



Understanding multimodal mobility patterns of micromobility users in urban environments: insights from Barcelona

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Abstract

Micromobility, which includes bicycle-sharing systems, e-scooters, and shared moped-style scooters, has emerged as a popular alternative to traditional transport modes in urban environments, thus expanding the number of transportation options available to urban travellers. Previous research has primarily relied on trip-based data to explore the multimodal character of micromobility. However, existing evidence has failed to understand the ways in which urban travellers have reshaped their mobility patterns as a consequence of the introduction of micromobility. Using a travel survey (N=902) set in Barcelona, Spain, cluster techniques are used to group micromobility users according to their frequency of use of three different micromobility modes (bicycle-sharing systems, private e-scooter, and moped-style scooter-sharing services). Then, a multinomial logistic regression was used, in order to explore each cluster's usage of traditional modes of transport, along with all potential weekly combinations between modes. Results show that most micromobility users rely on a single type of micromobility mode on a weekly basis. The model further indicates that private e-scooter, shared bicycle, and shared moped-style scooter users develop different weekly mobility combination patterns. While personal micromobility options (private e-scooter) are associated with monomodal tendencies, sharing services (bicycle sharing and moped-style scooter sharing) encourage multimodal behaviours. These findings contribute to the limited knowledge concerning the role of some micromobility alternatives in creating more rational and less habit-dependent travel behaviour choices.

Keywords Micromobility · Bicycle-sharing system · E-scooter · Moped-style scooter sharing · Travel behaviour · Multimodality

Introduction

From environmental, sociological, and economic perspectives, micromobility has the potential to promote a sustainable urban future (Hosseinzadeh et al. 2021a). One frequently cited argument is that the rise of micromobility can contribute to the reduction of car

Extended author information available on the last page of the article

use and its associated negative impacts, such as emissions, noise, and congestion (Wang et al. 2022), while also promoting the use of public transport, which includes buses, trams, trains, and the metropolitan underground railway system (hereinafter, metro) (Hosseinzadeh et al. 2021b; Oeschger et al. 2020). While the exact extent of the tangible benefits of micromobility is still under debate (Sun & Ertz 2022), its deployment in urban settlements has been gradually expanding, thus adding variety and complexity to urban transportation systems (Alessandretti et al. 2022). However, without a clear understanding of the ways in which these modes are being used, it is challenging to test most assumptions on micromobility's potential benefits, and then verify them. Hence, gaining insight into the role of micromobility in people's travel behaviour has become more important than ever. This paper contributes to the discussion about the multimodal or unimodal nature of micromobility in urban transportation, with a particular emphasis on understanding the usage patterns of micromobility. It examines whether micromobility users tend to exclusively rely on a single mode of transportation for all their travel needs or they incorporate micromobility options as complementary to traditional transportation modes. This understanding is crucial for planning and policies aimed at promoting cycling and multimodal transport.

Micromobility is a broad concept with no consensus definition (Oeschger et al. 2020). In the context of shared mobility, for instance, some definitions include only modes that enable individuals to conveniently switch between pedestrian and personal mobility vehicles (PMVs). Common examples include shared bikes or shared e-scooters, both designed for a single passenger and typically not exceeding speeds of 25 km/h (Shaheen and Cohen 2019b). However, given the rising popularity and significance of other mobility options in urban settings, this paper adopts the broader definition provided by the International Transport Forum (2020), which describes micromobility as human or electric-powered personal transportation (private or shared) vehicles with a speed limit no higher than 45 km/h. On this basis, the following micromobility transport modes are taken into consideration for the purpose of this paper: docked-shared bicycles, understood as *those systems that offer either conventional or electric bicycles to enable short-term rental from one docking station to another* (Fishman et al. 2013); privately-owned e-scooters, identified as *scooters with a standing design with a handlebar, deck and wheels that are propelled by an electric motor* (Shaheen and Cohen 2019a); and moped-style scooter sharing services (hereinafter e-moped), characterised as *those services in which free-floating electric mopeds can be picked up and left within a geo-fenced area* (Aguilera-García et al. 2020). Although some studies consider private bicycle as a micromobility option, this paper focuses on transportation choices that have recently emerged in cities (Shaheen and Cohen 2019a).

Micromobility and its integration into multimodal transportation systems has been a topic of interest in recent years. Traditionally, travel behaviour has been recognised as being significantly influenced by the impact of human habits (De Witte et al. 2013). However, the advent of micromobility might be challenging this assumption. Having a bike-sharing option available, for instance, could give people more confidence in their travel options, allowing them to rely less on privately owned vehicles (POVs) for unexpected trips during the day. Similarly, being able to bring personal e-scooters on the underground (railway/metro) for first/last mile trips could increase satisfaction with public transport and potentially draw drivers away from cars. This flexibility might enable people make more rational and adaptable transportation choices based on trip-specific needs. Therefore, understanding the capability of micromobility in shaping user's preferences and attitudes towards the whole transportation supply is crucial in calibrating its impact,

and for designing smarter and equitable transport management policies. To date, most of the research has mainly focussed on micromobility as a part of a trip chain, either in the context of access and egress trips to and from public transport (integration effect) (Bordagaray et al. 2016; Reck et al. 2022; Wong et al. 2020), or in counterfactual scenarios prior to micromobility trip realisation (substitution effect) (Reck et al. 2022; Ricci 2015; Wang et al. 2022). However, since humans tend to develop or adhere to a set of patterns in their daily lives (Nobis 2007), there is a need to complement these approaches and to take a broader perspective by observing micromobility on a weekly basis. Understanding the weekly patterns of micromobility use can help comprehend its role in multimodal transportation systems, and its contribution to overall travel behaviour. This research topic is particularly important when the issue under debate is micromobility's potential to influence the development of individual daily transport patterns.

Based on the above-mentioned issues, this paper seeks to answer the following research questions (RQ): (1) *What are the different profiles of micromobility users*, and (2) *Which factors influence their adoption of multimodal travel patterns?* To address these questions, this study proposes the following hypotheses to be tested:

Hypothesis 1 (H1): An overlap is expected in the usage of shared micromobility systems (i.e., bicycle-sharing and moped-style scooter sharing), while not between shared systems and privately-owned devices (i.e., private e-scooters).

This hypothesis is based on the premise that shared micromobility options are thought to act as a gateway to other shared micromobility options, encouraging users to explore and utilize multiple shared services (Aguilera-García et al. 2020; Liao and Correia 2022). In contrast, owning a micromobility device might be discouraging users to integrate extra shared services in their mobility patterns, as their micromobility needs might be already covered by the owned device itself.

Hypothesis 2 (H2): Shared micromobility users are expected to integrate traditional transport modes more intensively in their weekly travel patterns compared to users with a privately owned micromobility device.

This second hypothesis stems from the understanding that shared micromobility systems are thought to complement and extend existing traditional travel options (Wang et al. 2022). Users of sharing services most likely will show multimodal travel behaviour (i.e., not always choosing the same mode for each trip). In contrast, private micromobility vehicle ownership may lead to an abuse or an indiscriminate use of the mode of transport in question, i.e., a tendency to always use the same vehicle for different reasons or necessities, pattern observed for other privately-owned vehicles (Garcia-Sierra et al. 2018).

