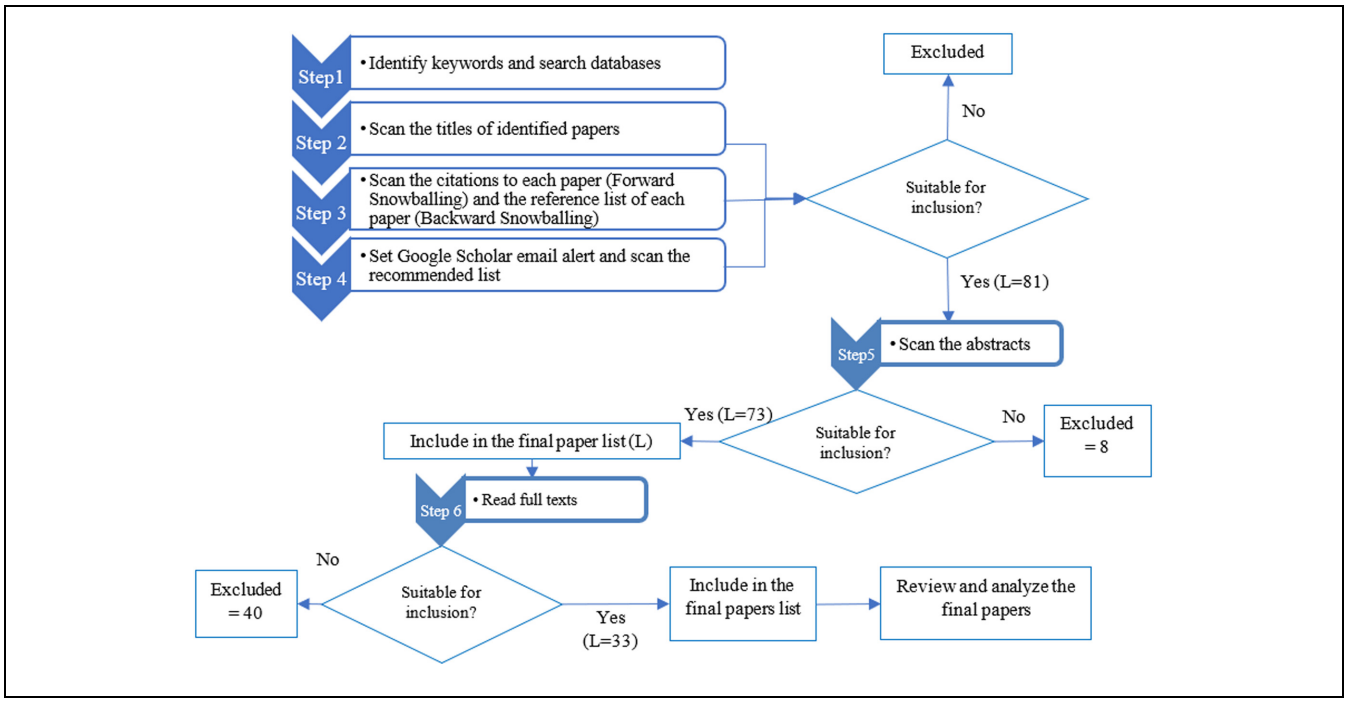

Figure 1. Flow chart of systematic search strategy.

final citation lists. It should be noted that, based on this search methodology, the boundary of grey papers in this study is restricted to Google Scholar.

4. Alerts were set which included all the aforementioned search keywords using a Google Scholar profile. This step was added to the process to capture any papers published after the initial review. The procedure for checking alert emails was to scan the titles once received for relevance (as per Stage 2). There were three further inclusions to the final extracted papers list from this step.
5. After finalizing the paper search process through steps 1–4 and finding a wide range of papers ($L = 81$), all the abstracts were read to check for relevance to the scope of the review. Scanning the abstracts by carefully checking the aim of the papers, methodologies, and results helped the authors to identify if the extracted papers discuss equity/inequity in cycling. For example, while there were papers with relevant titles, the content may have focused on equality in bicycle usage, rather than equity. Papers such as these were excluded from the final list, following a discussion between the authors. In this step, eight documents were excluded (seven documents because of lack of relevancy to the present investigation and one duplicate document).
6. In the final step, the full texts of the 73 remaining documents were read. The inclusion strategy for full texts was to retain all the documents which clearly investigated equity/inequity in cycling (not equality), discuss the reasons or outcomes of inequity/equity in cycling, or discuss bicycling equity policies. After this stage, 40 further documents were excluded and 33 documents remained ($L = 33$).

