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Perceptions of potential cycling infrastructure in a low-cycling context: Evidence from a medium-sized urban area

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ABSTRACT

A key factor for the use of bicycles for transportation is the presence of safe and pleasant infrastructure. While research mostly focuses on large cities, cycling infrastructure and use are still incipient in many small and medium-sized cities. Because of their spatial context and very low and demographically uneven cycle use, it is key to understand how the potential of growing infrastructure is perceived among the general population, as well as how these perceptions differ based on personal characteristics. We focus on Camp de Tarragona (Catalonia, Spain), a polycentric urban area where bicycles are used for transportation for less than 1% of trips, and where local authorities have shown renewed interest in expanding and improving the current infrastructure to increase bicycle usage. We examine the perception of residents in the study area regarding various bicycle infrastructure scenarios through a visual preference analysis using photo evaluation. The representative survey was conducted with over 1,000 individuals in 2022, which demonstrates a widespread willingness to cycle as a means of transportation. However, this desire remains unmet due to inadequate infrastructure and an urban configuration that generally discourages cycling. The results show a need for recognizable, safe and segregated cycling infrastructure, though with differing perceptions between gender and age groups and between levels of urban density. The understanding of diverse sociodemographic nuances in the preferences of non-cyclists emerges as vital for promoting cycling as a feasible and socially inclusive transportation choice, highlighting the importance of tailored infrastructure to encourage cycling and enhance accessibility.

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Active mobility; cycling; perception; transport equity; visual preference survey

1. Introduction

Recent urban policies and academic research agree that increased cycling mobility offers a solution for urban environmental issues, safer traffic, and healthier lifestyles. However, the reality is that considerable segments of urban populations do not currently cycle because of individual or built environment-related barriers. Outside of select countries and cities, the modal share of cycling does not often reach more than 1–2%. Despite this situation, more and more cities are focusing on the creation and upgrading of cycling infrastructure to meet gradually growing demands. However, it is not always clear where this demand comes from: more cycling does not necessarily converge the uptake differences between demographic groups. For example, the characteristics of those cycling tend to be socially unequal in terms of gender (Aldred et al., 2016; Garrard et al., 2008), age (Cavill & Davis, 2021; Garrard et al., 2021), and ethnicity (Braun et al., 2021; Crossa et al., 2022). Typically, in places with a low use of cycling as form of everyday transport, between two-thirds and three-quarters of the cycling population consists of men (Goel et al., 2022).

While arguably, the *end goal* of mobility is the facilitation of people with access to all destinations, regardless the travel mode, there is ample scope to position cycling more centrally within transitions toward more sustainable travel and as part of more healthy and socially equitable mobility futures (Arsenio et al., 2016; Sagaris & Tiznado-Aitken, 2023). From an environmental point of view, in addition, it is especially important to attract current non-cyclists to cycling because of the significantly higher mobility-related emission levels they produce (Brand et al., 2021). Therefore, we develop the argument that cycling research would benefit from a stronger focus on non-cyclists, particularly in cities with low cycling use. We propose to do this along the concept of cycling equity and by focusing on the perceptions of the general population in a polycentric urban area of smaller cities.

In theory, smaller cities are fertile grounds for cycling as a mode of transportation. They are variously characterized by shorter distances, lower road traffic densities, lower public transport service levels, and lower municipal budgets (Handy et al., 2012). These features would point to the suitability of a human-scale, granular, and relatively cheap

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mobility system centered around active mobility. Even so, smaller and medium-sized towns are also at greater risk of car dependency due to socio-technical provision aspects that usually exceed the remits or capacities of local authorities (Hodson et al., 2018; Mattioli et al., 2020). We mobilize this contradiction to understand the infrastructural features that would be needed for socially inclusive and equitably distributed cycling mobility in precisely those areas. Our focus on a polycentric urban area of smaller cities also aims to fill the need for research on those currently not cycling and the availability of data on functional urban areas instead of single cities (Nelson et al., 2021).

Therefore, in this article we examine both the potential role that infrastructure may have in increasing cycling in the region, as well as the perceptions around the different infrastructural elements across sociodemographic characteristics of residents. Based on the literature reviewed, we consider infrastructural elements such as the forms of separation and demarcation of cycling spaces, their circulation characteristics and width, as well as external environmental elements such as traffic speed, the presence of shade from the built or natural environment; all of which are valued as key for an inclusive infrastructure (Aldred & Dales, 2017; Garrard et al., 2008; Zacharias & Zhang, 2016). We develop this approach based on recent studies on cycling equity, which examine the infrastructural and built environment elements that would improve cycling access in a small-to-medium-sized urban area in a spatially and socially inclusive way.

We now continue to outline the existing knowledge on infrastructural design in low-cycling contexts, cycling adoption and socio-demographic variations, and cycling equity (Section 2). In Section 3, we introduce the case study characteristics, the survey content, and the analytical approach toward the evaluation of visual preference surveys and cycling perceptions. In Section 4, we present the results of the evaluation and of a regression analysis of the possible relationships with sociodemographic and mobility-related factors. In Section 5, we interpret the results and interpret in the context of the understanding of cycling potential in smaller urban areas.

2. Background

2.1. Cycling infrastructure in low-cycling contexts

A key factor to support cycling as a mode of transport is the existence of safe, direct, and convenient infrastructure. The most prominent design approaches to the requirements for such infrastructure have a strong focus on perceived safety and separation from other travel modes (Gössling & McRae, 2022). Both the Sustainable Safety principle (Wegman & Aarts, 2005) and the design manuals for cycling infrastructure (CROW, 2016) have been developed in the Netherlands, a quintessentially high-cycling context. These guidelines have been applied in various international contexts, often adapting them to the local context or developing variants (Buehler & Goel, 2022). In Spain, for instance, the national Ministry of Transport recently published a guide with design principles for cycling infrastructure (Ministerio de Transportes, Movilidad y Agenda Urbana, 2023). Although it was received positively, various design standards indicate that cycling facilities should foremostly not interfere with existing facilities for motorized vehicles. This framing goes against the insights that creating spaces for cycling should be accompanied by disincentivising the use of motorized vehicles (Nello-Deakin, 2020) and should enhance social safety (Xie & Spinney, 2018).

What is more, in low-cycling contexts, the existence of cycling infrastructure is a first necessity, but not a sufficient condition. While total cycling uptake may increase due to infrastructural improvement, it is unlikely that representation among demographic groups will improve (Aldred et al., 2017; Dill & McNeil, 2013). Given the low and uneven cycling adoption, it can be deduced that the infrastructures provided in low-cycling contexts are unsuitable for a wide range of social groups. For instance, a range of studies indicate that there is no singular cyclist or cycling experience this infrastructure should be premised on, and contend that the variety of potential users, vehicles, trips, and socio-relational behaviors creates a plurality of cycling in urban spaces (Cox & Koglin, 2020; Garrard et al., 2008; Lam, 2022; Soliz, 2021; Spinney, 2009). When setting the criteria to start building cycling infrastructures, such as in this paper, it is thus critical to understand how different typologies of infrastructure are perceived and may lead to cycling adoption. Dissecting these typologies and perceptions by demographic groups is similarly imperative, given the socially inequitable uptake of cycling found in places with a low modal cycling share and places with low but increasing shares (Félix et al., 2019).