This study uses data from a travel survey conducted in Barcelona, Spain, and is based on a three-step analysis. First, in order to identify homogeneous groups of micromobility users (1) a clustering analysis based on the weekly frequency of use of the three different micromobility options was performed. This first step addresses RQ1 by revealing different profiles of micromobility users. The clustering analysis helps test H1 by determining whether there is overlap in the usage patterns of distinct micromobility alternatives. Second, in order to identify which of these cluster groups are more likely to develop multimodal travel behaviours (2) a bivariate analysis was conducted. This step addresses RQ2 by exploring the relationship between cluster membership and multimodal travel patterns and helps test H2 by identifying whether users of shared systems exhibit more multimodal mobility patterns compared to users of private devices. Finally, in order to estimate who was more likely to belong to each cluster (3) a multivariate analysis was performed based on the frequency of use of traditional transport modes and sociodemographic attributes. This step further addresses RQ2 by determining the factors influencing the adoption of

multimodal travel patterns. The multinomial logistic regression model helped test both H1 and H2 by quantifying the likelihood of cluster membership in relation to various predictors.

The remainder of the paper is structured as follows. Sect. "[Literature review](#)" reviews how multimodality has been previously approached, as well as their link(s) with micromobility. Sect. "[Methodology](#)" presents the study area, the data collection process, and a description of the methodology used. Sect. "[Results](#)" provides the main results, while Sect. "[Discussion](#)" discusses those results, including a reflection on the role of micromobility in making cities and the transport system more sustainable and resilient. Finally, some conclusions and study limitations can be found in Sect. "[Conclusions](#)".

Literature review

Multimodality

Multimodal travel behaviour, defined as the utilisation of two or more modes of transportation within a specified interval of time (Diana and Pirra 2016), has garnered attention from researchers within the mobility and transportation field during the last two decades. Studies have found that the composition and existence of multimodal patterns is largely contingent upon the definition and measurement of the period of time under study. A particular instance of multimodality, for example, is intermodality, which involves the use of two or more transportation modes within the frame of a single trip, highlighting the consecutive integration of different transportation options to achieve a single purpose (Gebhardt et al. 2016). Beyond individual trips, multimodality has also been explored considering broader patterns of transportation use over extended periods. Particularly, as standard temporal unit that aligns with regular societal and cultural rhythms (Nobis 2007), the week has proven crucial for understanding the cyclical nature of travel behaviour, as evidenced by its widespread use across different authors and contexts (Garcia-Sierra et al. 2018; Heinen & Mattioli 2019; Kuhnimhof et al. 2012). Focusing on weekly patterns has enabled researchers to capture the regular, repeatable aspects of mobility that reflect both habitual behaviour and structured weekly activities, which has provided insights into how people plan and coordinate their use of various transport modes to meet their weekly schedules and commitments. Furthermore, some other research have even extended the time span by examining multimodal behaviours on a monthly (Lee et al. 2020; Miramontes et al. 2017) and annual basis (Alessandretti et al. 2022; Fu et al. 2024), providing a broader perspective on transportation patterns.

The importance of defining the temporal aspect of multimodality was first emphasised by Buehler and Hamre (2016), who showed that longer timeframes captured a greater degree of variability in travel behaviour. Based on data from the US National Travel Survey, they revealed that although American motorists typically relied on automobiles for roughly 93% of their daily trips, 25.1% of them used another mode of transportation for at least seven trips per week, and 13.5% regularly walked, cycled, or utilised public transportation for at least two trips per day. Following a related approach, Nobis (2007) used the 2002 German Mobility Survey to study multimodality patterns in Germany. The author found that 49% of the German population used more than one of the three modes of transportation (car, public transport, and bicycle) at least once per week. Similarly, Kuhnimhof et al. (2006) used multiday data from the German Mobility Panel (MOP)

to analyse individual mode choice behaviour in Germany. Their findings showed that about half of German drivers also used public transport. Moreover, besides the diversity of transport mode use, authors typically include detailed intensity or evenness measures to refine their definitions of monomodality and multimodality. Vij et al. (2011), for example, defined individuals using the same transport mode for over 90% of their trips as individuals with monomodal tendencies. Other authors applied a scale ranging from 0 to 1 (where values closer to zero indicated a multimodal travel behaviour, and values near to 1 suggested a monomodal travel behaviour), confirming great degrees of variability in day-to-day travel behaviour (Heinen and Chatterjee 2015). More recently, in an attempt to address the mode classification issue in measuring multimodality, Fu et al. (2023) constructed a multigroup multimodality index to measure the extent of the variability of transport mode use, effectively distinguishing the degrees of multimodality across different modes and groups.

Multimodality and micromobility

The introduction of micromobility in cities has substantially expanded the number of transportation options available to urban travellers. Modestly accelerated by the COVID-19 pandemic and consolidated in its aftermaths (Azimi et al. 2024; Bustamante et al. 2022; Nello-Deakin et al. 2024; Rossetti et al. 2024), micromobility popularization has added new travel opportunities, increasing the multimodality potential of urban transportation systems and allowing travellers to combine different modes of transportation to create more efficient and personalised travel experiences. This is expected to result in reduced congestion, lower emissions, and improved access to different parts of the city, ultimately contributing to a more sustainable and liveable urban environment. Given these potential benefits and the important influence on urban transportation and mobility patterns, researchers have begun to investigate the phenomena of multimodality and micromobility. However, to date, existing research in this area has mainly focused on multimodality on a trip-level (i.e., intermodality), mainly through two effects: the integration effect and the substitution effect (Reck et al. 2022; Ricci 2015; Wang et al. 2022).

On the one side, the integration effect refers to the potential of micromobility to complement other modes of transportation. Modal integration predominantly applies to individuals who use a micromobility device to cover the ‘first-mile to’ or the ‘last-mile from’ public transit (Oeschger et al. 2020), and has been explored using different methodologies. Following a survey approach, Adnan et al. (2019) and Fan et al. (2019) asked their respective respondents about their integration practices or preferences before and after the introduction of bicycle-sharing systems. Both sets of authors found that after bike-sharing introduction, shared bicycles became the preferred choice for first/last mile trips, followed by walking, private bicycles, and automobiles. In another study, Hamidi et al. (2019) developed an index to assess the role of a bike-sharing system in accessing the existing public transport network in Malmö, Sweden. Their findings illustrate that bike-sharing schemes are less likely to be extended to areas where people at higher risk of transport-related social exclusion live. In parallel, other authors have used big data from bike-sharing operators to identify start and end locations, trip duration, or user information (Böcker et al. 2020; Guo & He 2020). Drawing on a complete two years trip record of the Oslo bike-sharing system, Böcker et al. (2020) analysed the potential use of bike-sharing for accessing, egressing, and interchanging public transport. Their results suggest that bike-sharing ridership is substantially higher on routes that either start or end with metro/rail

connectivity, although they are less accessible by women and older population groups. In the case of e-scooters, research on the integration effect is less developed. In Austin, Texas, some studies analysed the relationships between land-use patterns and shared e-scooter usage, revealing that proximity to public transit nodes has a statistically significant and moderately positive impact on shared e-scooter ridership (Bai and Jiao 2020; Caspi et al. 2020). More recently, an analysis from Madrid incorporated private e-scooters into their research question (Aguilera-García et al. 2024). Their results indicate a lower likelihood of adopting these private devices among people holding a public transportation pass, while regular access to car or motorcycle shows the opposite effect. According to the authors, this finding may indicate that individuals who own private e-scooters also tend to favour privately-owned vehicles over public transportation. Conversely, their findings show some higher degree of complementarity for sharing e-scooters and public transport. However, the authors acknowledge it remains uncertain whether shared e-scooters are primarily utilized as first/last mile mobility solutions to connect with the public transport network.