Key Findings on Bicycling Equity

Most of the studies originate from the U.S., Canada, and the UK. Typically, the case study included one city or neighborhood. Only nine studies evaluated and compared a few cases, and there are five studies that included many (more than 10) cases. Equity in cycling can be discussed from various perspectives. Findings of this review can be categorized to: (a) equitable access to bicycle infrastructure, (b) equitable access to destinations by bicycle, and (c) equity issues in cycling policies (*21–32*). Studies mainly considered the relationships between equity and socioeconomic characteristics (mostly income and place of residence), cycling investments, infrastructure locations and accessibility, safety, and policymaking.

The 33 papers in the final list of papers for review were categorized based on their primary focus areas. Three clear sub-categories emerged. The sub-category "Equitable access to bicycle infrastructure" includes the selection of papers that discuss equity issues related to

bicycle infrastructure, which included access to bicycle lanes and bicycle sharing stations by different socio-demographic groups. The second sub-category, "Equitable access to destinations by bicycle," includes papers that discuss equity issues related to accessibility of different destinations. Papers in this category considered the use of private bicycles, BSS, or bicycle lanes to access key destinations. The third category, "Equity issues in cycling policies," considered papers that discuss the influence of policymaking and equity consideration (at policy level and decision-making level) for cycling. The papers in this category are different from "access to bicycle infrastructure" and "access to destinations by bicycle" as they are related to policy, and explore equity issues at a higher level by using case studies in bicycle usage. These papers consider equity in investments in cycling projects, public awareness about cycling facilities, and policy views and equity considerations in BSS and infrastructure projects. Table 1 presents the three sub-categories and details (authors, study area, focus of study) for each of the 33 papers.

Equitable Access to Bicycle Infrastructure

The majority of studies on equity of bicycle infrastructure focused on socioeconomic levels and income levels, to assess if disadvantaged groups have the required accessibility to bicycle networks and BSSs/DBSSs. A common finding from these studies is that bicycle infrastructure is not equitably distributed among different population groups. It is typically reported that there is lower access to bicycle infrastructure for disadvantaged populations. As shown in Table 1, studies considered different criteria and methods including density of cycling routes, availability of bicycling infrastructure and topography, using a network analysis and level of stress experienced by cyclists, availability, coverage, connectivity, and proximity of bicycle lanes, and the Gini coefficient (*6, 21, 22, 37–39, 48*). The studies considered various types of bicycle infrastructure and socio-demographic characteristics, including education, age, employment status, occupation, car ownership, ethnicity, and race. This shows some evidence of inequitable investment by governments and a lack of equity consideration by policymakers.

In contrast, a limited number of studies discussed better access for low-income populations and disadvantaged populations (*33, 34, 41*). Deka and Connelly suggested that low-income and minority populations' lower participation in physical activities could be caused by other external factors, such as cultural norms (*34*). Winters et al. reported that neighborhoods with higher-density populations were prioritized for bicycle infrastructure investment in Victoria and Kelowna (Canada) cycling policies (*41*). Therefore, the urban form of these cities influenced greater access for lower-income population groups, since the higher-income areas were more suburban in nature with lower-density populations.

Some studies evaluated equity in investments over a period of time and reported that bicycle infrastructure improvements were not undertaken in an equitable way, so that investments benefitted people of European ethnicity and those living in gentrified neighborhoods or provided lower accessibility to bicycle lanes for non-European, African-Americans, those without a vehicle, and those with low income (*23, 35, 37, 48*). In contrast, Houde et al. noted that accessibility for recent immigrants and the elderly did improve over a 25-year period of bicycle lane expansion in Montreal, Longueuil, and Laval in Canada (*23*).

In relation to equity in the distribution of BSS stations, the majority of studies have attempted to investigate whether the distribution of BSS stations is equitable. A study, by Conrow et al., tried to identify suitable locations for BSS stations considering both social and spatial equity, as well as budgetary limitations and realities (*42*).

In contrast to BSS, DBSSs are free-floating systems working without any stations; bicycles are moved based on user destinations and rebalances are based on demand. As the system is not dependent on stations, the equity consideration is different to BSSs. Evidence indicates that DBSSs appear to be more equitable than BSSs in relation to accessibility and, for example, in Seattle, Mooney et al. found that no neighborhoods were disadvantaged and inequity of access to bicycles was notably low, as the number of available bicycles remained high in all neighborhoods (*24, 49*). However, it was noted that slightly more bicycles were available in neighborhoods with more local community resources and higher incomes.