2.2. Cycling adoption and preferences

There are various reasons why cycling adoption persistently differs between different social groups, of which we discuss three. First, initial cycling infrastructure is often built to meet labor mobility demands, which is seen as a productive way to attract a substantial 'critical mass' of cyclists. However, men in low-cycling contexts are already more likely than women to undertake cycle commutes while a primary network facilitating linear movements between home and workplace overlooks the possibility of making trip combinations, which often involve more dispersed and plural trips and are more common among women, children, and older people (Beecham & Wood, 2014; Steinbach et al., 2011; Xie & Spinney, 2018). Second, and related, most urban contexts have lower cycling adoption among both old and young people. Several studies show that these groups are more risk averse, alluding to the danger associated with cycling in low-cycling cities, or do not have the same cycling experience or physical strength as young-to-middle aged people to cycle under such circumstances (Aldred et al., 2017; Van Cauwenberg et al., 2019). In addition, they may prefer or need to cycle in company, which is further complicated when infrastructures are unsafe or incomplete (McDonald, 2012). For older people, interactions with pedestrians and other cyclists in cycling spaces may also increase safety concerns (Winters, Sims-Gould, et al., 2015). Third, the link between cycling and current urban dynamics is of increasing concern in cycling literature. The creation of greener and environmentally friendlier cities and urban mobilities may stimulate inequalities related to the placement of cycling infrastructure. Concurrent investments in cycling and wider urban redevelopment, for instance, present a sustainable urban lifestyle that attracts mainly high-income people of working age (Oscilowicz et al., 2022; Stehlin, 2015). Similarly, recent facilities such as sharing systems may favor the cycling of people from privileged backgrounds such as white, higher educated and higher income groups (Crossa et al., 2022).

Following these variations in cycling adoption, we understand that urban environments contain barriers to cycling that differ according to personal perceptions and characteristics, infrastructural features, and the wider urban structure (Aldred et al., 2017; Félix et al., 2019). Félix et al. (2019), examining the first two, define its physical effort, the lack of safe cycling network, and bike ownership as the main barriers for people currently not cycling. Contrarily, triggers to start cycling are formed by the existence of cycling facilities, (access to) an extensive cycling network or a bike-sharing system, (e-)bike ownership, integration with public transport, and home storage. The surrounding urban structure, furthermore, may further stimulate cycling, for instance through the presence of tree shade, traffic speed, the presence of urban amenities, and a high urban density (Nello-Deakin, 2020; Zacharias & Zhang, 2016). Based on a visual preferences survey, (Aldred & Dales, 2017) even identify light infrastructural elements (*armadillos*, painted lines, buffer zones) and heavier separators (planters, rails, curbs) as beneficial for a more inclusive cycling uptake. A last factor that may increase the motivation to cycle is its attractiveness as a pleasant activity. This esthetic dimension includes the reception of positive visible, audible and olfactory stimuli while cycling (Stefansdottir, 2014).

Marqués et al. (2015), for the case of Seville (Spain), outlines the network design criteria to meet this set of cycling requirements. The main characteristics of it's a cycling network are that of continuity and connectivity, cohesion and homogeneity, directness and visibility, and comfort. The criteria for the cycle lanes themselves are segregation from motorized traffic, bi-directional and wide, uniform in terms of paving and signposting, and located between the lanes for motorized traffic and the pedestrian zone (Marqués et al., 2015). Besides cycle lane infrastructures, other authors point to the need for adequate parking facilities are essential to connect different destinations (Aldred & Jungnickel, 2013), the availability of diverse bike types, the possibility to acquire or improve cycling skills, and the perception that cycling is feasible and 'normal' as everyday mobility option. This can for instance be stimulated by moving away from presenting cycling as a sporty activity, communicating its utility purposes, and by integrating planning instruments and policies in education, road safety, health, and infrastructural planning (Anaya-Boig, 2021; Goodman et al., 2014).

2.3. Equity and cycling

The concept of cycling equity has been frequently adopted to highlight the gender and age dimensions of cycling uptake and infrastructural preferences across social groups and trip purposes (Aldred et al., 2016, 2017; Goodman & Aldred, 2018). For example, there is widespread and long-standing agreement that separation from motorized traffic is more important for women and older people, although the general cycling population would also welcome the safety of greater modal segregation (Aldred et al., 2017; Garrard et al., 2008). Most recently, studies from North America and Europe have shed further light on cycling equity as a concept to further understand the distributive effects of safe and convenient cycling facilities (Doran et al., 2021; Hudde, 2023; Ravensbergen et al., 2024).

The social stratifications of cycling and perceptions on cycling leads various scholars to argue that cycling facilities should not just be part of well-intended sustainable transportation plans, but rather aim for a redistributive mobility equity (Arsenio et al., 2016; Doran et al., 2021; Sosa López, 2021). If not, fragmented cycling interventions may increase socio-spatial inequalities, especially in rapidly urbanizing places with increasing motorized traffic uptake (Soliz, 2021). Similarly, in a Western European context, it is found that cycling promotion may not improve cycling equity if differences in educational levels are not overcome (Hudde, 2023). Finally, the association between cycling and risk aversity (Section 2.2) and the differences in safety subjectivity create the expectation that the journey toward 'safety in numbers' will always be exclusive to some population groups (Gössling & McRae, 2022). In this sense, it is helpful to envision future cycling interventions to promote equity through "(…) interventions that connect the areas where priority population groups live to their everyday destinations, including enhanced investments to act on unaddressed need" (Fischer & Winters, 2021, p. 388).

The studies cited thus far are largely situated in places that already experienced an initial or more established impetus to cycling or (largely) included samples of people *already cycling*. As a limited number of empirical studies show, a focus non-cyclists broadens the potential cycling population and provides a control group for the everyday perceptions and experiences of those who already cycle regularly (Félix et al., 2019; Leyland et al., 2019). In addition, while the empirical understanding of experiences and limitations of existing cycling infrastructures or of particular population segments is growing, research using self-reported visual preferences remains exploratory (e.g. Cafiso et al., 2021). We thus propose to focus our analysis on the general population of an urban context without an existing functional cycling network, targeting their perceptions on *potential* cycling use in a low (to none) cycling context. We proceed by outlining the perceptions on infrastructural elements with sensitivity to the intersectional elements that may explain them, in an attempt to ensure that cycling growth does not only start or continue, but also progresses equity and inclusion (Lam, 2022).

