

DETERMINANTS OF URBAN CYCLING FROM THE PERSPECTIVE OF  
BRONFENBRENNER'S ECOLOGICAL MODEL

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**ABSTRACT**

Purpose: Human behavior is complex, resulting from dynamic person-environment interactions. The study of determinants in an ecological model can be useful to understand this complexity. When it comes to bicycle commuting, previous research has identified several individual and environmental determinants that can influence behaviour and likelihood to cycle. The purpose of this article is to provide an analytical framework integrating the determinants of cycling in an analysis from the perspective of Bronfenbrenner's ecological model.

Methodology: Through a literature review, we select scientific articles that include studies conducted from a variety of cities in the Americas, Europe and Asia.

Findings: As a result, the article presents the determining factors for bicycle commuting in a diagram based on Bronfenbrenner's ecological model.

Research limitation: Further research, which may include a systematic or an umbrella review, could be conducted to confirm the determining factors that influence bicycle commuting in urban areas. In addition, broader work is needed to understand which factors influence the adhesion of shared bicycles and how they fit into the ecological model proposed by Bronfenbrenner.

Originality: Our article provides guidelines for an analytic framework that can be a useful tool in case studies or comparative research on mobility and urbanism.

**KEYWORD:** cycling, factors, determinants, ecological model, Bronfenbrenner.

DETERMINANTES DO CICLISMO URBANO PELA PERSPECTIVA DO  
MODELO ECOLÓGICO DE BRONFENBRENNER**RESUMO**

Objetivo: O comportamento humano é complexo, resultante de interações dinâmicas entre pessoa e ambiente. O estudo dos determinantes em um modelo ecológico pode ser útil para entender essa complexidade. Em se tratando do ciclismo, pesquisas anteriores identificaram vários determinantes individuais e ambientais que podem influenciar o comportamento e a probabilidade de pedalar. O objetivo deste artigo é fornecer uma estrutura analítica integrando os determinantes do ciclismo em uma análise na perspectiva do modelo ecológico de Bronfenbrenner.

Metodologia: Por meio de uma revisão da literatura foram selecionados artigos científicos que incluem estudos realizados em diversas cidades das Américas, Europa e Ásia.

Resultados: O artigo apresenta os fatores determinantes para o deslocamento o ciclismo urbano em um diagrama baseado no modelo ecológico de Bronfenbrenner.

Limitações da pesquisa: Pesquisas adicionais, que podem incluir uma revisão sistemática ou *umbrella review*, poderiam ser realizadas para confirmar os fatores determinantes que influenciam o deslocamento de bicicletas em áreas urbanas. Além disso, é necessário um trabalho mais amplo para entender quais fatores influenciam a adesão das bicicletas compartilhadas e como se enquadram no modelo ecológico proposto por Bronfenbrenner.

Originalidade: O artigo fornece diretrizes para uma estrutura analítica que pode ser uma ferramenta útil em estudos de caso ou pesquisa comparativa sobre mobilidade e urbanismo.

**PALAVRAS-CHAVE:** ciclismo, fatores, determinantes, modelo ecológico, Bronfenbrenner

## 1. INTRODUCTION

Attitudes towards something (a product, an object, a service, a religion, etc.) are formed by a combination of social experiences and cultural influences (Underwood et al., 2014). According to Bronfenbrenner's ecological model (1979), human behavior can vary according to country, time, culture or other factors such as tradition and values. Each of these characteristics can be determinant (i.e. that decides an action or a thing) in the decision making process for a specific group of people, or in a specific place.

The ecological model reflects the complexity of human development and behaviors. The Bronfenbrenner's model is sensitive to the interaction between people and their environment, as a set of dimensions (social, physical, etc.) and levels (personal, family, community, etc.). According to Titze et al. (2008), ecological models can be used to explain the complex range of factors that influence physical activity practices, such as cycling, which emphasizes elements of the environment.

Regarding the choice of transport modes, several personal or environmental characteristics can be crucial in the decision making process. Individuals can have a behavior of inertia, that is, very difficult to change, even when they are exposed to an intervention or an action to promote a new means of transportation (Heinen et al., 2017). In addition, each person assigns a different weight or value to each determinant factor.