In summary, studies in this topic mainly reported lower access for disadvantaged populations: for instance, slightly more access to BSS stations for the employed, more access for residents with European ethnicity, lower accessibility for those residing in lower-socioeconomic areas, more access for higher-income areas, and better access for advantaged and wealthier areas (*25, 36, 43–47*).

Equitable Access to Destinations by Bicycle

This section includes studies which explored equity in relation to accessibility to destinations by bicycle, made possible by the provision of bicycle infrastructure or BSSs. These studies mainly considered access to various key destinations including job destinations, grocery stores, hospitals, schools, shopping opportunities, pharmacies, banks, and libraries (*25, 27, 38, 43*). They mainly reported more access to key destinations for the affluent, people of European ethnicity, or neighborhoods within and around the downtown area (*25, 38, 43, 50*). Only a limited number of studies focused on disadvantaged

Table 1. An Overview of Literature on Bicycling Equity

Sub-categories	Authors	Study area	Focus of study
(a) Equitable access to bicycle infrastructure	Vanderslice et al. (*33*)	Portland, U.S.	Association along socioeconomic lines and access to bicycle lanes
	Deka and Connelly (*34*)	New Jersey, U.S.	Association along socioeconomic lines and access to bicycle infrastructure
	Pistoll and Goodman (*21*)	Melbourne, Australia	Association between socioeconomic characteristics and access to cycling infrastructure and investment
	Flanagan et al. (*35*)	Chicago and Portland, U.S.	Equity in investments in cycling infrastructure over 20 years
	Clark and Curl (*36*)	Glasgow, UK	Equity in access to BSS stations
	Wang and Lindsey (*37*)	Minnesota, U.S.	Association between socioeconomic characteristics and access to bicycle network
	Fuller and Winters (*22*)	Calgary, Halifax, Moncton, Montreal, Saskatoon, Toronto, Vancouver, and Victoria, Canada	Association along socioeconomic lines and access to bicycle lanes
	Tucker and Manaugh (*38*)	Rio de Janeiro and Curitiba, Brazil	Association along socioeconomic lines and access to bicycle lanes
	Braun (*39*)	22 large U.S. cities	Association along socioeconomic lines and access to bicycle lanes and equity in investments in cycling infrastructure over 25 years
	Parra et al. (*40*)	Bogotá, Colombia	Association along socioeconomic lines and access to bicycle lanes
	Winters et al. (*41*)	Victoria, Kelowna, and Halifax, Canada	Association along socioeconomic lines and access to bicycle lanes
	Houde et al. (*23*)	Montreal, Longueuil, and Laval, Canada	The effect of bicycle lane expansions on accessibility inequities over 25 years
	Conrow et al. (*42*)	Phoenix, Arizona, U.S.	Equitable locating of BSS stations
	Barajas (*43*)	29 BSSs in U.S.	Equity in access to BSS stations
	Duran et al. (*44*)	Porto Alegre, Recife, Salvador, Sao Paulo, and Rio de Janeiro, Brazil	Equity in access to BSS stations
	Hosford and Winters (*45*)	Vancouver, Hamilton, Toronto, Ottawa-Gatineau, and Montréal, Canada	Equity in access to BSS stations
	Meng and Welch (*46*)	Chicago, U.S.	Equity in access to BSS stations
	Babagoli et al. (*47*)	New York, U.S.	Equity in access to BSS stations over 2 years.
	Qian and Niemeier (*25*)	Chicago and Philadelphia, U.S.	Equity in access to BSS stations
	Braun et al. (*48*)	22 large U.S. cities	Association along socioeconomic lines and access to bicycle lanes over 4 years
	Mooney et al. (*24*)	Seattle, U.S.	Equity of access to bicycles in a DBSS along socio-demographic and economic lines, bicycle locations, bicycle idle time, and rebalancing patterns
	Couch and Smalley (*49*)	73 BSSs and DBSSs in the U.S.	Comparing spatial equity of 73 DBSSs and BSSs
(b) Equitable access to destinations by bicycle	Tucker and Manaugh (*38*)	Rio de Janeiro and Curitiba, Brazil	The impact of bicycle lanes on accessibility of different income level population groups to key destinations
	Barajas (*43*)	29 BSSs in the U.S.	Equity in access to key destinations by using a BSS