3. Study design

In order to meet the aims of our study, we developed a survey that enquires the perceptions about 12 different scenarios of cycling infrastructure. We used a representative survey with over 1,000 responses in the urban area in Camp de Tarragona (Catalonia, Spain), comprising of six municipalities with a total population of around 330,000. In this city region, cycling can be seen as a residual transport mode, accounting for 0.9% of urban trips on workdays (Autoritat Territorial de Mobilitat del Camp de Tarragona, 2021), although various of its municipalities have taken initiatives to improve this figure. In the Spanish context, the uptake of cycling has diverse historical trajectories, uptake levels and social norms around cycling that vary between cities and autonomous regions (Jordi Sánchez, 2016; Ruiz-Apilánez & Solís, 2021). For example, Seville and Vitoria-Gasteiz have made large advances since the mid-2000s, whereas Valencia and Barcelona are showing a gradual increase in more recent years. In general terms, however, inhabitants of municipalities with between 100,000 and 450,000 inhabitants are the most likely to prefer other means of transport to cycling (GESOP, 2022)

3.1. Study area

This study is set in the urban area of Camp de Tarragona, located in Catalonia, Spain, southwest of Barcelona. This urban area is composed of Tarragona and Reus (the two main cities in the region; the former being the capital of the homonymous province), the neighboring municipalities of Cambrils, Salou, and Vila-seca (located along the coast), and the municipality of La Canonja, situated between Tarragona and Reus (see map in Figure 1). This territory has a resident population of approximately 330,000 inhabitants. Morphologically, on the one hand it comprises densely populated urban areas, particularly in the two main municipalities and the centers of smaller municipalities, corresponding to the traditional Mediterranean urban form. On the other hand, the region also comprises less densely populated interstitial spaces, with higher degrees of land use segregation and a higher reliance on motorized transportation infrastructure such as large roads and highways, giving the urban reality of this area a somewhat fragmented nature. This area is also characterized by its coastal environment, which has traditionally linked this territory to the leisure and tourism dynamics of Costa Daurada.

The everyday mobility of residents mostly relies on walking and car use. Based on the latest official household travel survey in the region (Autoritat Territorial de Mobilitat del Camp de Tarragona, 2021), 46% of trips on workdays are conducted by car, 45% are conducted on foot, approximately 5% by public transportation (mostly local and interurban buses), 2% on motorcycles, and under 1% on other modes. Lastly, bicycles are used for 1% of all everyday trips in the region. Presently, cycling policies are limited to individual cities such as Tarragona and Reus, although the execution of their Sustainable Urban Mobility Plans has stalled since 2017, and the construction of new cycling facilities is negligible. Newer plans, including at the city-regional level, are currently in the drafting phase or pending political approval (Autoritat Territorial de Mobilitat del Camp de Tarragona, 2023).

In terms of cycling infrastructure, at the time of the study this area had approximately 140 km of either segregated cycle lanes or shared streets with painted signs indicating the priority of bicycles. The distribution of such infrastructure can also be observed in Figure 1. Segregated cycle lanes started in the early 2000s in the coastal municipalities of Cambrils and Salou, designed initially for the recreational use of bicycles. Similarly, cycle lanes were also built in Vila-seca (to connect with its coastal neighborhood of la Pineda, and with Salou), and later in Tarragona along its shoreline, with a similar intent. More recently, especially in the city centers of Tarragona and Reus, new cycle lanes have been built, along with the implementation of shared streets. Despite these efforts, although new lanes are planned for the short term, cycling infrastructure at this point is partial and still lacks connectivity both within municipalities and especially between them.

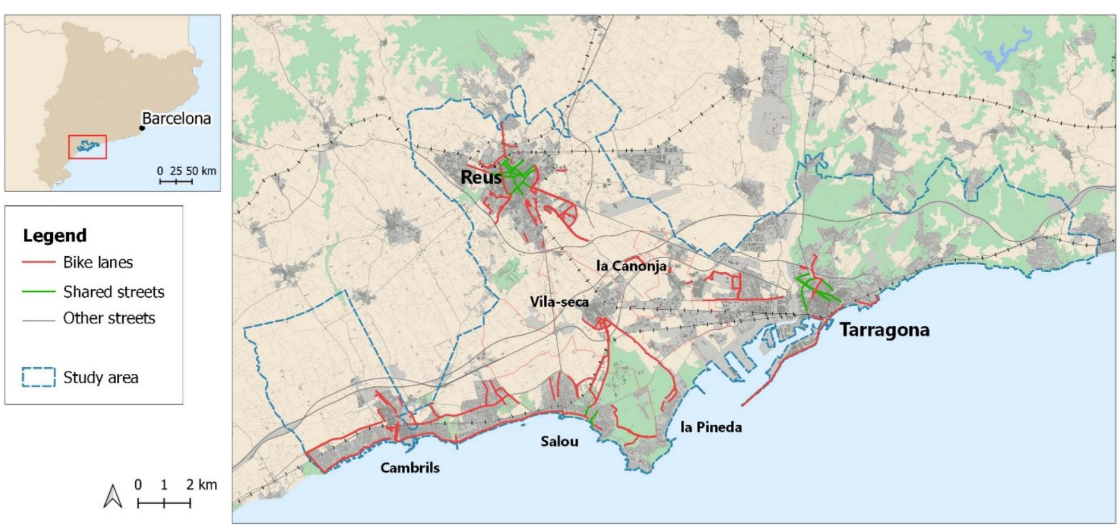

Figure 1. Map of the study area and current cycling infrastructure.

3.2. Data and variables

The study is based on data collected from a survey conducted among the residents of the study area in 2022, regarding their habits and perceptions related to the use of bicycles as a daily means of transportation. Target population included all adult residents in this territory. The survey was conducted in person by a group of four interviewers using the CAPI (Computer-Assisted Personal Interview) methodology. The surveys were carried out in June, July, September, and October of 2022, at a total of 12 key locations within the study area, strategically chosen to ensure representation of residents both in socioeconomic and territorial terms. In the end, a total of 1,052 individuals were surveyed, of which 1,038 responses were considered valid. The characteristics of the sample are presented in Table 1. The distribution of the sample in terms of gender, age, and socioeconomic level closely aligns with the population characteristics of the study area. In terms of their spatial relationship with cycling infrastructure, 14.5% survey respondents lived less than 50 m away from either segregated cycle lanes or shared streets, almost 30% lived between 50 and 150 m from cycling infrastructure, 30% between 150 and 300 m, 15% between 300 and 600 m, and 4.2% lived farther than 600 m away from any kind of cycling infrastructure.