On the other side, the substitution effect refers to micromobility trips that replace trips formerly made by another mode of transport. Usually, these studies are based on counterfactual survey questions like *“Thinking about your last trip on a [micromobility mode under study], which mode of transport would you have taken if it had not existed?”* (Arellano and Fang 2019; Wang et al. 2022). The previous literature on micromobility acknowledged that emergent modes mostly substitute active and public transportation trips, while the effect on car users is limited (Felipe-Falgas et al. 2021; Fishman et al. 2013; Reck et al. 2022; Teixeira et al. 2020; Wang et al. 2022). This is especially remarkable for bike-sharing systems, for which substitution patterns have been confirmed across different geographical contexts, including Australia (Fishman et al. 2014a), Ireland (Murphy & Usher 2015), and Poland (Bieliński et al. 2021). While research on the substitution effects of e-scooters is still in an early stage, preliminary findings reached similar conclusions as those findings previously reached by bike-sharing studies. Studies conducted by Christoforou et al. (2021) in Paris (France) and Bai & Jiao (2020) in Austin (Texas, USA) suggest that e-scooters are often used for short trips, thus replacing walking, cycling, or public transit. In Vienna, Laa & Leth (2020) differentiated between two typologies of e-scooter users, owners and renters, and uncovered that whereas in both groups e-scooter trips mostly replaced walking and public transport, e-scooter owners showed a considerable mode-shift from private car trips. In the specific case of e-moped sharing systems, available studies are even more scarce. Taking Barcelona (Spain) as the case study, Roig-Costa et al. (2021) suggest that e-mopeds reached similar substitution rates as other micromobility devices. Overall, while substitution patterns across distinct micromobility vehicles are similar around the globe (higher level of substitution from active and public modes, and lower level of substitution from private modes), it is noteworthy that substitution rates vary considerably according to different mobility cultures. Indeed, several authors have suggested that substitution rates are related to contextual modal split. For example, the review addressed by Wang et al. (2022) shows that shared e-scooters users reported walking as being, effectively, the most commonly substituted travel mode. However, those authors note that substitution percentages range from 30 to 60% of trips, according to different cities. Similarly, in their reviews on bike-sharing determinants, Fishman et al. (2014b), Reck et al. (2022) and Teixeira et al. (2020) suggest that higher proportions of shared bicycles substituting cars are generally found in contexts where the car represents a higher percentage in the modal share.

As previously noted, to gain a more comprehensive understanding of multimodality, a significant number of existing studies on traditional modes of transport tend to gather data

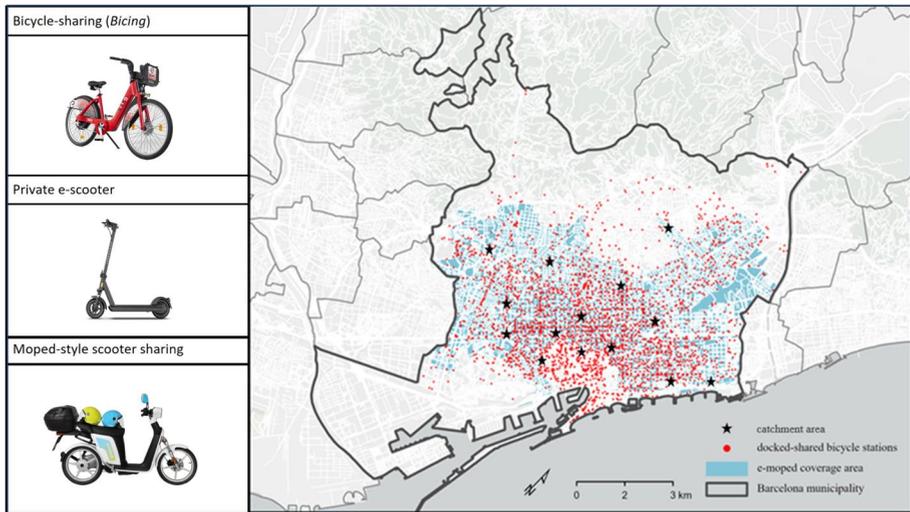


Fig. 1 Docked-shared bicycle stations and e-moped coverage area in the City of Barcelona. Source: Own elaboration

that inform about travel behaviour for a period of one week and longer. However, when researchers have included micromobility as part of their multimodal mobility analyses, they have commonly used one-trip data. While these approaches provide valuable insights into the immediate and direct impacts of micromobility on mobility patterns, they miss long-term behavioural trends and habits of users, overlooking deeper integration patterns that might emerge only from observing a broader range of usage over time. In order to yield a more comprehensive analysis and to expand what the previous literature has already found regarding micromobility and the use of other transport modes, the present study evaluates the interaction between micromobility and traditional modes of transport within the frame of a complete week. Expanding the timespan can help in providing a more complete understanding of its impact on the transportation landscape and can also inform on future policy decisions.

Methodology

Study area

The study took place in the municipality of Barcelona (1.6 million inhabitants), which is located in northeastern Spain (Fig. 1). The transport system of Barcelona offers 12 metro (underground) lines, 14 trains and 108 bus lines covering the whole municipality. The main mode of travel of the population in Barcelona is active mobility (57.2%), followed by public transport (24.0%), and private vehicles with 18.8% of weekday trips (EMEF 2022). In terms of micromobility, the municipality has a public system of conventional- and electric-shared bicycles, under the operator known as *Bicing*, with a fleet of 7,000 bicycles (Soriguera & Jiménez-Meroño, 2020). Additionally, in 2021, the Barcelona City Council announced the regulation and licensing of moped-style sharing companies to operate within the city limits. Currently, the number of companies providing such services has

reduced to nine, and the number of licenses to 5407. Since 2017, shared e-scooters operated by private companies (e.g., Lime) are not allowed to operate within the city boundaries (Ajuntament de Barcelona 2017). Consequently, the current e-scooter use in Barcelona is restricted to riding a privately-owned e-scooter, device that has emerged as a core micromobility component in the city (Roig-Costa et al. 2024).

Data collection and key variables

A questionnaire was disseminated in September 2020 using a computer-assisted personal interviews (CAPI) approach. Data collection was conducted by eight street interviewers, as detailed in Supplementary Table 1. In order to organise the fieldwork and obtain a sample of users circulating in different parts of the city, recruitment was conducted from 14 survey points covering nine out of ten city districts (Fig. 1). To ensure homogeneity on the conducted interviews, interviewers were first trained in a session prior to the start of the data collection. As a measure of quality control, the research team of the study conducted three random street checks to ensure that interviewers were positioned within the designated influential areas and adhered to the established protocols. Participants were randomly intercepted in the street and at bike-sharing stations before or after the realisation of a micromobility trip, by using a convenience sampling approach. While this is a non-probabilistic sampling method (the only criterion was whether people were willing to participate), it is a cost-effective, faster, and easier way to collect data. In total, 902 micromobility users were interviewed. This paper uses data from the NEWMOB project, data that have been used in other studies (e.g., a life cycle assessment in Felipe-Falgas et al. (2021)). Our study will use the same data to explore weekly mobility patterns of micromobility users.

The questionnaire structure consisted of three blocks. The first block related to the respondents' socioeconomic characteristics and residence/workplace location variables. Socioeconomic characteristics included age, gender (*Woman, Man, Non-binary* or *Prefer not to say*), level of studies (*Primary or None, Secondary* or *University*), professional status (*Employed, Unemployed, Retired* or *Student*), and access to a car (*Yes* or *No*). Residence/workplace location variables included questions such as whether participants lived in Barcelona (*Yes* or *No*) and whether they worked within Barcelona city boundaries (*Yes* or *No*). Table 1 shows some descriptive statistics for these variables. Both younger participants and men are overrepresented in our sample, but this is consistent with the sociodemographic profile of micromobility users in Barcelona (EMEF 2022; IERMB 2021), and in other Spanish urban areas (Aguilera-García et al. 2020).

The second block covered questions related to the usage frequency of the three micromobility devices of interest in this paper: private e-scooter, bicycle-sharing system, and e-moped sharing services. In particular, the question asked for each device was: "*In the last seven days, have you used the following micromobility mode of transport?*"¹ Potential responses were (1) *Yes, 3 or more days*; (2) *Yes, 1 or 2 days*; and (3) *No, I have not*. For the purpose of this paper, these categories were renamed as (1) *Often*; (2) *Sometimes*; and (3) *Never*.