(continued)

Table 1. (continued)

Sub-categories	Authors	Study area	Focus of study
	Kent and Karner (*27*)	Baltimore, U.S.	Prioritization of bicycle network projects in relation to equity and investigating the impact of reductions in level of stress experienced by cyclists on improvement of accessibility to some key destinations
	Qian and Niemeier (*25*)	Chicago and Philadelphia, U.S.	Equity in access to key destinations by using a BSS
	Chen et al. (*50*)	Southern Tampa, U.S.	Equity in access to key destinations by using a BSS
	Hamidi (*51*)	Malmo, Sweden	Equity in access to key destinations by using a BSS or private bicycles
(c) Equity issues in cycling policies	Bernatchez et al. (*28*)	Montréal, Canada	Changes in awareness of people about a BSS during a period of 2 years, considering their educational levels and proximity to BSS stations
	Piatkowski et al. (*29*)	Chicago, Cincinnati, Philadelphia, Portland, U.S.	The effect of web-based community engagement in equitable distribution of the BSS stations
	Howland et al. (*30*)	56 BSSs in the U.S.	Equity considerations in BSS projects
	Lam (*31*)	Hackney, UK	Equity considerations in cycling policies
	Rebentisch et al. (*32*)	New York, U.S.	Equity in safety investments considering reported bicycle crash rates

Note: BSS = bicycle sharing system; DBSS = dock-less bicycle sharing system.

population groups and they reported that these population groups experience more inequities related to access to destinations by bicycle.

There are also some studies that focused on specific key destinations. Hamidi examined accessibility by bicycle to major public transport key destinations, including bus and train stations, and found no significant difference in access to transport hubs between native Swedish and immigrant populations (*51*). Also, a study by Kent and Karner discussed prioritized bicycle network projects in Baltimore to improve equity, and investigated the impact of reductions in level of stress experienced by cyclists because of improved accessibility to some key destinations including supermarkets, pharmacies, banks, and libraries (*27*).

Equity Issues in Cycling Policies

As detailed above, most of the studies in the field of cycling equity focused on "accessibility." However, a limited number of studies have examined equity and cycling from a different perspective, including equity in safety investments, public awareness about cycling facilities, and policy views and equity considerations in transport projects. Similar to previous sections, disadvantaged population groups, such as those with lower income and educational levels, usually experienced greater inequity.

For instance, a recent study related to crash rates in cycling and walking in New York revealed that crash rates in lower-income neighborhoods were higher (*32*). This study also found that safety investments were lower in the areas with higher crash rates. Bernatchez et al. found that lower educational levels and lack of a BSS station within walkable distance led to lower awareness of the system (*28*). In spite of an increase in the level of awareness, those with lower levels of education were most unaware of BSS. This study concluded that differences between the levels of awareness did not change even after improvements in accessibility to BSS stations, and that it therefore appears to be a multi-faceted issue. A study in four U.S. cities (Chicago, Cincinnati, Philadelphia, Portland) revealed that locating stations based solely on public participation through a web-based engagement led to inequitable distribution of stations. The outreach of this participatory planning was not fair for minority population groups (*29*).

Several studies focused on policy views and equity considerations based on case studies. Howland et al. assessed equity considerations of 56 BSSs in the U.S. through a survey circulated to each service provider, for the attention of staff capable of responding about their equity policies (*30*). They found that around 25% of studied BSSs and 50% of the schemes with more than 500 bicycles had written equity policies which affect their