The English translation of the survey questionnaire is presented in Supplementary Material B. Aside from sociodemographic characteristics, the survey was structured around two different sections: one focusing on mobility habits (for example, the frequency of using different modes of transportation) with a particular focus on bicycle use, and a second section centered around perceptions related to bicycle use, barriers to the adoption of bicycles as a daily means of transportation, and opinions regarding various policies and strategies to promote bicycle use. In this section we included the central question for this analysis: a visual evaluation of different bicycle infrastructure scenarios based on photographs. Survey respondents were presented with a total of 12 photographs, and they were asked to rate, on a scale of 1–5, how comfortable they would feel cycling in each scenario: *1-Very uncomfortable, 2-Uncomfortable, 3-Indifferent, 4-Comfortable, and 5-Very comfortable.* The photographs included in the survey questionnaire can be provided upon request by contacting the corresponding author Supplementary material A.

Table 1. Sample characteristics.

	n (%)
Total	1,038
Gender	
Men	464 (45%)
Women	567 (55%)
Nonbinary	5 (0.5%)
No data	2 (0.2%)
Age group	
18–39	440 (42%)
40–69	497 (48%)
70+	99 (9.6%)
No data	2 (0.2%)
Education level	
No studies	18 (1.8%)
Primary education	253 (25%)
Secondary education	493 (47.5%)
University degree	237 (24%)
No data	37 (3.6%)
Household monthly income	
Under 2.000€	347 (39%)
Between 2.000 and 4.000€	444 (49%)
Over 4.000€	107 (12%)
No data	140 (13.5%)
Household type	
Lives alone	110 (11%)
Couple	320 (31%)
With friends or others	43 (4.2%)
Lives with parents	218 (21%)
Family with children	337 (33%)
Lives with parents and children	6 (0.6%)
No data	4 (0.4%)
Neighborhood population density	
Low (<5.000 inhab./km^2)	510 (51%)
Middle (5.000–15.000 inhab./km^2)	190 (19%)
High (>15,000 inhab./km^2)	303 (30%)
No data	35 (3.4%)
Distance to nearest bicycle infrastructure	
<50 m	150 (14.5%)
50–150 m	294 (28.3%)
150–300 m	320 (30.8%)
300–600 m	155 (14.9%)
600< m	44 (4.2%)
No data	75 (7.2%)

3.3. Analysis

The analysis in this study is divided into three parts: first, we present a description of the mobility characteristics of the surveyed population and their use current bicycle use; second, we examined factors influencing why the population in the study area does not use bicycles as their primary means of transportation, or why they do not use them more frequently; third, the core of the study involves an analysis of visual preferences based on the content of the photographs, using an approach similar to that employed in previous studies (Aldred & Dales, 2017; Noland et al., 2023; Tilahun et al., 2007). To achieve this, each photograph was coded for the elements it contains, as summarized in the rating table included as Supplementary Table SB1. The elements rated for each photograph were: the presence of a segregated cycle lane, and if so, whether the segregation was minor (e.g. a simple painted line, curb or bollard) or major (e.g. a buffer zone or a row of parked cars, possibly combined with lines or bollards); whether the segregated lanes were unidirectional or bidirectional; if the street in the photograph had a speed limit of 30 km/h for vehicles; whether the context was urban or interurban; if the infrastructure shown allowed to cycle abreast; whether the infrastructure was marked with colored paint other than white; and finally, whether there was shade.

The analysis of visual preferences consisted of two main steps. First, we evaluated the difference in scores obtained in the photographs based on the presence or absence of each element related to infrastructure characteristics. For each individual, we calculated the difference (in percentage) in the average score reported in pictures showing a segregated cycle lane versus the average score reported in pictures without a segregated lane. Second, we examined possible associations between differences in scores for each infrastructure element and individual and contextual characteristics of survey respondents. To do so, we estimated eight linear regression models, one for each outcome (e.g. segregated/non-segregated, major/minor segregation, speed limit under 30 km/h/over, among others), and as independent variables we used relevant sociodemographic characteristics (i.e. gender, age, income, children), mobility habits and perceptions (i.e. frequency of use of each mode of transportation and desire to bike), and contextual characteristics at the residential level (i.e. population density and distance to nearest cycle lane). These regression models enable the assessment of the association between sociodemographic and mobility-related factors and differences in perceptions of infrastructure among survey participants, accounting for the combined effect of these variables, as done in previous studies (Jahanshahi et al., 2023; Noland et al., 2023). In this study, we specifically applied ordinary least squares (OLS) multiple regression models, given that the outcome variables represent continuous differences in preference scores and follow a normal distribution as confirmed by density plots (see density pots for each outcome in Supplementary Figure SB1).

Table 2. Relationship with bicycle as a mode of transportation.

	n (%)
Total	1,038
Mode transport use frequency (1–5)[a], mean (SD)	
Walk	4.5 (0.8)
Bicycle	1.6 (1.0)
Scooter or similar	1.3 (0.8)
Car	3.5 (1.6)
Motorcycle	1.2 (0.8)
Public transportation	2.4 (1.4)
Bicycle use frequency	
Never	648 (62.4%)
Once a year	197 (19.0%)
Once a month	135 (13.0%)
Once a week	36 (3.5%)
Every day	21 (2.0%)
No data	1 (0.1%)
Desire to bike for transportation	
No desire	338 (32.6%)
Indifferent	83 (8.0%)
Wants to bike for transportation	552 (53.2%)
Wants to bike, but only with e-bike	15 (1.4%)
Already bikes, and enjoys it	34 (3.3%)
Already bikes, and doesn't enjoy it	2 (0.2%)
No data	14 (1.3%)
Would bike if infrastructure was near?	
Yes	759 (73.1%)
No	226 (21.8%)
No data	53 (5.1%)

[a]1-Never, 2 = Once a year, 3 = Once a month, 4 = Once a week, 5 = Every day.

4. Results

4.1. The relevance of infrastructure in a low-cycling context

As described in the previous section, based on official data from 2020, the modal share in the study area mostly consists of walking and car use. This is confirmed by the results obtained in our survey, showing average frequencies of 4.5 and 3.5 out of 5, respectively, 1 being '*Never*' and 5 being '*Always*' (Table 2). Public transportation is next (2.4), and bicycle use falls in fourth position (1.6). If we take a closer look at cycling frequency, we observe how over 60% of respondents declare to never use bicycles for transportation, 19% do so once a year, 13% once a month, 3.5% once a week, and only 2% declare to cycle daily.

Confronted with these results, we observed that there is a considerable desire to bike for transportation in this region. Over 53.2% of survey respondents declare that they would like to bike for transportation, to which we could add 1.4% that would like to do so only if it was by means of an electric bike, aside from the 3.3% corresponding to those who already bike and enjoy it. In contrast, 33% of the population would not want to do so, 8.0% are indifferent and 0.2% already bike but do not enjoy it.

In this context, the question why residents in this area do not bike for transportation or do not do it more often is of particular interest. First, we observed that over 73% of survey respondents stated that if cycling infrastructure was near their place of residence, they would use it. Second, we examined the factors that could explain the difference between this willingness and current low cycling levels. To do so, we presented survey respondents with a set of possible factors that could explain why they do not bike for transportation (or why they do not do it more often), and we asked them to rank each factor from 1 to 5 in terms of how important it was (1 being not important at all, and 5 being very important or determinant).