Commuting behaviors can be linked to costs, time, safety and environmental concerns (Wang et al., 2015). For example, bicycle commuting depends on climate, topography and public policies such as shared bicycle systems and infrastructure (Fuller et al., 2011; Cole-Hunter et al., 2015). Likewise, extreme weather conditions, the need to transport objects and the destination accessibility can be decisive for choosing the bicycle (Wang et al., 2015). Population density, diversity of land use (e.g. residences, shops and others), traffic and public safety, access to public transportation and employment are also determining factors for bicycle's choice (Sun et al., 2017).

Determining factors can have a positive or negative influence on behavior. For example, organized civil society groups have a positive impact on increasing the number of cyclists (Rosas-Satizábal and Rodríguez-Valencia, 2019) as they give a sense of belonging and community. On the other hand, if cycling is not socially normalized in a community, teenagers are less likely to accept it (Underwood et al., 2014). Parents' values are also important. If parents have values that undermines the importance of physical activities, their children tend to walk and cycle less to go to school (Stewart et al., 2012).

There are still few studies that explore how the interactions between these environmental and social determinants affect cycling. Therefore, the aim of this article is to provide an analytic framework based on Bronfenbrenner's model to provide some guidelines for the use of this framework in different urban contexts, for example, within the scope of comparative studies.

After the introduction, the article presents briefly describes the ecological model developed by Bronfenbrenner and the systems of influence on human behavior. Section 3 presents the methodology and section 4 the literature review with the main determining factors for cycling. Then section 5 presents the results of the article, where each determining factor for cycling was allocated to one or more systems of the ecological model and presented in the form of a diagram. Finally, section 6 presents the conclusions, recommendations and the research limits.

## 2. BRONFENBRENNER'S ECOLOGICAL MODEL

The ecology of human development is the study of progressive interactions between a person and the changing properties of the systems in which that person lives. In addition, the model takes into account that this process is also affected by the relations between the systems (Bronfenbrenner, 1979). From this perspective, human development, including preferences,

behaviors and values, is affected by several environmental factors that are constantly evolving. These factors can affect the individual at different levels, or through different systems. Some of them have immediate influence, such as family relationships, and others have a broader influence, such as culture.

The ecological model aims to go far beyond the immediate situation that affects directly the person and seeks to understand the wider environment to which they respond and the people with whom they interact. Briefly, Bronfenbrenner's ecological model integrates different systems (Bronfenbrenner, 1979):

- **Microsystem:** a set of activities, roles and interpersonal relationships experienced by the person in a given framework of face-to-face relationships, such as home, school and family.
- **Mesosystem:** a system of microsystems. These are the interactions between contexts in which the person actively participates, such as work, school, neighborhood, etc.
- **Exosystem:** refers to one or more frameworks that do not involve the person as an active participant, but in which events affect what happens in the frame containing the person (e.g. activities of friends or relatives, community activities, public policies in the city, etc.).
- **Macrosystem:** refers to the form and content of micro, meso and exosystems. This exists at the level of culture as a whole, including belief systems, traditions, values and ideologies.

This article aims to identify the main environmental determinants that influence bicycle commuting from an ecologic perspective. Thus, the identified determinants will be allocated in one or more of the systems proposed by Bronfenbrenner.

### **3. METHODOLOGY**

The articles were selected through a research on Science Direct and Google Scholar portals. The searches were made from a combination of the following keywords: bicycle, factors, determinants and cycling. The surveys were conducted in English, Portuguese and French. In the first search, 14 articles were selected and from reading these, other articles, books and studies were added by hand searching. The articles include studies from several cities in countries like Australia, Brazil, Canada, China, Colombia, Spain and the United States.

The most cited factors affecting cycling in the selected articles, or those indicated by the authors as being of great importance, were identified, classified and included in the model. Following the data analysis, each determining factor was assigned in one or more systems of the Bronfenbrenner's model (micro, meso, exo and macrosystems), resulting in a summary model in the form of a figure. Then, a second researcher validated the findings and the disagreements were discussed among the authors.