Finally, the third block consisted of questions regarding the frequency of use of traditional transport modes, such as private bicycle, metro, urban bus, train, private motorcycle, and private car. Similarly to the previous block, the question was stated as follows: "*In the*

¹ This is a direct translation from Catalan, as the survey was collected in this language.

Table 1 Sociodemographic characteristics of the sample (%)

		Private e-scooter (n = 326)	Bicycle sharing systems (n = 325)	E-moped sharing services (n = 251)	Total sample (N = 902)
Gender	Male	63.5	53.6	69.1	61.6
	Female	35.9	45.5	29.9	37.7
Age	<i>mean (std)</i>	31,33 (10,6)	31,9 (12,4)	29,5 (10,0)	31,0 (11,7)
Level of studies	University	41.4	59.8	47.4	49.7
	Secondary	49.1	33.5	51.0	44.0
	Primary or none	9.5	6.7	1.5	6.2
Professional status	Employed	78.2	66.7	67.5	71.2
	Student	13.5	26.8	31.1	23.2
	Unemployed	5.8	5.2	1.4	4.2
	Retired	2.5	1.3	0.0	1.4
Access to a car	(Yes)	80.1	64.3	91.6	77.1
Living in Bcn	(Yes)	78.8	95	81.5	85.4
Working in Bcn	(Yes)	74.8	56.1	68.3	66.4

*last seven days, have you used the following mode of transport?*² with respondents having the possibility to answer either (1) *Yes, 3 or more days*; (2) *Yes, 1 or 2 days*; and (3) *No, I have not*. Again, categories were redefined as (1) *Often*; (2) *Sometimes*; and (3) *Never*. Walking was not included in this analysis as most individuals reported walking on most days, rendering the responses to this question somewhat redundant. Therefore, we decided that omitting walking would focus the analysis on differences in the usage of less universally frequent modes of transport. This methodological decision aligns with approaches taken by previous authors analysing monomodal and multimodal travel behaviour tendencies, such as those by Diana and Mokhtarian (2009) and Klinger (2017).

Statistical analysis

The methodology followed a three-step approach. Firstly, cluster analyses were applied to identify homogeneous groups of micromobility users. Secondly, bivariate correlations were run between the clusters identified and the usage frequency of traditional transport modes (compiled in the questionnaire). Thirdly, a multinomial logistic regression model was performed to estimate the correlates of the six group of travellers.

Cluster analyses

Based on the above-mentioned questionnaire (Sect. 3.2), the frequency of use for each micromobility device (private e-scooter, bicycle-sharing system, and e-moped services) served as input for clustering individuals. Each cluster was made up of people with a similar micromobility travel behaviour. In view of the categorical nature of the data, the K-modes algorithm was chosen. The algorithm iterates reallocating objects until no

² This is a direct translation from Catalan, as the survey was collected in this language.

changes of objects between clusters are perceived. The K-modes algorithm was run in the *klaR* package of the R statistical computing environment, to obtain three, four, five, six and seven different clusters. Based on the preliminary data assessment, we focused on the solutions for 4, 5, and 6 clusters which indicated that these cluster sizes provided the most meaningful and interpretable groupings for our dataset. Finally, six clusters were taken for this study (895 observations, 99.2% of the cases) based on the average silhouette width test and the value of the silhouette coefficient. Values under 0.25 suggested the inability to establish a substantial consistency for the clusters; values between 0.26 and 0.50 suggested a weak and artificial cluster consistency; values ranging between 0.51 and 0.70 indicated a reasonable cluster consistency; and values higher than 0.71 denoted a strong cluster consistency.

Cluster bivariate associations

Bivariate analyses were carried out using the Fisher's Exact Test to explore each cluster's use of traditional means of transport. This helped in providing an accurate description of the complete modal mix of each cluster and confirmed the relationship between micromobility and traditional transport modes, which shed some light before applying multivariate methods. To reduce complexity, private car and private motorcycle were merged under the category *Private motorised vehicle*. In addition, traditional modes showing low frequencies of use were excluded from the analysis (e.g., electric private bicycle and electric private motorcycle). This helped in simplifying the analysis and reducing the complexity of the data, as including modes of transport with low usage frequencies did not contribute significantly to our research question.

Multivariate analysis of micromobility: multinomial logistic regression

A multinomial logistic regression analysis was used to identify the correlates of the six groups of travellers, taking Cluster 3 as the reference group. The independent variables comprised the frequency of use of traditional transport modes (e.g., own bicycle, metro, urban bus, train, private vehicle) while controlling for the sociodemographic attributes (age, gender, work status, level of education, access to car) and a residence related variable (city of residency). To avoid multicollinearity issues, the Spearman's rank correlation test was run for the independent variables. It was found that *professional status* and *place of work* were highly correlated ($p > 0.7$), thus removing the latter from the analyses. The estimated equation was:

$$P(Y = k|X) = \frac{e^{(\beta_{0k} + \beta_{1k}X_1 + \beta_{2k}X_2 + \dots + \beta_{pk}X_p)}}{\sum_{j=1}^K e^{(\beta_{0j} + \beta_{1j}X_1 + \beta_{2j}X_2 + \dots + \beta_{pj}X_p)}}$$

where: $P(Y=k|X)$ is the probability of the outcome being in category k given the predictors X . In the context of our study, the outcome variable Y represents membership to one of the different clusters, while categories k represent the different clusters of micromobility users. e is the base of the natural logarithm. β_{0k} , β_{1k} , β_{2k} , ..., β_{pk} are the coefficients corresponding to each predictor variable for category k . X_1 , X_2 , ..., X_p are the predictor variables. The denominator is the sum of the exponentiated linear combinations of predictors for all categories. This ensures that the probabilities sum up to 1 across all categories.

Exp(B) -or odds ratio (OR)- and 95% confidence levels (CI) were computed for each Exp(B) value. The Exp(B) value is the predicted change in odds for a unit increase in the predictor variable. When Exp(B) is less than one, increasing values of the variable correspond to decreasing odds of belonging to a specific cluster compared to the reference group. Conversely, when Exp(B) is greater than one, increasing values of the predictor variable correspond to increasing odds of belonging to a specific cluster compared to the reference group. All variables were first tested one-by-one in unadjusted models. Variables that were independently associated with at least one cluster were then combined into the model. The multinomial logistic regression analysis was conducted using the NOMREG procedure in IBM SPSS Statistics version 21.

Results

Cluster analyses

As mentioned in Sect. 3.3.1, a six-cluster solution proved to yield the best results. The average Silhouette width is 0.67, which indicates that the clusters presented a reasonable structure. The remainder of this section describes each cluster, as well as the frequency of use of the micromobility devices that are considered in this study (Table 2).

- Cluster 1 (*Bike-sharing lovers*): individuals within this cluster are frequent users of bicycle-sharing systems, while they never (or almost never) use private e-scooter or e-moped services. Silhouette coefficient is 0.81, which denotes a strong cluster consistency.
- Cluster 2 (*Trivial e-scooter users*): individuals within this cluster never (or almost never) use micromobility. If occasionally using micromobility, they ride a private e-scooter. Silhouette coefficient is 0.68, which indicates a reasonable cluster consistency.
- Cluster 3 (*E-scooter enthusiasts*): individuals within this cluster are frequent users of a private e-scooter, while they never (or almost never) use bicycle-sharing systems or e-moped services. Silhouette coefficient is 0.78, which denotes a strong cluster consistency.
- Cluster 4 (*Casual bike-sharing users*): individuals within this cluster are occasional users of bicycle-sharing systems, while they never (or almost never) use private e-scooter or e-moped services. Silhouette coefficient is 0.42, which denotes a weak cluster consistency.
- Cluster 5 (*Casual e-moped users*): individuals within this cluster are occasional users of e-moped services. They never (or almost never) use other micromobility devices. Silhouette coefficient is 0.42, which denotes a weak cluster consistency.
- Cluster 6 (*E-moped enthusiasts*): individuals within this cluster are frequent users of e-moped services, while they never (or almost never) use other micromobility devices. Silhouette coefficient is 0.64, which denotes a reasonable cluster consistency.