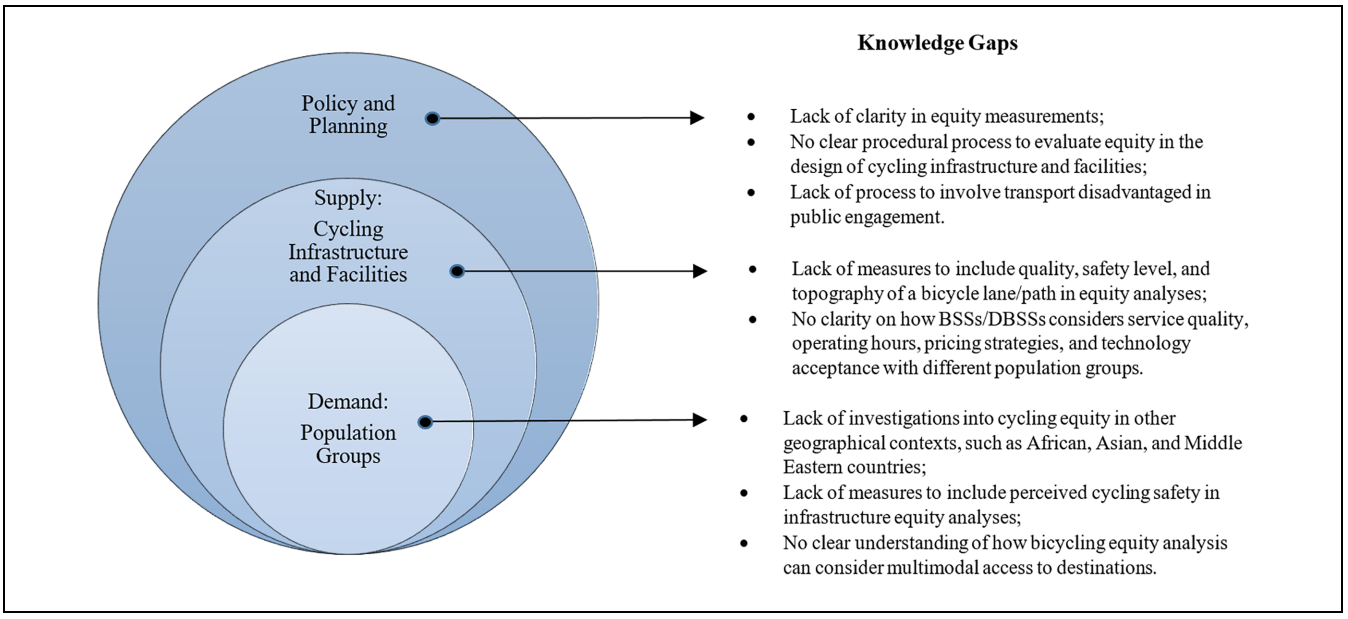

Figure 2. Onion model for bicycling equity.
Note: BSS = bicycle sharing system; DBSS = dock-less bicycle sharing system.

station locating, cost and pricing principles, marketing, and operations. They also found that accessibility and affordability of the systems are the biggest barriers for implementing equitable BSSs. Hosford and Winters showed that inequity in access to BSS stations is associated with the type of organization, in that greater equity was evident in systems operated by non-profit organizations, and greater inequity was evident in privately operated systems (*45*). A qualitative study in the London Borough of Hackney showed that, despite Hackney having a good reputation for bicycle usage rates, the cycling policies did not consider equity for race and gender and that they needed to incorporate the social justice approach more in their planning and policies (*31*).

Knowledge Gaps and Research Challenges

This review has identified some key knowledge gaps and directions for future research. Bicycling equity is a relatively new topic, given that the first paper to address bicycling equity was published in 2009 (*33*). The significance of bicycling equity is rising because of increasing social consciousness and it is increasingly receiving attention in both academia and in practice. The gaps in the literature and research challenges will be discussed within the context of three layers, as shown in Figure 2.

Demand: Population Groups

The first layer of the onion model shown in Figure 2 is related to demand and focuses on the differences between population groups, in relation to socioeconomic characteristics. Bicycling equity is influenced by socioeconomic differences among population groups, such as age, gender, income, ethnicity, and education, and also with respect to their place of residence and destination choices (employment location, places of shopping, etc.). As explained above, this influence of socio-demographic characteristics is not shaped by a single axis of social division and it is the "intersections of them" (the combination of multiple socio-demographic variables) that create differences among different population groups (*18*). Such differences induce different needs with respect to the importance of cycling-related access to destinations, as well as safety concerns. The second layer focuses on the supply side: the provision of more equitable bicycle infrastructure and facilities (because the concept of equity is strongly, but not exclusively, related to the spatial distribution of cycling facilities) and, more importantly, the beneficial effects of these facilities on population groups. It includes bicycle infrastructure, such as bicycle networks, and facilities, such as BSSs, DBSSs, bike shops and bike repair workshops. Because the population, infrastructure, and facilities are spatially distributed in a non-homogeneous way, cycling infrastructure and facilities influence bicycle equity levels. Finally, the third layer focuses on policy and planning with respect to the first two layers. They can influence the first and second layers, through land use planning (location of houses, employment, retail, schools, medical services, etc.), housing policies, and the provision of cycling infrastructure and facilities. Note that the provision of facilities is not

entirely in the hands of the public sector, as the private sector also offers such facilities. For example, the private sector mainly operates BSS and DBSS, bike parking facilities, shops, and repair facilities, and employers sometimes provide bicycle storage and showers.