### **4. LITERATURE REVIEW: CYCLING DETERMINANTS**

Human behavior is complex and heterogeneous, as it can vary depending on several factors. The individual decision-making process is a mix of real factors and the appreciation of these factors (Cole-Hunter et al., 2015). When it comes to choosing a means of transportation, a combination of factors can be decisive for a particular person in the context of a particular place. Given this complexity, several authors have studied the factors that influence positively or negatively bicycle

commuting. In general, factors influencing individual's choice can be classified into two main groups (Goldsmith, 1992):

- Subjective: factors that are linked to non-measurable conditions and vary according to individual perceptions and needs.
- Objective: physical factors that exist for everyone, even though the appreciation of these factors may differ for each individual.

Goldsmith (1992) classifies valuation of exercise, habits, group and family acceptance, values, cost, and convenience as subjective factors. The author also classifies distance, traffic safety and time as subjective factors for individual choice to bicycle as the perception of them can vary from person to person. On the other hand, according to the author, climate, topography, infrastructure characteristics, transportation alternatives can be classified as objective factors. However, as will be discussed in section 4.3, more recent studies point to a subjective character in the perception of climate and relief.

Socio-economic factors, such as age, gender, physical ability, cycling habit, income, etc., are also important in the decision-making process. It is important to highlight that several subjective factors (such as the perception or appreciation of comfort, temperature, travel time and social acceptance) may vary depending on socio-economic factors. These socio-economic factors play an important role in the formation of positive attitudes towards cycling (Underwood et al., 2014).

#### **4.1. Built environment**

The built environment is the set of elements that have been built by human action, such as roads, buildings, stores, green spaces, schools, etc. These elements can be facilitators or obstacles to cycling. Using Bronfenbrenner's model as a reference, built environment elements would be on the meso and the exosystems.

For Titze et al. (2008), for example, the features of functionality, safety, aesthetics and destination characteristics provided the conceptual framework for assessing the built environment in Graz, Austria. In Washington, Buehler (2012) examined the role of bicycle and car parking and the benefits of public transit as determinants of cycling.

In China, Zhao's research (2014) focused on three main characteristics of the built environment: urban form (density, distance, etc.), transport system (public transport, shared bikes, etc.) and design (neighborhood size, street connectivity, land use, etc.). It has shown that the diversity of land use and the destination accessibility are the most powerful built environment factors influencing individual choice to bicycle in some Chinese cities.

These elements (urban form, transport system and design) can be crucial in individual choice. Characteristics like maximum speed and presence of cycle paths, can be decisive for traffic safety and support (or discourage) active transport. For example, when a person lives in a neighborhood with many crossings on a main road, it is less likely that they will choose to commute by bicycle (Zhao, 2014; Ma et al., 2021), since a large number of intersections or the high speed of cars can threaten cyclists.

Scattered cities can have almost prohibitive travel distances for biking. Long distance travel is strongly and frequently associated with less walking and cycling to school (Stewart et al., 2012). In most Dutch cities, where the bicycle is widely used, cyclists travel short distances: around 36% of all bicycle-commuting distances are smaller than 5 km (Xavier et al., 2009). In Brazil, people who live in very small cities, which therefore have short travel distances, use the bicycle extensively for various reasons that go beyond commuting: such as taxi, delivery, ambulance and firefighters (Soares and Guth, 2019).

In some European countries an average of 50% of all car journeys are shorter than 5 km (Titze et al., 2008). The same scenario can be observed in large Brazilian cities where around 30% of car journeys are made over distances shorter than 5 km (Viola, 2016). One of the reasons that many short daily trips are made by car is the urban design, as a large number of intersections or the high speed of cars can threaten cyclists and pedestrians. When a person lives in an area with a greater number of crossings on a main road, it is less likely that they will choose to commute by bicycle (Zhao, 2014).

Thus, public policies related to cycling facilities should be integrated with vehicle traffic management policies, for example setting speed limits (Zhao, 2014). Features related to the built environment, such as high speed streets and lack of facilities for cyclists, can contribute to parents' fears about child independent commuting (Stewart et al., 2012). For example, in neighborhoods with mixed land use, dense and very connected to other destinations, children are more likely to walk or cycle to school (Stewart et al., 2012).