It is noteworthy that the relatively weak silhouette coefficients observed for clusters 4 and 5 may stem from their status as occasional users of micromobility. Consequently, they

Table 2 Self-reported frequency of use of micromobility modes of transport (frequency in %)

	1. Bike-sharing lovers (22.2%)	2. Trivial e-scooter users (11.0%)	3. E-scooter enthusiasts (33.1%)	4. Casual bike-sharing users (11.2%)	5. Casual e-moped users (14.2%)	6. E-moped enthusiasts (7.5%)	Sample average (99.2%)
<i>Private e-scooter</i>							
Often	1.5	0.0	93.6	8.9	2.3	2.9	33.2
Sometimes	6.0	22.2	6.4	9.9	7.0	2.9	8.3
Never	92.5	77.8	0.0	81.2	90.6	94.1	58.5
<i>Shared bicycle</i>							
Often	100.0	0.0	1.0	0.0	10.2	5.9	24.6
Sometimes	0.0	0.0	2.7	100.0	7.8	11.8	14.2
Never	0.0	100.0	96.3	0.0	82.0	82.4	61.2
<i>E-moped sharing</i>							
Often	0.5	0.0	2.0	1.0	0.0	100.0	8.5
Sometimes	4.0	0.0	2.3	10.9	100.0	0.0	17.2
Never	95.5	100.0	95.7	88.1	0.0	0.0	74.3

Cluster shares are given in brackets. Numbers in bold indicate a statistically significant difference (Fisher Exact Test) compared to the overall distribution of the sample (p value < 0.05)

do not have constant and clear micromobility behaviour, becoming “outliers” in our sample. This variability could introduce some degree of “noise” into the clustering process.

Cluster bivariate associations

Bivariate associations were estimated between individuals included in each of the six clusters and their self-reported usage frequency of traditional transport modes (Table 3). Overall, two travel behaviour trends are identified. On the one side, clusters with a predominant monomodal travel behaviour (i.e., people who mainly rely on micromobility transport modes). Monomodal use is identified within Cluster 3 “*E-scooter enthusiasts*” and Cluster 6 “*E-moped enthusiasts*”. Together, these clusters comprise more than 40% of the sample. On the other side, multimodal travellers combining micromobility with other traditional modes of transport are identified. Likewise, within multimodal users two profiles can be recognised: (i) multimodal users committed to public transport (e.g., Cluster 1 “*Bike-sharing lovers*”, Cluster 2 “*Trivial e-scooter users*”, and Cluster 4 “*Casual bike-sharing users*”) and (ii) multimodal users who are dependent on private transport, being those participants who are included in Cluster 5 “*Casual e-moped users*”. Within the first sub-group of multimodal travellers, micromobility ranges from being a pillar to being a complementary mode according to each cluster. For instance, users in Cluster 1, the so-called *Bike-sharing lovers*, rely mostly on bicycle-sharing systems to cover their mobility needs. However, while bicycle-sharing is a key component of their weekly mobility strategies, they still supplement their transportation needs with public transport modes, such as the metro and the bus. In contrast, Cluster 4, *Casual bike-sharing users*, use bicycle-sharing as a complementary mode of transport. Although they rely on short-term rental bicycles for certain mobility needs, in their case the metro is the primary mode of transportation around which their weekly mobility needs are organised. Similarly, Cluster 2, *Trivial e-scooter users*, are travellers who are mainly making use of public transport modes. However, in an occasional manner (we use the term ‘trivial’), they complement their mobility needs by making use of a privately owned e-scooter. Within the second sub-group of multimodal travellers (i.e., those dependent on private transport modes), micromobility only plays a complementary role. Is the case of *Casual e-moped users* (Cluster 5), whose individuals are primarily private vehicle drivers who occasionally rent e-mopeds to supplement their weekly mobility needs.

Micromobility multivariate analysis: multinomial logistic regression model

This section aims to provide a comprehensive analysis of the factors explaining the likelihood to belong to one of these six clusters using a multinomial logistic regression model (Table 4). The primary objective is to understand the characteristics and behaviours associated with each cluster, with Cluster 3, “*E-scooter enthusiasts*”, serving as the reference group, as it represented the highest level of monomodal travel patterns, also being the largest cluster. By examining the multivariate associations between travel behaviours, sociodemographic factors, and cluster membership, we uncover the underlying patterns that differentiate various micromobility users.

Table 3 Self-reported frequency of use of other traditional modes of transport

	1. Bike-sharing lovers (22.2%)	2. Trivial e-scooter users (11.0%)	3. E-scooter enthusiasts (33.1%)	4. Casual bike-sharing users (11.2%)	5. Casual e-moped users (14.2%)	6. E-moped enthusiasts (7.5%)	Sample average (99.2%)
<i>Own bicycle</i>							
Often	6.5	5.1	5.4	5.0	7.0	7.4	5.9
Sometimes	4.5	13.1	9.4	5.9	14.1	7.4	8.8
Never	89.0	81.8	85.3	89.1	78.9	85.3	85.3
<i>Private vehicle</i>							
Often	4.5	21.2	10.7	11.9	47.7	23.5	16.9
Sometimes	13.0	17.2	20.7	15.8	17.2	23.5	17.8
Never	82.5	61.6	68.6	72.3	35.2	52.9	65.4
<i>Metro</i>							
Often	19.5	29.3	14.0	31.7	15.6	8.8	18.8
Sometimes	48.5	35.4	26.1	33.7	25.0	29.4	33.1
Never	32.0	35.4	59.9	34.7	59.4	61.8	48.2
<i>Bus</i>							
Often	12.5	16.2	6.4	11.9	7.8	5.9	9.6
Sometimes	32.0	30.3	19.4	33.7	21.1	17.6	25.1
Never	55.5	53.5	74.2	54.5	71.1	76.5	65.3
<i>Train</i>							
Often	4.0	6.1	7.7	5.0	3.9	4.4	5.6
Sometimes	13.0	20.2	7.0	16.8	10.9	8.8	11.6
Never	83.0	73.7	85.3	78.2	85.2	86.8	82.8

Cluster shares are given in brackets. Numbers in bold indicate a statistically significant difference (Fisher Exact Test) compared to the overall distribution of the sample (p value < 0.05)

Table 4 Adjusted associations between the frequency of use of traditional modes of transportation, socioeconomic characteristics, locational variables, and clusters of micro-mobility travel behaviors. Multinomial logistic regression model (Reference = Cluster 3 “E-scooter lovers”)