An initial gap observed is that there is limited understanding of demand from the perspective of certain population groups. All the studies to date have been undertaken in western contexts, predominantly in North America. Consequently, there is a lack of knowledge with respect to bicycling equity in other geographical contexts, such as African and Asian countries. The demand for cycling can be context-specific because of differences in income, and because of cultural and religious reasons. For example, in Mashhad city in Iran, women are not allowed to use BSS programs (*52*).

The impact of the geographical context is not limited to the demand side. The supply side, as well as policy and planning, can also be context-specific. For example, some developing countries may have limited funding for the provision of cycling infrastructure. In addition, safety levels for cyclists can significantly differ between countries and regions. To put it more generally, the extent to which policymakers and planners pay attention to inequity in transportation, and in particular cycling, can influence these context-specific issues. Therefore, studying cycling equity in different geographical contexts presents an opportunity for future research.

There are a limited number of studies on safety concerns related to bicycling inequity. Studies to date have focused on the equitable distribution of safe cycling infrastructure (*32*). In addition, it is necessary to understand different population groups' perceived cycling safety to provide equitable cycling facilities. This is because low levels of perceived safety can be a barrier to cycling for many, and a reason not to allow their children to cycle. Consequently, research into perceived cycling safety should include all population groups, even those who currently do not cycle. A new approach to study perceived cycling safety could be to make use of virtual and augmented reality. Previous studies have shown that it can be successfully implemented in the transport context to evaluate travel behavior (*53, 54*). It could also be used to evaluate perceived levels of safety, and the results used to assess the equitable distribution of safe cycling infrastructure among different population groups.

Most studies have focused on access to bicycle facilities and infrastructure, or accessibility by bicycle from origin to destination. However, only a limited number of studies have focused on cycling as an access and egress mode, to and from public transport hubs. A promising direction for future research, therefore, is to study multimodal access to destinations, combining bicycle and public transport. Finally, studies on access to some destination types, in particular in the areas of health, education, and recreation, are very limited, and future research in these areas is recommended.

Supply: Cycling Infrastructure and Facilities

Although half of the literature on bicycling equity focuses on bicycle infrastructure, these studies were limited to access to infrastructure, and did not consider the specific characteristics of the infrastructure itself (*21, 41*). However, characteristics such as quality, (perceived) safety level, and topography of a bicycle lane or path can also influence a population group's willingness to ride a bicycle (*55, 56*). The perceptions of different population groups in relation to these characteristics are not clearly understood. For instance, vulnerable groups can be more risk-averse and sensitive to the difficulty of riding a bicycle up steep inclines and down steep descents. Therefore, further research is recommended to take into account different population groups' sensitivity and perceptions of safety and topography in the context of bicycling equity.

BSSs and DBSSs are often operated by the private sector. The literature on BSS and DBSS is limited to spatial analyses of stations (in BSS) and bicycles (in DBSS). However, apart from providing equitably distributed BSS stations and bicycles geographically, these systems should also provide BSS services and bicycles that are compatible with different groups of the population in relation to design and service quality. Further research on BSSs/DBSSs is recommended to focus on equity in service quality, operating hours, pricing strategies, and technology acceptance issues, in an attempt to solve service inequity in BSSs and DBSSs. Both the location of such facilities and their payment options could be considered as barriers to accessing BSSs and are potential topics to investigate in future research.

Policy and Planning

Equity measurement indicators such as levels of access to destinations, or facilities, play an important role in policy decision making. Literature on bicycling equity mainly focused on the importance of providing improved accessibility for disadvantaged populations. Some of these studies used measures such as the Gini coefficient as indicators of inequity (*26, 37, 50*). However, to the best of the authors' knowledge, the literature does not provide a tool or methodology to systematically evaluate the distribution of cycling benefits across population groups. This is important, because cities have limited financial resources, and generally work within constrained budgets. Therefore, research is required to develop methods capable of systematically analyzing the impact of policy interventions and the spatial allocation

of infrastructure on the distribution of benefits. Such research should explicitly include the specific needs of population groups. A first step could be a trial of multiple indicators (such as the Gini coefficient, the Theil index, or the Palma Ratio) using case studies, and the evaluation of their advantages and disadvantages. Then, based on the results, methodologies for wider application could be developed.