Beyond urban form and design, public policies aimed at encouraging the use of transit and cycling, or even at discouraging the use of the car, can also be determining factors in the choice of the person. In Barcelona the number of shared bicycle stations close to home had a positive influence on cycling (Cole-Hunter et al., 2015). In Chicago (the United States), the use of shared bikes is higher in places with high residential density and employment rates (Sun et al., 2017). Similarly, the research made by Faghih-Imani et al. (2014) in Montreal (Canada), showed that population density, the number of restaurants, the number of commercial enterprises and proximity to universities were decisive for the use of shared bikes systems. Despite that, further research is needed to understand the extent of the influence of shared bicycle availability on cycling.

Built environment determinants are diverse and individual valuation of these determinants can vary by neighborhood and city. Among elements cited, the presence of cycle paths is perhaps one of the most important. The influence of cycling infrastructure on individual behavior will be discussed below.

## 4.2. Infrastructure

By influencing commuting times, convenience, safety and comfort, the infrastructure characteristics (e.g. width, paving, connectivity, etc.) have a direct influence on individual choice to bicycle (Cole-Hunter et al., 2015). In Bronfenbrenner's model, bicycle facilities, such as cycle paths, would be on the macro and exosystem.

Cycling infrastructure can potentially increase cycling rates, thus encouraging more people to choose the bicycle as a means of transport (Amiri and Sadeghpour, 2015). Usually the association is simple: the more cycle paths, the more cyclists (Pucher and Buehler, 2012; Amiri and Sadeghpour, 2015) and the more cyclists there are the more attractive cycling will be for everyone (Wang et al., 2015).

The infrastructure encourages both use of private bikes and shared bike systems (Faghih-Imani et al., 2014; Sun et al., 2017). For example, in Belo Horizonte, Brazil, the counting carried out on a street where there was a cycle path in 2010, shows a decrease of 37% in the number of cyclists on this street in 2016, when this cycle path no longer existed. Yet, there was a 380% increase in the number of cyclists on another avenue when a cycle path was installed (Campos, 2016).

If the presence of cycle paths encourages cycling, their absence can be an obstacle depending on the context and the conditions of coexistence of street users. Lack of cycling infrastructure and the perceived risk of collision with cars usually are major concerns for cyclists, regardless of their bicycle experience (Pucher and Buehler, 2012; Fishman et al., 2013; Viola 2016).

Although cycling infrastructure is an important factor in attracting cyclists, it is not the only factor (Wang et al., 2015). In Chinese cities, for example, factors of accessibility to destinations and traffic safety are more decisive than the presence of cycle paths (Zhao, 2014). Researchers conducted by Titze et al. (2008) in Austria, and Heinen et al. (2017) in the United Kingdom, found no association between the attractiveness of cycling infrastructure and cycling. Moreover, Rowangould and Tayarani (2016) found that about 75% of cyclists in Albuquerque, United States, would continue to bike even if the cycling infrastructure did not exist.

The relative importance of cycling infrastructure as a factor influencing cycling can be explained by the broader cycling culture already established in many places. The widespread use of bicycles as a means of transportation, with or without specific infrastructure, is possible thanks to decades of public policies promoting the bicycle, as is the case in Amsterdam, Bogota, Davis, among others (Pucher and Buehler, 2012; Rosas-Satizábal and Rodríguez-Valencia, 2019).

### **4.3. Topography and climate**

Studies show that cycling is highly dependent on weather conditions, particularly temperature (Amiri and Sadeghpour, 2015). Weather conditions have been reported as either a barrier or a facilitator for cycling and walking (Stewart et al., 2012). Generally, the number of cyclists increases with higher temperatures on sunny days and, on the contrary, rainy or snow days can be less attractive to cyclists (Amiri and Sadeghpour, 2015).

The weather was one of the three most important factors for about 80% of cyclists in Ohio, United States (Wang et al., 2015). According to Rosas-Satizábal and Rodríguez-Valencia (2019) one of the reasons for the success of cycling in Bogota, Colombia, is that the city has favorable conditions with a cool climate, no snow or extreme heat. In Montreal, Canada, people are less likely to cycle in rainy or very humid weather (Faghieh-Imani et al., 2014). However, still in Canada, in Calgary, some cyclists indicated that they ride their bike regardless of low winter temperatures (Amiri and Sadeghpour, 2015).