As presented in Figure 2, we observed that the first ranking factor is that "*cycling infrastructure is insufficient and/or it is in bad condition*", considering that again 73% of respondents considered this factor to be important or, especially, very important. This value suggests that infrastructure is the only factor on which a vast majority of residents agree in terms of what is important or very important when explaining low cycling use. The second factor refers to "*places I want to go to are too far to be accessed by bike*" and is considered important or very important by 50% of respondents. *Weather conditions* fall in third place (48%), *steepness* to the fourth (43%) and *health issues or bad shape* to the fifth (41%). At the bottom of the graph, we see factors that are found less relevant, such as the cost of having a bike, hygiene (assumingly related to sweating from exercise involved in cycling), and not knowing how to ride a bike.

4.2. Perceptions of cycling infrastructure

Considering the seeming relevance of infrastructure as the key factor behind current low cycling use in the study area, we also examined how different types and scenarios of infrastructure were perceived by means of the visual preference analysis described earlier. Figure 3 shows the boxplots of all respondents' valuation scores for each picture, categorizing these based on the presence or absence of certain design element. For example, the first boxplot ("*Not segregated*") refers to respondents' valuation score of pictures where a segregated bike lane is not present, while the second boxplot ("*Segregated*") refers to their valuation of pictures where it is present. Table 3 shows the descriptive statistics of the percent differences in scores for each element among

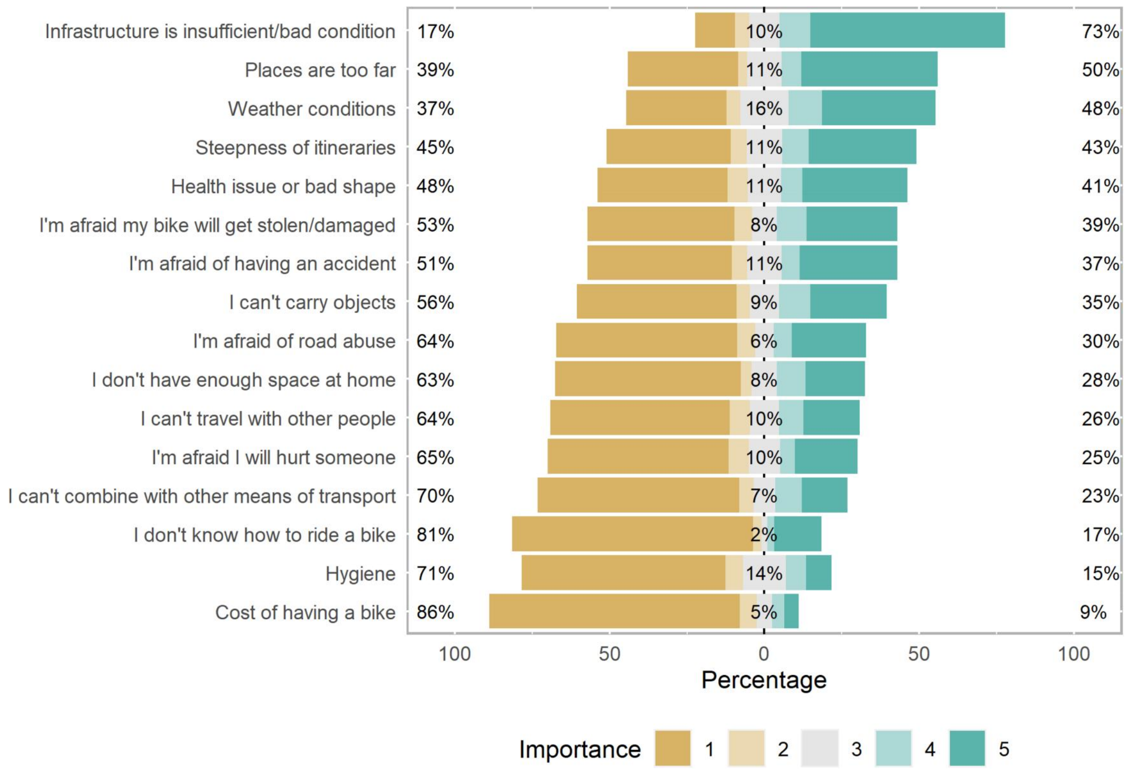

Figure 2. Main reasons why survey respondents do not bike for transportation regularly, or do not do it more frequently.

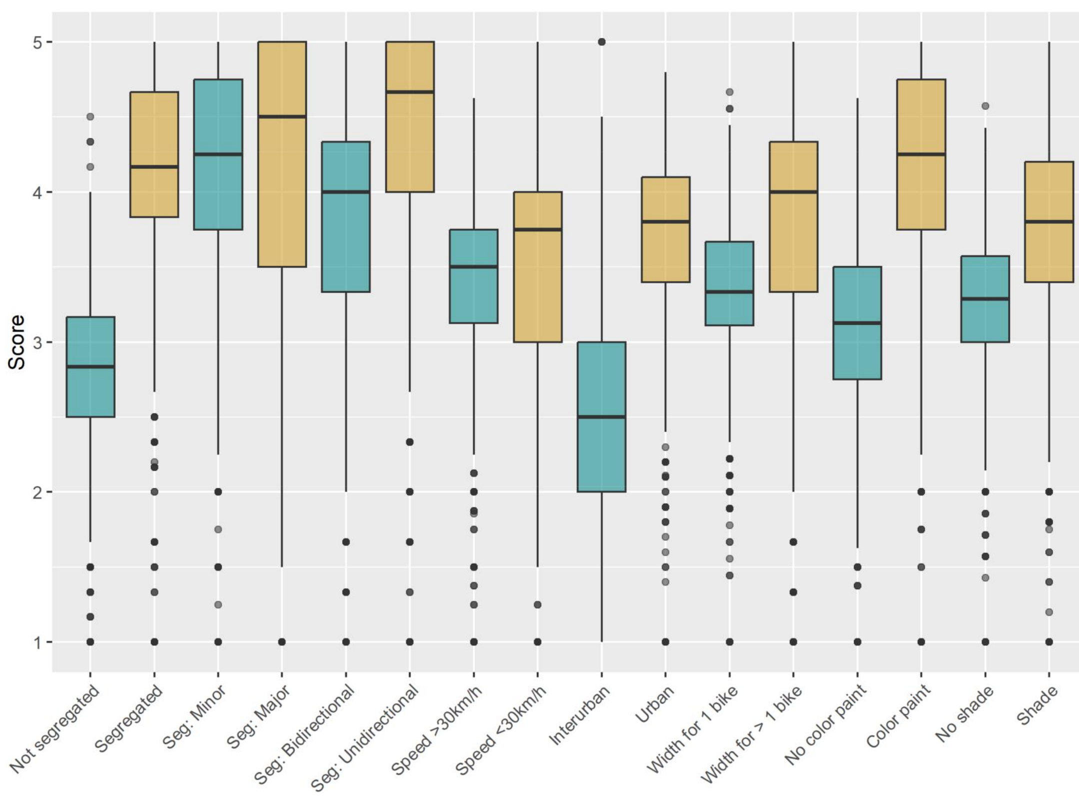

Figure 3. Box plots for scores of pictures categorized by the absence or presence of a selection of key items related to bike infrastructure.