	Cluster 1 Bike-sharing lovers			Cluster 2 Trivial e-scooter users			Cluster 4 Casual Bike-sharing users		
	B (S.E.)	OR Exp(B)	CI 95%	B (S.E.)	OR Exp(B)	CI 95%	B (S.E.)	OR Exp(B)	CI 95%
Use of own bicycle (ref=never)	Often 0,360 (0,420)	1,433	(0,629;3,263)	0,165 (0,556)	1,180	(0,397;3,507)	0,044 (0,555)	1,045	(0,352;3,102)
	Sometimes -0,748 (0,417)	,473	(0,209;1,072)	0,300 (0,397)	1,350	(0,62;2,94)	-0,733 (0,524)	,480	(0,172;1,342)
Use of metro (ref=never)	Often 0,612 (0,321)	1,844	(0,982;3,462)	1,071 (0,377)	2,918**	(1,393;6,11)	1,214 (0,373)	3,365**	(1,621;6,986)
	Sometimes 1,081 (0,236)	2,948***	(1,857;4,68)	0,851 (0,307)	2,343**	(1,283;4,279)	0,714 (0,308)	2,043*	(1,116;3,739)
Use of bus (ref=never)	Often 0,723 (0,385)	2,061	(0,969;4,385)	0,818 (0,439)	2,266	(0,959;5,357)	0,523 (0,476)	1,687	(0,664;4,29)
	Sometimes 0,368 (0,249)	1,446	(0,887;2,356)	0,357 (0,313)	1,429	(0,774;2,636)	0,590 (0,305)	1,804	(0,992;3,281)
Use of train (ref=never)	Often 0,257 (0,321)	1,293	(0,69;2,424)	-0,278 (0,414)	,757	(0,336;1,705)	0,109 (0,403)	1,115	(0,506;2,457)
	Sometimes 0,278 (0,323)	1,320	(0,702;2,485)	0,791 (0,355)	2,205*	(1,1;4,42)	0,000 (0,402)	1,000	(0,454;2,199)
Use of private mode (ref=never)	Often -0,452 (0,422)	,636	(0,278;1,456)	1,377 (0,376)	3,964***	(1,896;8,288)	0,831 (0,425)	2,296*	(1,018;5,178)
	Sometimes -0,420 (0,285)	,657	(0,376;1,15)	0,295 (0,353)	1,344	(0,673;2,685)	0,070 (0,352)	1,073	(0,538;2,14)
City of residence (ref=no Barcelona)	Barcelona 1,591 (0,364)	4,909***	(2,404;10,026)	0,441 (0,344)	1,554	(0,792;3,052)	2,359 (0,633)	10,581***	(3,057;36,617)
Age	0,022 (0,011)	1,022*	(1,001;1,044)	0,022 (0,014)	1,022	(0,994;1,051)	0,014 (0,014)	1,015	(0,988;1,042)
Gender (ref=man)	0,439 (0,206)	1,551*	(1,036;2,322)	0,096 (0,264)	1,100	(0,655;1,848)	0,011 (0,263)	1,011	(0,604;1,692)

Table 4 (continued)

	Cluster 5 Casual e-moped users			Cluster 6 E-moped enthusiasts		
	B (S.E.)	OR Exp(B)	CI 95%	B (S.E.)	OR Exp(B)	CI 95%
Use of train (ref=never)	Sometimes 0,198 (0,307) Often -0,450 (0,423)	1,219 ,638	(0,667;2,226) (0,279;1,46)	-0,123 (0,401) 0,490 (0,473)	,885 1,633	(0,403;1,94) (0,646;4,131)
Use of private mode (ref=never)	Sometimes 0,490 (0,356) Often 2,192 (0,315)	1,632 8,949***	(0,812;3,28) (4,83;16,584)	0,865 (0,429) 0,992 (0,408)	2,374* 2,696*	(1,025;5,499) (1,211;6,002)
City of residence (ref=no Barcelona)	Sometimes 0,417 (0,322) Barcelona 0,389 (0,319)	1,518 1,476	(0,808;2,851) (0,79;2,757)	0,396 (0,361) 1,326 (0,487)	1,485 3,766**	(0,732;3,016) (1,45;9,783)
Age	-0,003 (0,013)	,997	(0,972;1,022)	-0,018 (0,016)	,983	(0,952;1,014)
Gender (ref=man)	-0,190 (0,253)	,827	(0,504;1,357)	-0,574 (0,322)	,563	(0,299;1,06)
Professional situation (ref=employed)	Student 0,870 (0,356)	2,386*	(1,187;4,796)	-0,170 (0,437)	,843	(0,358;1,988)
Level of studies (ref=no university)	Other -0,726 (0,605) University 0,816 (0,258)	,484 2,261**	(0,148;1,582) (1,363;3,752)	-20,769 (0,000) -0,228 (0,304)	,000 ,796	(0,000;0,000) (0,438;1,446)
Access to car (ref=no)	Yes 0,398 (0,400)	1,488	(0,679;3,262)	0,191 (0,440)	1,210	(0,51;2,869)

Pseudo R (Nagelkerke)=0,359; **p* value < 0,10; ***p* value < 0,05; ****p* value < 0,001; B (S.E.): coefficient (standard error); OR: odds ratio; CI: confidence interval

Cluster 1 “Bike-sharing lovers” versus Cluster 3 “E-scooter enthusiasts”

Among the use of traditional modes of transport, it is confirmed that an occasional metro use increased the odds of belonging to Cluster 1 “Bike-sharing lovers” compared with the referent Cluster 3. Living within Barcelona city boundaries increased the odds of belonging to Cluster 1, by almost 5 times (4.909). As for sociodemographic factors, being a student and holding a university degree strongly increased the odds of belonging to Cluster 1, while being a woman and a year older slightly increased the odds of belonging to Cluster 1. In contrast, having access to car decreased by more almost 50% the odds of belonging to Cluster 1.

Cluster 2 “Trivial e-scooter users” versus Cluster 3 “E-scooter enthusiasts”.

Among the use of public modes of transportation, regular and casual uses of the metro, on the one side, and an occasional use of the train, on the other side, increased the likelihood of belonging to Cluster 2, compared to Cluster 3. In addition, a regular use of private modes increased the likelihood of belonging to Cluster 2. As for sociodemographic factors, being a student and holding a university degree increased the odds of belonging to Cluster 2. In contrast, Cluster 2 presented the same association with having access to car, as Cluster 1 compared to Cluster 3.

Cluster 4 “Casual bike-sharing users” versus Cluster 3 “E-scooter enthusiasts”

A regular and an occasional use of metro usage were associated with an increase in the odds of being in Cluster 4 compared with Cluster 3. Additionally, a frequent use of private modes increased the likelihood of belonging to Cluster 4. Living within Barcelona city boundaries strongly increased the odds of belonging to Cluster 4, by more than 10 times. As for sociodemographic factors, being a student and being highly educated increased the odds of belonging to Cluster 4. In contrast, having access to car decreased the likelihood of belonging to Cluster 4, compared to Cluster 3.

Cluster 5 “Casual e-moped user” versus Cluster 3 “E-scooter enthusiasts”

Among the use of traditional modes of transport, a frequent use of private modes of transport was highly associated with an increase in the odds of being in Cluster 6 compared with Cluster 3. Additionally, being a student and specially holding a university degree increased the odds of belonging to Cluster 6.

Cluster 6 “E-moped enthusiasts” versus Cluster 3 “E-scooter enthusiasts”

Among the use of traditional modes of transport, an occasional use of metropolitan public transport modes such as the train and a regular use of private modes of transport was associated with an increase in the odds of being in Cluster 6 compared with Cluster 3.

Additionally, living within Barcelona city boundaries also increased the odds of belonging to Cluster 6.

Discussion

Often presented as an alternative to traditional modes of transport, micromobility has expanded the number of transportation options available to urban travellers. However, despite its increasing popularity, it remains unclear whether its deployment in urban ecosystems has triggered more or less sustainable travel patterns. The present study explores whether micromobility users in Barcelona have preferences towards monomodal or multimodal travel behaviours. Through an analysis of how frequently do micromobility users opt for traditional transportation modes, we investigated how micromobility modes fits into the wider transportation mix, gaining insights into the specific patterns of multimodality among micromobility users.