Finally, topography and slope can be perceived as an obstacle to cycling. The slope was indicated as the minor factor on individual choice of the route among Brazilian cyclists interviewed by Segadilha and Sanches (2014). Even if the slope is an important factor, this result is consistent with scientific literature that shows that generally this factor is not an important determinant for the choice to bike (Viola, 2016; Sousa and Penha-Sanches, 2019). Besides that, with the assisted electric bikes becoming more common in urban areas, the impact of the topography and slope as a determinant factor may decrease.

Climate and topography can also be important factors in transportation choice. Climate and topography are on the exosystem in Bronfenbrenner's model.

### **4.4. Age and gender**

The perception or valuation of some factors, for instance, distance, traffic safety, comfort, travel time, etc., can vary according to age, gender and place of residence. Factors that vary with place, age and gender can be found in any of the systems.

Women are less likely to cycle in Calgary, Canada (Amiri and Sadeghpour, 2015), in Ohio, United States (Wang et al., 2015), in Graz, Austria (Titze et al., 2008), in Washington, United States (Buehler, 2012), in São Paulo and Belo Horizonte, Brazil (Lemos et al., 2017; Viola, 2016) and in Barcelona, Spain (Cole-Hunter et al., 2015). The cycling rates contrast for men and women can be explained in part by the gender differences in cycling safety perceptions (Emond et al., 2009).

Likewise, age has a significant influence on cycling. Underwood and colleagues (2014) explain that the low rate of adult cycling in the United States may be due in part to unpleasant childhood cycling experiences. In general, those who cycled in high school are much more likely to cycle as adults (Pucher and Buehler, 2012; Underwood et al., 2014; Ferraz et al., 2017).

Young girls usually have a less positive attitude towards cycling than boys and the culture can negatively affect the percentage of women and girls who ride a bicycle (Underwood et al., 2014). Similarly, the research conducted by Emond et al. (2009) in six small cities in the United States shows that age is a determining factor for women where the older the respondent was, the less likely she was to ride a bicycle.

#### **4.5. Cost and time**

The bicycle has many advantages, and compared to the car, its cost is much lower. Various studies show that a car driver who starts to use a bicycle can save time and money (Pucher and Buehler, 2012). The bicycle is faster than the car in urban centers and this advantage can be a great motivation for cycling, even more relevant than the health and environmental benefits (Tranter, 2012).

Among the advantages of cycling, there is the cost, the facility of parking and the freedom from limited public transit schedules (Underwood et al., 2014). When it comes to bicycle sharing systems it can be even more convenient because individuals can use the service without having the costs and responsibilities associated with owning a bicycle (Faghih-Imani et al., 2014).

As mentioned earlier, income can be a determining factor in choosing how to commute. Often the affordability of a private car, public transport fares or a bicycle can be what determines the choice of mode of transport. A research conducted by Dill and Voros in Portland (2007) shows, for example, that those with the highest incomes were less likely to use the bicycle for transport. This may indicate a perception of the convenience of the car as a means of transportation and of seeing the bicycle only as a leisure activity (Viola, 2016).

Costs of using the car or public transit can be underestimated since "the cost of time", as a subjective perception, is rarely taken into account. Not only can cyclists save time on urban journeys, but also cities that invest in bicycle promotion policies can become "faster" and save more financial resources, as the cost of cycle paths is much lower than in other road infrastructures (Tranter, 2012). In Bronfenbrenner's model, cost would be on the meso and microsystem, and time would be on the exo and microsystem.

### **5. RESULTS**

Many factors can influence objectively or subjectively individual choice to bicycle in different levels (e.g. social, economic, neighborhood, city, family, etc.). Other determinants are important even though they are not widely addressed in the literature, such as vehicle traffic, pollution, risk of accidents, etc. Road hierarchy and the number of vehicles on the streets can be decisive for the practice of cycling. According to Zhao (2014), traffic insecurity and air pollution are important factors that reduce the use of bicycles for commuting.

The risk of accidents and crime also influence the choice of bicycle. A large number of violent crimes tend to reduce the use of bicycles (Sun et al., 2017) and the greater the concern for safety, the lower the probability of choosing the bicycle (Wang et al., 2015). However, concerns about crime may be based more on social norms than on real risks (Stewart et al., 2012).

Age had an important relationship to cycling safety concerns in Calgary (Amiri and Sadeghpour, 2015). Parents' concerns about trafficking or criminal danger are normally significantly associated with children's cycling (Stewart et al., 2012). Parents' fears may also

explain the correlation that girls are less likely to go to school on foot or by bicycle, once they tend to be more protected from the outside world than boys (Stewart et al., 2012).