Considering equity at the early stages of policymaking and planning should result in a more equitable cycling environment by helping to avoid inequity issues at a later stage. The literature mainly focuses on the evaluation of equity considerations in the development of cycling policies by governments and BSS service provision by companies (*30, 31*). However, there is a lack of understanding of the design of such policies. For example, the barriers to including equity in the design process of cycling infrastructure and facilities are not yet clearly understood. Such research is considered an important step forward, to provide guidance for practitioners on how to better include equity in planning activities. Lee et al. stated that procedural equity (which refers to the fairness of decision making) is not yet appropriately considered in bicycling equity research (*5*). Procedural equity in transport planning processes aims for all population groups' demands to be equally heard by policymakers (*6*). While improvement of equity in bicycle infrastructure is commonly undertaken by spatial analysis techniques, addressing procedural equity seems to be more complicated (*27*). The literature on bicycling equity showed that minorities in a community are relatively worse off. It is, therefore, essential that these population groups have a spokesperson in planning and policy decision making. Therefore, local governments are advised to design procedural equity policies that explicitly target minority population groups. In addition, with regards to "Black Lives Matter" and other movements, specific attention could also be given to cycling equity policies to improve antiracism.

Public engagement in cycling policymaking and planning is one of the ways to explore the needs of different population groups. Piatkowski et al. discovered that planning solely based on this method might result in inequity (*29*). This can stem from not all population groups participating. Some people might not participate because of cultural norms, a lack of information and communication technology resources, because of their remote place of residence, being historically underrepresented or dismissed in participatory processes, time constraints on participating in meetings or outreach events, or family/childcare responsibilities. However, knowing the needs of all population groups is important to provide an equitable cycling environment. Although public participation attempts to address this, challenges with representative participation can result in biases in the outcomes. This can be particularly evident in disadvantaged populations. Consequently, further research is required to understand how the population groups that are underrepresented can be persuaded to participate and influence policymaking, which in turn will contribute to improved policy and planning. In addition, to better gather feedback from disadvantaged neighborhoods, strategies such as offering virtual meetings, providing consultancy opportunity directly to disadvantaged communities instead of expecting meeting attendance, providing childcare, ensuring the availability of materials (translated into appropriate languages), and ensuring diverse hiring practices so that planners reflect the communities they serve.

Conclusion

This study provides a review of current and relevant literature on bicycling equity, highlighting the gaps in knowledge, providing recommendations for future studies, and highlighting implications for policy. It shows that the literature mainly considered accessibility, focusing on bicycle infrastructure and BSS. There are also a limited number of studies related to other aspects of bicycling equity, such as safety and policy. The review revealed that, typically, disadvantaged population groups who live in lower-income neighborhoods, often minority population groups, experience more inequity in cycling.

Overall, through a review of the literature on bicycling equity and subsequent identification of the gaps in the literature, it can be concluded that future researchers should focus on the following key topics:

- Developing a better understanding of an equitable cycling environment, by exploring various aspects of cycling such as population needs, usage behavior, and perceived safety.
- Developing equity measures for policymaking that incorporate various aspects of bicycling equity, and evaluating their effectiveness.
- Highlighting barriers to implementing bicycling equity policies in practice.

Providing a comprehensive equitable cycling environment, representing the needs of all population groups, might be problematic because of financial constraints. Therefore, from a policy perspective, it is important to prioritize cycling projects, considering both equity and investment limitations. In addition, services and facilities should preferably be flexible, so that they can adapt to future changes. Finally, policymakers and planners need to better understand the needs of population groups, to facilitate the design of more equitable cycling policies.

Therefore, involving all population groups in participatory planning processes is key. The outcomes can be helpful to design and evaluate options for policies including multiple policy instruments, such as infrastructure and service investments, traffic regulations, and urban planning. Preferably, different governmental levels, ranging from (sub) local, to regional and national, as well as private companies, should collaborate to help develop comprehensive equitable cycling outcomes.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: D. Jahanshahi and S. Chowdhury; data collection: D. Jahanshahi; analysis and interpretation of results: all authors; draft manuscript preparation: all authors. All authors reviewed the results and approved the final version of the manuscript.

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