From the supply side, Barcelona presents a variety of micromobility options that offer a wide set of choices to travellers, ranging from public bike-sharing systems to moped-sharing services (Bach et al. 2023a; Bretones & Marquet 2023; Roig-Costa et al. 2021). Nonetheless, and contrary to our initial hypothesis (H1), our results show that micromobility users are essentially attached to a single micromobility device, showing almost no interest for other micromobility alternatives. This means, for instance, that most e-scooter users in our sample were unlikely to use any other micromobility mode during their everyday travel. Similarly, users of bicycle-sharing systems hardly ever used any other micromobility mode. In fact, multimodality within micromobility is almost non-existent, as virtually no participants declared using a combination of e-scooter, bike-sharing, and/or e-moped during the week. In the specific case of e-scooters, this inexistent combination with other micromobility alternatives was already anticipated by hypothesis 1 (H1) and may be explained by the fact that e-scooters in Barcelona can only be privately owned. In this case, owning the device may act as a mechanism reinforcing its usage (Klinger 2017), reducing the necessity to consider other micromobility options. However, given the shared features of both systems, we expected a larger overlap in user coverage between shared bikes and shared e-mopeds than was observed. These findings contradict previous studies suggesting that moped-sharing services may complement other shared mobility options, such as bike-sharing (Aguilera-García et al. 2021), and call into question the ability of e-moped services to act a gateway to encourage the adoption of other micromobility modes (Bach et al. 2023a).

At the modal mix level, our week-based analysis has revealed a greater variance than previous trip-based analyses. This aligns with multimodality studies focusing exclusively on traditional modes of transport, which found that longer time periods captured a wider variability of profiles (Buehler and Hamre 2016; Kuhnimhof et al. 2012). Our findings indicate that while micromobility users rarely switch between micromobility modes, they do engage in multimodal behaviour with traditional modes of transport, displaying a diverse modal mix. This is consistent with the trends described in the study by Klinger (2017), who found that the traditional classification of users as either solely car-drivers or users exclusively preferring sustainable modes of transport was somewhat obsolete. According to that study, individuals tend to make decisions about the most appropriate mode of transport in a more pragmatic way, based on a situational rationale. Similarly, our results show that for some users, micromobility

constitutes their core mode of transportation, while for others it merely represents an additional or complementary option within their weekly modal mixes. These findings support a more flexible understanding of traveller typologies and travel choice behaviours.

In line with this, our findings show that different typologies of micromobility options trigger distinct modal patterns. To the best of our knowledge, the present study is among the first to find a strong association between e-scooter and monomodal behaviours, as anticipated in our second hypothesis (H2). However, this result is consistent with previous findings by Diana and Mokhtarian (2009) and Garcia-Sierra et al. (2018), who established a clear association between vehicle ownership and monomodal tendencies. Related to this, prior research had also found that entering professional life drastically attenuates multimodal behaviours (Nobis 2007). In a life-stage where daily routines become more complex, the inherent characteristics of the daily commute, such as fixed distances, routes, schedules, or frequencies, make occupational trips the kind of trip that is most significantly influenced by habits (Kun Gao et al. 2020). Our results seem to reflect this, showing that employed individuals are characterised by an intensive monomodal use of micromobility modes, especially private e-scooter, and tend to have lower multimodality rates. The specific context of Barcelona, where the city council effectively banned sharing e-scooter services, pushing individuals to buy their own e-scooter, may be affecting these results (Roig-Costa et al. 2024). The combination of private ownership plus the convenient features of e-scooters -small and lightweight- allows for easy door-to-door travel and may create a greater degree of owner attachment to the device, reducing any incentive to use other modes of transport. In this sense, the behaviour of private e-scooter owners might be more similar to that of motorcycle owners (Marquet and Miralles-Guasch 2016), rather than traditional private bicycle owners, who exhibit slightly more multimodal tendencies across various contexts (Fu et al. 2024; Olafsson et al. 2016).

However, a relation of exclusivity and dependence with a single mode can be problematic in the long term, especially when the micromobility device in question is not available (due to maintenance issues, for instance), or when circumstances make its usage unsuitable (longer trips, trips to areas without adequate infrastructure, adverse weather conditions, or while carrying heavy loads). A lack of flexibility in switching to alternative modes of transportation could eventually lead to increments in immobility rates or, as suggested by Haworth et al. (2021), to misuses or risky behaviours. In this respect, policymakers should promote the attractiveness and efficiency of public transport, both in combination with and independent of these small devices. This would encourage more rational and safe mobility choices, particularly in situations where door-to-door e-scooter travel is not feasible or advisable. Additionally, as seen with other mobility options, repetitive and exclusive use of a particular mode of transport can lead to a lack of consideration for other users with whom e-scooters have to share space. In Barcelona, for example, motorcycle riders who exhibit high levels of monomodality (Marquet & Miralles-Guasch 2016), are frequently observed parking on pedestrian areas, which creates hazards for pedestrians (Catalunya Camina & Eixample Respira 2022), or driving in the bus lanes, which results in slowing down bus traffic. Similarly, e-scooter users entrenched in monomodal habits might more easily engage in unsafe or inconsiderate practices such as riding on sidewalks (Haworth et al. 2021). As suggested by Gibson et al. (2022), more research is needed to better understand the travel behaviour associated with such a monomodal device, especially when the device does not fit neatly into a specific category and violations of transport space boundaries can threaten both the integrity of the e-scooter riders themselves and the safety of pedestrians (Ma et al. 2021; Sikka et al. 2019).

In contrast, as also anticipated in our second hypothesis (H2), sharing services in our study appear to be associated with more multimodal weekly patterns. Among our sample, bicycle-sharing users show a higher disposition to using other modes of transport other than micromobility. Consistent with the body of literature, our results indicate that a change in the transportation culture towards more frequent use of sharing systems and lower ownership rates might be expanding the set of modes of transport that travellers rely on, on a weekly basis (Miramontes et al. 2017). In Barcelona, bicycle-sharing has become both a pillar for some users' daily mobility strategies, and a flexible and convenient mode of transportation that complements other options for others. Aligning with previous research (Levy 2013; Roberts et al. 2011), our findings reveal that female micromobility users tend to use the widest variety of modes of transport on a weekly basis, and interestingly, they seem to be more likely to rely on a public sharing system (i.e. bike sharing system) as the backbone of their mobility strategies. This finding might be explained by the greater variance in the characteristics of their trips, as women tend to travel shorter distances and make more unplanned trips for personal and household purposes (Maciejewska et al. 2019; Maciejewska and Miralles-Guasch 2020), trip characteristics ideally accommodated by the flexibility and accessibility of bike-sharing systems. Therefore, the success of bike-sharing systems might be creating a group of multimodal users that are able to choose their mode of transportation based on their real-time needs and contexts, making modal choice a more rational process potentially less dependent on habit, which women might be taking good advantage of. This represents a departure point from the traditional approach of choosing a mode of transportation for the entire day, allowing users to select the most suitable mode of transportation for each individual trip that they need to make.

In parallel, multimodal tendencies are also observed within users relying on solutions provided by private sharing operators. Barcelona is a city with a long-standing tradition of using private mopeds and motorcycles for urban transport (Marquet and Miralles-Guasch 2016). Because of that, shared moped-style systems are thought to have much appeal and potential to expand and, thus, have started to attract the attention of a number of studies (Bach et al. 2023a, 2023b). According to our results, a great proportion of users who pay for on-demand e-moped sharing services primarily rely on car/motorcycle-trips and only use shared mopeds on an occasional basis. This is consistent with the work of Aguilera-García et al. (2020), who identified a positive association between car ownership and shared-moped use in Madrid, suggesting that shared moped systems in Spain, in general, might be viewed as a "crutch" vehicle that offers the benefits of a motorised private vehicle without the problems and burdens of the ownership. The results of their study also suggest that moped sharing services may be complementing rather than replacing private vehicle ownership. In fact, in relation to that, when adjusting for all the correlates in our multinomial model, results in our study show that even the specific subset of e-moped enthusiasts initially depicted as exclusively monomodal users tend to rely on private modes of transportation for some of their mobility needs. This confirms that e-moped sharing systems are associated with multimodal travel patterns and reveals a worrisome disconnection between e-moped usages and urban public transport modes. While shared mopeds are certainly a step in the right direction towards more sustainable transportation options, they may not be sufficient to trigger deep changes in travel behaviour.