Although public and traffic safety are measurable and objective factors, individuals can perceive them differently, depending on age, gender and social norms. These factors and others such as group acceptance and values, distance and environmental concerns can also be classified into more than one of the Bronfenbrenner's systems.

Finally, certain attributes of the built environment have been less systematically treated in the existing literature, such as the presence of green spaces and noise (Cole-Hunter et al., 2015). Other factors such as air pollution, environmental concerns, educational level, social status and physical capacity can be decisive in the choice of bicycle and require further research.

### 5.1. Ecological model for cycling determinant factors

Figure 1 represents the ecological model for the factors found in this literature review that can influence individual choice to bicycle.

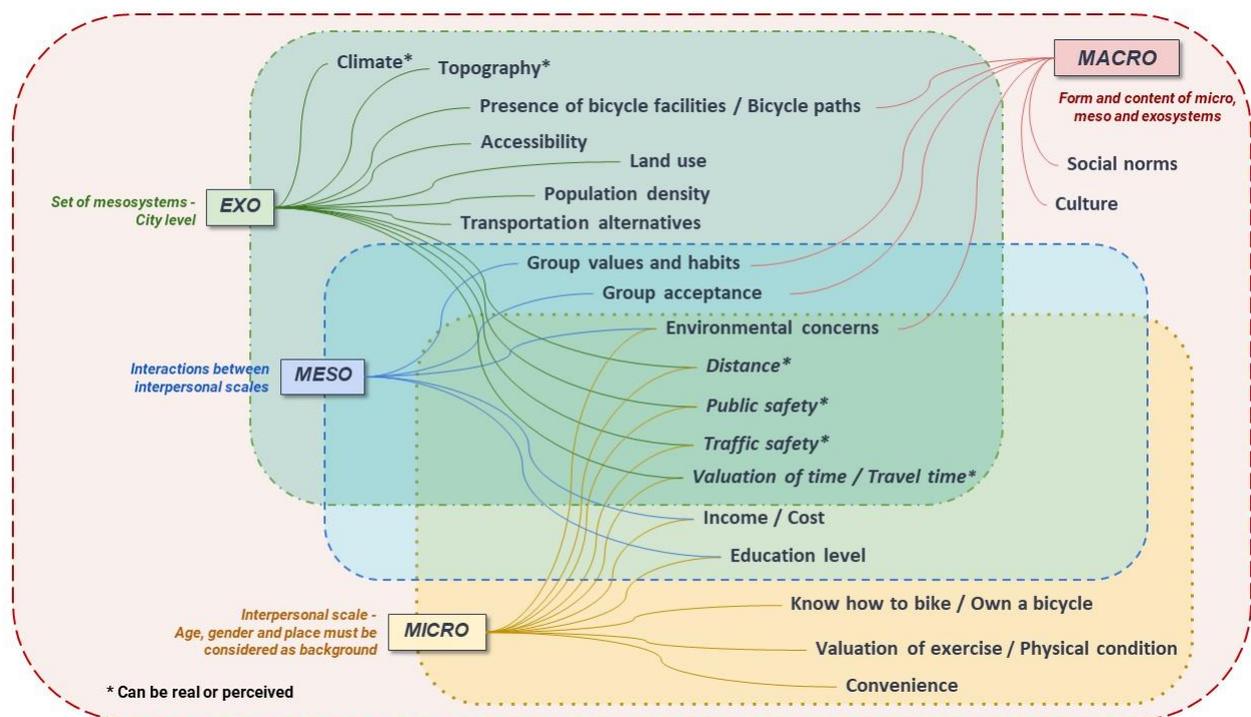


Figure 1: Ecological model for determinant factors influencing individual choice to bicycle

In the microsystem are factors that depend mainly on personal preferences and / or interpersonal scale, such as immediate family (parents, siblings, etc.) and the environment in which these relationships take place (home, school, college, etc.). Bicycle ownership, knowing how to bike, physical condition, valuation of exercise and convenience are in the microsystem. It is important to emphasize that age, gender and place must be considered in the analysis of microsystem factors.