participants. For each respondent, we calculated the percent difference between the evaluation given in each set of pictures according to the absence or presence of a specific design element. For example, if a respondent showed an average valuation of 4 among the pictures where a segregated bike lane was present and an average valuation score of 3 in pictures without a segregated bike lane, his/her difference percent difference would be of 33.3% (he/her showed a 33.3% higher valuation of pictures where a segregated bike lane was present compared with pictures without

Table 3. Descriptive statistics of outcomes calculated at an individual level.

% difference in score between pictures showing …	Mean	SD	p25	Median	p75
… segregated vs non-segregated lanes	51.3	−34.3	30.8	50.0	68.8
… major vs minor segregation in lanes	2.0	−25.1	−10.0	0.0	7.1
… unidirectional vs bidirectional street/lanes	18.1	−31.6	0.0	10.0	27.3
… speed <30kmh vs speed >30kmh street/lanes	6.2	−24.4	−7.1	3.7	18.2
… urban vs interurban contexts	74.8	−65.8	28.0	60.0	106.7
… street/lanes with width for >1 bike vs for 1 bike	16.2	−22.2	4.5	17.9	28.6
… color vs no color lanes	33.7	−22.7	20.0	33.3	47.8
… shade vs no shade above street/lanes	16.7	−18.6	6.4	17.6	27.3

segregated bike lanes). Lastly, density plots for the 8 variables showing the difference in valuations between the absence and presence of each design element are presented in Supplementary Figure SB1.

First, photographs with the highest scores are those in which segregated infrastructure appears, and specifically with a unidirectional lane (this type of photograph has an average score of 4.38 out of 5). However, the variable that shows the greatest difference is whether the scenario presented is urban versus interurban: photographs depicting an urban setting have an average evaluation of 3.68 out of 5, compared to 2.32 for photographs taken in interurban contexts (showing a mean difference of 74.8% in scores). The second element in terms of largest difference from its counterpart refers to the presence of a segregated lane: photographs depicting a segregated lanes for bicycles, separated from other vehicles and pedestrians, show a mean score of 4.12, while those in which bicycles share space with other vehicles or pedestrians score an average of 2.79 (a difference of 51.3%).

In the third place, we find the relevance of paint (photographs showing paint in a color other than white score an average of 33.7% higher than those without it). This is followed by the difference between unidirectional versus bidirectional lanes (the first showing 18.1% higher scores on average), the presence of shade (photographs with shade score 16.7% higher), and the width of the lane (those with a wider lane score 16.2% higher). The limitation of speed to 30 km/h on the street shows a smaller difference (photographs taken on streets with a speed limit of 30 km/h score 6.2% higher), and there is practically no difference in scores between photographs showing major versus minor segregation.

4.3. Associations between perceptions of cycling infrastructure and individual and mobility characteristics

Lastly, we conducted regression analyses to examine the sociodemographic and mobility related factors associated with preferences related to different cycle lane characteristics. As described earlier, we adjusted one linear regression model for each of the outcomes described in the previous section, calculated as differences between the absence and presence of certain infrastructure or street design elements, and their associations with personal and mobility characteristics. The results of a total of eight regression models are presented in Table 4.

A first result to underline is the presence of high intercepts of some of these models, which is explained by the differences in valuation in sets of pictures, for example in terms of the difference between pictures with segregated versus non-segregated cycle lanes (Model 1), or the difference between urban and interurban infrastructure (Model 5).

With respect to cycling equity, in terms of segregated cycle lanes (Model 1), we generally observed no differences in terms of personal characteristics (except for the age group of 40–69, who show a higher preference for segregated lanes). However, individuals who cycled less frequently or resided in areas with lower population density exhibited a stronger preference for segregated cycle lanes. Again, in terms of cycle lane segregation, we observed that men and older adults (70+ years old) show a higher preference for major segregation (Model 2). In terms of the direction of these lanes (Model 3), women, older adults and those with middle incomes showed a higher preference for unidirectional lanes, while curiously, we did not observe such difference among individuals who use public transportation more frequently.

In terms of speed (Model 4), we observed that frequent cyclists are the only group that showed a significantly higher preference for traffic-calmed streets compared to others. However, we saw that there are many significant differences in terms of urban versus interurban settings (Model 5). For example, as income increases, the preference for urban settings when cycling seems to increase. Secondly, those who want to cycle also seem to prefer urban settings, while, on the other hand, it is not a significant factor for frequent walkers, frequent cyclists and frequent drivers. Lastly, those who live in urban settings also show a smaller difference between scores in urban and interurban settings.

In terms of cycling infrastructure width (Model 6), we observed that women and those who reside in denser areas showed less preference for wider lanes. Adults between 40 and 69 and those with middle income showed a higher preference for infrastructure that presented paint with color other than white (Model 7). Lastly, we observed a significant association between preferring shaded infrastructure and having children and wanting to cycle for transportation, and an inverse relationship with being a frequent walker or driver (Model 8).

5. Discussion of scientific and practical applications

Most studies on cycling and its potential demand among demographic groups have generally focused on large cities, capital cities, or other sets of large, urbanized areas (Goel

Table 4. Regression results.