In contrast, one association that the introduction of micromobility may have significantly altered is the link between multimodality and socioeconomic backgrounds. Traditionally, the use of multiple modes of transportation, which requires considerable effort and extensive information for effective geographic and temporal travel organization (Nobis 2007), has been associated to low-income population groups (Diana and Mokhtarian

2009; Kroesen 2014; Molin et al. 2016). Although context-dependent, multimodality has generally been perceived as a burden, leading to experiences of transport inadequacies and reduced accessibility (Fu et al. 2024). Consequently, high-income populations are often unwilling to incur the complexities and the costs associated with multi-option mobility schemes. Previous studies, for instance, have tested the relationship between the number of household vehicles -which might be a proxy of income- and multimodality, showing that people having more household vehicles have a higher possibility of being monomodal car user (Buehler and Hamre 2016; Maciejewska et al. 2023). However, our models consistently find higher socioeconomic profiles to be associated with a higher multimodal behaviour, while lower profiles appear to be skewed to monomodal practices. The introduction and access to diverse micromobility options may be significantly simplifying the complexities and uncertainties of mobility-planning, alleviating the need to rigidly plan out transportation strategies far in advance.

However, this ability of some micromobility services to break well-established theories on urban travel behaviour may be partially explained by Barcelona's bicycle-sharing system layout and e-moped services coverage area, which operates exclusively within the Barcelona city boundaries and thus concentrates its network mostly in central areas of the city. In fact, what these findings may be highlighting is the role of shared micromobility services in exacerbating existing transportation inequalities based on socioeconomic status, with higher-income individuals benefiting more from the increased travel choices. Conversely, lower-income individuals are potentially left behind with fewer options, leading them opt for e-scooter ownership, which entails a monomodal behaviour. As others have anticipated, shared options are scarcer in the outskirts of the cities, which might be translating into more intensive use of private micromobility options (Aguilera-García et al. 2024). This finding suggests that for micromobility to have a real ability to break well-established theories on urban travel behaviour, policy interventions should first ensure micromobility accessibility and affordability for all income groups, rather than solely benefiting those who are already better off (Spinney 2020).

Finally, the possibility to access a diversified range of micromobility options may be reducing the reliance on any single mode of transport, boosting more rational travel behaviour choices but also mitigating risks associated to eventual disruptions, schedule changes, or even low or null public transport offer at certain times of the day. Ultimately, in contingency scenarios, micromobility's inherent cost-effectiveness becomes even more pronounced, offering a substantial advantage over more traditional transport modes commonly associated to unexpected scenarios, such as taxis or more recently introduced ride-hailing platforms like Uber or Cabify (De Souza Silva et al. 2018). This advantage is key not only in reducing economic burdens, enhancing accessibility, or improving the ease of mobility for urban dwellers at critical times, but also for reducing externalities such as air pollution and congestion (Tirachini 2020), thus enhancing urban sustainability. However, the lack of centralised information across travel modes might be slowing down the maximisation of this potential. If transportation suppliers succeeded in reducing both the uneven accessibility levels across groups of population and the fragmentation in the access to information, the use of bicycles on an as-needed basis could arise as a convenient option with which to meet weekly transport demand of people with different cycling preferences and expectations. As previous authors have noted (Arias-Molinares & Carlos García-Palomares 2020; Becker et al. 2020), a plausible way of simplifying the provision of information and access to information is to create a unique common information source in the form of a Mobility as a Service (MaaS). Developing a digital channel enabling users to book for multiple types of mobility services (buses, trams, subways, and bike-sharing options now operated

by different entities and accessed through different systems) could help boosting the potential to use bike-sharing for multimodality and unplanned trips. This integration would improve the experience of travellers already opting for sustainable choices and likely contribute to the shift from motorized private modes of transportation to sustainable options.

Conclusions

This study has addressed weekly multimodal travel behaviour among micromobility users. We have studied whether, and to what extent, individuals combine different types of micromobility devices or combine micromobility use with traditional modes of transport. This is important, in order to (1) understand the potential benefits that an integration of these new modes of transport could bring into the whole transportation system, and (2) to assess to what extent a higher number of transportation options would translate into more rational travel behaviour choices. For that purpose, we used cluster techniques to identify six clusters of micromobility users: (1) Bike-sharing lovers, (2) Trivial e-scooter users, (3) E-scooter enthusiasts, (4) Casual bike-sharing users, (5) Casual e-moped users, and (6) E-moped enthusiasts. Our findings, in the first instance, have demonstrated that individuals using micromobility options exhibit a clear preference for a single type of device, while not engaging in the complementary use of alternative micromobility modes. At the same time, they highlight the heterogeneity of the function of each micromobility alternative across different groups of users' weekly mobility patterns. While some users demonstrate a tendency towards monomodality and rely solely on micromobility as a pillar and exclusive component of their mobility strategy (Cluster 3 and, to a lesser extent, Cluster 6), others exhibit weekly multimodal travel patterns where micromobility plays both a pillar role (Cluster 1) and a complementary role (Clusters 2, 4 and 5).

This study is not without limitations. Firstly, the utilisation of a non-probabilistic sampling technique, followed by a random intercept mechanism, limits our study's ability to extrapolate our findings to the entire municipality of Barcelona. However, to ensure the representativeness of our sample, we undertook a validation exercise using alternative data sources, revealing that the demographic characteristics of our sample, including gender and age, align with those of the broader population utilising micromobility within the city. Secondly, the authors acknowledge that the data collection occurred during a uniquely atypical global traffic situation caused by the COVID-19 pandemic, which necessitates cautious interpretation of the results. However, restrictions in Spain changed from wave to wave and specially in between waves. On June 21, 2020, the first state of alarm ended and the whole country officially entered the phase of "new normality". It was not until October 25, 2020, that the Government declared the second state of alarm. Therefore, during the second half of September 2020, when our project data gathering took place, the country had been in the "new normality" for more than 3 months. Travel restrictions were way more relaxed compared to the previous months and the urban transportation dynamics more normalized. Therefore, we think that the potential bias of replies is much lower than compared with other COVID-19 windows. Finally, future research must consider making a distinction between mechanical and electric bicycle-sharing, as more accurate profiles and modal mixes would appear from the analysis.

In conclusion, our findings help to better understand micromobility behaviour in all of their complexities, and to depicting micromobility users not as a monolithic community. Without a deep understanding of micromobility multimodality, cities are left to plan based

on trial and error, resulting in inefficient and often unsustainable infrastructure. For the future, more research is needed to better understand how and why different modes are used, and whether these decisions are based on habit or are made on a trip-to-trip basis.

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Author contribution ORC designed the conceptualization of the paper, the data curation, the formal analysis and the methodology. He also contributed in the software, the validation and the visualization process. He led the writing of the original draft preparation OM undertook the validation and the writing—review and editing process. He also was in charge of the supervision and the project administration. AAL undertook the methodology, the software, the validation and the formal analysis. As well he contributed to the writing—review and editing process. CMG contributed to the resources, supervision and project administration part of the paper. VVA led the methodology and the formal analysis. She also contributed to the writing-review and editing process.

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Declarations

Conflict of interest The authors declare no competing interests.

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