Income, cost, environmental concerns and education level are in both microsystem and mesosystem as these factors are also influenced by the interactions between the interpersonal scales. The mesosystem is formed by the interactions between contexts in which the person actively participates (work, neighborhood, etc.). The educational level can be influenced, for example, by professional ambitions stimulated by co-workers or by the type and quality of educational institutions available in the neighborhood where the person lives or was raised. In the mesosystem, it is also found group acceptance, values and habits.

Other microsystem factors are traffic safety, public safety, valuation of time, time travel and distance. These ones are also in the exosystem and can be real or perceived, characteristics that will be described below. The exosystem refers to one or more local frameworks that do not involve the person directly, such as friends or relatives work and activities, public policies, community activities in city level, etc. In this case, transportation alternatives, population density, presence of bicycle paths and cycling facilities, accessibility, topography, land use and climate are exosystem's factors.

The macrosystem is a set containing all the other systems. This system includes culture, social norms, group acceptance, values and habits, and environmental concerns. The presence of bicycle facilities (restrooms, bike racks, shared bike stations, etc.) or bicycle paths is a macrosystem factor as well. As explained before, the influence of bicycle paths presence or absence can vary according to the local cycling culture.

Finally, some determinants, such as traffic and public safety, distance, time, topography and climate can be real or perceived. These factors are objectively real and measurable, yet they can be perceived differently, depending on the person's background. For example, the distance between two points can be the shortest path measured in kilometers and time can be measurable in minutes, however, the evaluation of these factors is different from person to person. Lastly, as previously described, women, parents and children have perceptions of risk (traffic and public safety) that may differ, or not, from real accident or crime data.

## 6. CONCLUSION

The studies consulted for this paper show that cycling determinants are not universal; they vary from place and individual appreciation. Individual attitudes towards the bicycle are strongly linked to cultural norms, to the image of the cyclist and to the social support of cycling (Titze et al., 2008; Underwood et al., 2014). Age, education, gender, nationality, ability to exercise, among others, have a significant influence on attitudes and the propensity to ride a bike (Cole-Hunter et al., 2015).

In addition, many environmental factors have shown to be of great influence for cycling, such as the presence of infrastructure and facilities for cyclists, risk of accidents, distance, urban form and density, availability of other means of transportation, cost, among others. It is interesting to note that some factors can be objective and / or subjective, that is, they can have a real measure or an importance that varies according to the perception of each individual, as is the case of traffic and public safety, climate, time, distance and relief.

As each individual has a different perception of cycling, each city has its own geographic, economic and cultural characteristics. In order to understand cycling determinants it is necessary to look at each city case individually. Perhaps one of the most common mistakes is to ignore the perception of people from different places regarding transport issues, and more specifically, regarding cycling infrastructure (Rosas-Satizábal and Rodríguez-Valencia, 2019). Therefore, a better understanding of cyclists' perception in different cities is an opportunity to develop comparative urban research and is essential for the development of effective public policies.

Despite a good range of factors selected in this study, further research, which may include a systematic or an umbrella review, could be conducted to confirm the determining factors that influence bicycle commuting in urban areas. Furthermore, broader work is needed to understand which factors influence the adhesion of shared bicycles and how they fit into the ecological model proposed by Bronfenbrenner.

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## DECLARATION OF CONTRIBUTIONS TO THE ARTICLE - CRediT

ROLE	PViola	JTorres	LCardoso
Conceptualization – Ideas; formulation or evolution of overarching research goals and aims.	x	x	x
Data curation – Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later re-use.	x		
Formal analysis – Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data.			
Funding acquisition - Acquisition of the financial support for the project leading to this publication.			
Investigation – Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection.	x		
Methodology – Development or design of methodology; creation of models.	x	x	
Project administration – Management and coordination responsibility for the research activity planning and execution.	x		
Resources – Provision of study materials, reagents, materials, patients, laboratory samples, animals, instrumentation, computing resources, or other analysis tools.			
Software – Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code components.			
Supervision – Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team.		x	x
Validation – Verification, whether as a part of the activity or separate, of the overall replication/reproducibility of results/experiments and other research outputs.		x	x
Visualization – Preparation, creation and/or presentation of the published work, specifically visualization/data presentation.	x		
Writing – original draft – Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation).	x		
Writing – review & editing – Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre- or post-publication stages.		x	x