	Model 1: Diff. between **segregated** and non-segregated lanes	Model 2: Diff. between **major** and minor segregation	Model 3: Diff. between **unidirectional** and bidirectional	Model 4: Diff. between **speed <30km/h** and >30km/h	Model 5: Diff. between **urban** and interurban	Model 6: Diff. between **width for 1+ bikes** and for 1 bike	Model 7: Diff. between **color** and no color	Model 8: Diff. between **shade** and no shade
Independent variables								
Intercept	77.609***	−3.138	21.289*	−3.129	178.196***	26.427***	43.185***	33.631***
Women (Ref.= Men)	1.266	−4.083*	8.576***	0.497	5.309	−3.960*	2.145	−2.089
Nonbinary (Ref. = Men)	−4.047	−17.936	1.193	−27.077	15.657	−2.999	−14.106	−15.933
Age 40–69 (Ref. = 18–39)	7.323**	0.996	2.125	−3.382.	8.774.	1.521	4.344*	0.209
Age 70+ (Ref.= 18–39)	2.244	6.921*	12.683**	0.725	0.547	−5.122	5.005	−0.292
Income 2k–4k€ (Ref.= <2k)	3.462	0.693	4.852*	−2.258	17.149***	−0.907	3.584*	2.604.
Income >4k€ (Ref.= <2k)	2.441	−2.748	5.460	−2.919	28.895***	−3.198	3.085	1.149
Have children (Yes)	−3.230	3.625.	−4.563.	0.522	−1.134	1.277	2.142	3.468*
Wants to bike (Yes)	−1.255	0.886	−3.642	0.047	13.623**	1.558	2.748	3.116*
Walking frequency (1–5)	−2.018	0.579	−0.009	0.496	−13.521***	−0.525	−2.297*	−2.258**
Cycling frequency (1–5)	−5.053***	−0.130	−1.791	2.640**	−8.402***	−1.103	−2.574**	−0.218
Driving frequency (1–5)	−1.970*	0.327	−0.383	1.281.	−10.706***	−0.815	−0.451	−2.165***
Public transport freq. (1–5)	−0.742	1.157	−2.495*	−0.729	−2.386	0.538	0.871	0.037
Pop. density (inh. /km^2)	−0.000188*	−0.000061	0.000026	0.000114.	−0.000549**	−0.000131*	−0.000050	−0.000094.
Dist. to bike lane (m)	−0.003	−0.003	−0.001	0.001	−0.006	−0.002	−0.004	−0.001
Model statistics								
Adj. R^2	0.0328	0.01008	0.03811	0.01275	0.1047	0.004297	0.02418	0.0433
F-statistic	2.96 on 14	1.587 on 14	3.284 on 14	1.744 on 14	7.74 on 14	1.249 on 14	2.429 on 14	3.609 on 14
DF	793 DF	793 DF	793 DF	793 DF	793 DF	793 DF	793 DF	793 DF
p-value	0.000	0.077	0.000	0.043	0.000	0.234	0.002	0.000

Statistical significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

et al., 2022). However, we hypothesized that smaller cities may have different characteristics in terms of potential cycling mobility, e.g. in terms of distance, trip length or traffic levels, and the role of infrastructure. Similarly, from emerging scholarship on cycling equity we derived cycling's potential for socially transformative effects. This leads us to believe that cycling promotion is a socio-political issue that may define and redistribute the benefits of corresponding changes to mobility systems if inclusive design principles and equity principles are applied in urban mobility policy (Arsenio et al., 2016; Doran et al., 2021). By focusing on a medium-sized, polycentric urban area situated in Camp de Tarragona, Catalonia (Spain), we shed light on the perceptions, preferences, and barriers related to cycling infrastructure in a context with low user rates. Based on a representative survey including visual preference options, we observe that residents in this area, who at present barely cycle, have an existing and considerable desire to cycle as a form of transportation. Yet, this latent demand remains generally unsatisfied to this date. A crucial factor behind this is the apparent lack of infrastructure coupled with an urban form that detracts residents to cycle, as daily locations are not perceived as cycling destinations. Beyond the need of infrastructure, our results suggest that in this context not all types of infrastructure are perceived equally, highlighting that segregated, easily recognizable and safe infrastructure is generally perceived as better than others. However, we also identify some nuances in how infrastructure is perceived among different sociodemographic groups, which can have relevant implications for cycling equity.

Although individuals' willingness to cycle has become clear in this study, it has also underlined that their adoption of cycling as a mode of transportation depends on infrastructure. Our study further corroborates that the presence and quality of cycling infrastructure are central determinants of cycling behavior, in this case also among residents of places without substantial cycling infrastructure. Specifically, its insufficiency and poor condition emerges as the most significant factor hindering cycling adoption in the study area. This aligns with international research highlighting the crucial importance of well-maintained and comprehensive infrastructure (Pucher & Buehler, 2016). In addition, we consider that the role of infrastructure is closely intertwined with the urban form of the study area, as suggested by differences in perceptions of cycling infrastructure between urban and interurban contexts. Respondents express a marked preference for urban settings over interurban ones when it comes to potential cycling. These findings indicate that urban environments, with their shorter trip distances and higher population density, are more conducive to cycling adoption. This could be related to the fact that, aside from the presence or absence of infrastructure, the feeling that in the study area daily locations are too far away to be easily accessed by bicycle has been identified as a key barrier for cycling adoption. This result may seem somewhat counterintuitive, being a small to medium-sized urban area. However, urban growth in the study area, especially from the end of the twentieth century and beginning of the twenty first century, was characterized by a higher degree of urban fragmentation, increased land use segregation and a growth on the reliance on large transportation infrastructure and motorized transportation for daily mobility needs, similar to urban growth in North America or Australia (Bonham & Burke, 2016). In combination with the socio-political imperative of car-dependency (Mattioli et al., 2020), this study thus presents residents' willingness to cycle alongside the challenge to improve cycling facilities density of urban services and residential functions in the case of smaller and/or polycentric urban areas.

Based on the visual preference analysis, our study substantiates the evidence from other European countries on the importance of segregated, visible, and safe infrastructure (Pucher & Buehler, 2008), while contradicting another visual preference study in North America (Noland et al., 2023). Respondents expressed a strong preference for scenarios with segregated lanes, particularly those that are unidirectional. This underscores the need for dedicated cycling infrastructure that provides a sense of safety and separation from motorized traffic. The distinction between major and minor elements of segregation did not significantly affect preferences, suggesting that even minor segregation measures can enhance perceived safety or, in other words, having any sort of segregation can make a great difference. Even though minor elements of segregation such as lines or little distance from motorized traffic are not generally regarded as the safest infrastructure option (Aldred, 2015), it can be a first step to offering cycling opportunities which are currently inexistent. This is not to say that a potential cycling network should not strive for full connectivity, homogeneity, continuity, and directness, making cycling "easy and comfortable" based on the needs of those currently not cycling, as successfully done in Seville (Marqués et al., 2015, p. 42).

Between social groups, we found that residents' perceptions and attitudes are stratified by age and gender, underlining the unaddressed potential and its variabilities across parts of the population (Doran et al., 2021; Fischer & Winters, 2021; Hudde, 2023). For example, women expressed a stronger preference for unidirectional lanes, which is consistent with existing research highlighting the importance of safety and comfort for women cyclists, who may have different risk perceptions and preferences (Aldred & Dales, 2017; Winters, Barnes, et al., 2015). However, women also showed less preference than men for wider lanes, which we consider is a surprising result given that wider lanes not only are expected to feel safer, but also can enable side-by-side cycling, especially relevant for mobilities related to care (i.e. riding with children). Adults aged 40–69 displayed a higher preference for segregated lanes and unidirectional lanes, whereas older adults (70+) showed a higher preference for major as opposed to minor segregation. This may reflect the desire for safer and more predictable infrastructure among middle and older age groups. Income also played a role, with middle-income individuals expressing a stronger preference for infrastructure featuring paint with colors other than white. This preference may indicate that individuals with higher incomes are more attuned to the esthetic aspects of infrastructure or perceive colored lanes as more visually appealing. These results suggest that further research, as well as infrastructure design and implementation, needs to pay attention to esthetic needs which can help in making for an urban environment based on inclusive mobility needs (Musselwhite & Haddad, 2010; Stefánsdóttir, 2014). Along this line, we suggest that contexts like the polycentric urban area in Camp de Tarragona show a need to combine both intra and inter-urban networks and inclusive cycling promotion as part of a sustainable mobility transition, in line with the relatively high cycling desire (57.9%) observed in this study across a (non-cycling) general population.

Despite the strengths of our study, we would like to list additional considerations that could inform future studies, especially those set in small and medium-sized urban areas or other low-cycling contexts. The survey used in this study focused on resident adults, which means that people under 18 years of age were not included. This is a clear avenue for further research, considering that mobility habits are strongly developed during infancy and adolescence (Haustein et al., 2009) and the usually low adoption rates by children in low-cycling contexts (Aldred et al., 2017). Similarly, while part of the target population, individuals older than 70 were slightly underrepresented. Along this line, by employing a generalist approach to the target population, our study did not focus on other potentially disadvantaged groups, also including those of lower income and education levels and people with disabilities, which could provide more detailed insight into more specific access barriers in future studies, particularly if scholarship on cycling equity were to be further expanded to low-cycling contexts. Moreover, and similar to other studies using photography to depict cycling scenarios (Noland et al., 2023), perceptions of infrastructure depicted in photos could be biased or influenced by other, uncontrolled, elements present in the pictures such as the position and placement of other people cycling, the presence of people walking, or of other means of transport. In terms of methods, while several of the theoretically relevant factors considered did not show statistically significant associations with differences in perception, their inclusion was necessary to ensure the accurate estimation of the effects of significant variables. Similarly, low adjusted R^2 values are not uncommon in studies analyzing perceptions or subjective preferences, as they reflect highly individualized behaviors that are difficult to predict with high accuracy, since a wide range of factors may shape individual preferences and perceptions.

Along these lines, our study design focused on the perceptions and self-reported intentions regarding cycling adoption, following the rationale of the Theory of Planned Behavior (Ajzen, 1985). This rationale assumes that human behavior is entirely reasoned, despite there may be other relevant factors shaping actual behavior, such as morals, identities, lifestyles or even underlying social aspects such as cultural and historical factors that may play a significant role in mobility habits. In our case, we could hypothesize that low cycling levels in the region may also be influenced by the almost non-existent culture of cycling as a daily means of transportation, or at least one that disappeared with the mainstreaming of the automobile during the twentieth century. In other words, this calls to reflect on the geographic stability of our results, meaning that while the findings from this study provide important insights into the preferences for cycling infrastructure in the urban area of Camp de Tarragona, it is important to acknowledge that the geographic context may limit the generalizability of the results. The study area is a fragmented, low-cycling region, and the perceptions observed here may differ in cities with more established cycling cultures or different urban configurations. As such, the geographic stability of our models should be tested by applying this methodology in other urban settings, for instance considering density of population or urban amenities, areas with distinct cycling cultures or built environments, or with otherwise different infrastructure and urban planning characteristics. We recommend that future research extends this work to a broader range of geographic regions to validate whether the relationships identified in this study hold in areas with distinct cycling cultures or built environments. Similarly, as cycling infrastructure expands and becomes more normalized, public perceptions of cycling infrastructure may also evolve. While this study captures perceptions at a specific point in time, it is possible that these preferences will shift as new infrastructure is introduced, or as broader cultural attitudes toward cycling change. Given that our study area is historically car-dependent, with a near absence of a cycling culture, current perceptions could be influenced by this context. Longitudinal studies would provide valuable insights into how preferences change over time as cycling infrastructure develops. We suggest that future research should track these shifts to reassess the stability of our models over time and ensure they remain applicable as urban mobility patterns evolve.

Consequently, we encourage follow-up studies with qualitative work on small to medium-sized cities with low or non-existing cycling levels to provide a deeper understanding of how cultural and historical backgrounds shape perceptions of cycling and infrastructure and how strategies to discourage ingrained car use could be best employed in this type of urban contexts. Such work could be complemented with comparative work on the cycling demand between large conurbations and smaller towns and cities to gain a place-based understanding of desired infrastructural requirements. In practical terms, national, regional, and local authorities should join forces to develop or adjust current design guidelines in accordance with local perceptions, inclusivity standards, and high-quality design principles.

6. Conclusion

Our research aimed to improve the understanding of cycling adoption in the context of the urban area in Camp de Tarragona, Catalonia, by examining the interplay of infrastructure, perceptions, preferences, and sociodemographic factors shaping residents' decisions regarding cycling for transportation. Our findings resonate with the critical importance of cycling infrastructure as a determining factor in the adoption and frequency of cycling among residents in similar regions. Specifically, our findings demonstrate that infrastructure—especially one that is perceived as segregated, recognizable, and safe—plays a critical role in shaping perceptions of cycling environments, even in regions where cycling is not a predominant mode of transport. The implications of this study extend beyond Camp de Tarragona, offering lessons for cities of similar size and cycling levels. We especially aimed to contribute to laying the groundwork for informed policymaking and targeted interventions that foster a cycling-friendly environment in medium-sized urban areas with low cycling levels, both in Spain and across Europe. The prevailing modal share in such areas, dominated by walking and car use, juxtaposed with the comparatively lower prevalence of cycling, emphasizes a significant discrepancy between the desire to cycle and the current reality on the ground. A pivotal factor contributing to this disparity is the evidently deficient cycling infrastructure coupled with an urban landscape that discourages cycling by rendering daily destinations seemingly inaccessible on two wheels.

The preferences for safe, segregated and especially unidirectional infrastructure echo findings from larger urban areas, clearly showing a consensus among respondents that the insufficiency and poor condition of cycling infrastructure stand as primary obstacles impeding greater cycling adoption, and thus suggesting that increasing the availability and quality of infrastructure could help bridge the gap between the desire to cycle and actual cycling behavior in such settings. Moreover, the nuances shown in how different demographic groups perceive these elements in a low-cycling context underscore the need for tailored policy interventions to accommodate diverse needs and perceptions. The preferences observed, especially among women and older adults, highlight the need for inclusive infrastructure planning that addresses the concerns of typically underrepresented groups in cycling. Consequently, as cities across Europe continue to expand their cycling networks, attention must be paid to ensuring that infrastructure investments cater to diverse population needs, promoting not only cycling adoption but also cycling equity.

Ethical approval

The Ethics Committee for Research on People, Society and the Environment of Rovira i Virgili University after reviewing the survey for this study determined that it did not need ethics evaluation and permission, as the survey was not collecting any personal or sensitive data.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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