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Riding to health: Investigating the relationship between micromobility use and objective physical activity in Barcelona adults

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ABSTRACT

Background: In recent years there has been an increase in the use of micromobility devices in cities worldwide. Due to their novelty, their effects on population health are still unknown. In this study, we aim to explore the association between conventional and electric micromobility modes and daily physical activity levels in an adult population in the city of Barcelona.
Methods: Tracking data for 129 adults were collected in 2020 and 2021 as part of the NEWMOB project. Participants each wore an accelerometer and answered daily travel diaries for a week. Participants reported their daily use of micromobility devices through the travel log. Objective daily reports of physical activity levels were obtained from the accelerometer data. Statistical analysis explored the association between self-reported use of micromobility modes -shared bike, shared e-bike, e-scooter- and objective levels of physical activity.
Results: On average, bike users, and users that combined different micromobility modes reported higher daily time spent in moderate-to-vigorous physical activity (MVPA) than other users. The lowest mean daily levels of MVPA were found among electric scooter users and non-micromobility users. In terms of light activity levels, the highest mean daily levels correspond to users of mixed modes and electric scooters. Analysing health guidelines compliance, bike users and mix modes users were the groups that more often met physical activity guidelines.
Conclusions: Micromobility modes such as conventional and electric bikes can help to maintain high levels of MVPA, while meeting health guidelines, in contrast to e-scooters.

1. Introduction and theoretical framework

Active travel and active modes of transport are increasingly seen as key elements to promote physical activity at the population level. The World Health Organization (WHO) recommends undertaking at least 150–300 min of moderate-intensity or 75–150 min of vigorous-intensity aerobic physical activity throughout the week, for substantial health benefits (World Health Organization, 2020). However, evidence suggests that worldwide, 23% of adults do not meet the WHO global recommendations on physical activity (World Health Organization, 2013), and instead spend most of their waking day inactive. This physical inactivity increases the risk of mortality and morbidity from chronic non-communicable diseases (NCDs), which account for 60% of all deaths worldwide (Lee et al.,

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2012). Across its many different forms, daily physical activity (PA) has multiplicative benefits for health, partly linked with activity resulting from travel, such as by walking or cycling. Therefore, apart from meeting the physical recommendations established by the WHO, active travel present specific health benefits such as improving cardiovascular fitness and reduce the risk of heart disease, stroke, and other cardiovascular conditions; burn calories and promote weight loss or maintenance; reduce stress, improve mood, and reduce the risk of depression and anxiety; improve cognitive function; and, reduce the risk of chronic diseases such as type 2 diabetes, certain cancers and osteoporosis, among others (Doorley et al., 2015; Lee et al., 2012; Mueller et al., 2015; Raustorp and Koglin, 2019; Rojas-Rueda et al., 2016; Saunders et al., 2013). In this context, the increasing adoption and popularity of micromobility as a new mode of transport is opening new research questions regarding whether these new vehicles can further promote, or rather discourage, active travel (Abduljabbar et al., 2021; Castro et al., 2019; Sanders et al., 2022).

In general, micromobility refers to human or electric-powered light, small-sized vehicles such as bicycles, e-bikes, e-scooters, and various other electrically powered micro-vehicles, for both shared and private use. While the literature has long demonstrated how conventional bike users are more prone to maintain a physically active lifestyle together with better mental health and wellbeing levels (Castro et al., 2019; Ma et al., 2021; Oja et al., 2011; Otero et al., 2018; Raustorp and Koglin, 2019; Woodcock et al., 2014), to date not much evidence exists on the link between electric micromobility modes such as electric bikes or electric scooters and physical activity. Because the electrical assistance likely reduces PA exertion, it is possible that e-bikes and e-scooters generate less overall physical activity levels, given that travel conditions and routes do not change. Researchers have thus expressed concerns that in the case where e-micromobility modes end up replacing active forms of transport, such as walking and conventional cycling, this would eventually lead to a decrease in the population's PA levels (Glenn et al., 2020; Sanders et al., 2022). This is a relevant issue in the case of e-scooters, with some arguing that they may be used as a substitute for walking or biking, particularly for shorter trips, which could reduce the overall physical activity levels of the population (Glenn et al., 2020; Sanders et al., 2020, 2022). Another concern is that e-scooters may be used to facilitate the so-called "last mile" of a trip, which could discourage walking or biking for that portion of the journey (Sanders et al., 2020). This could potentially reduce the physical activity levels of individuals who might otherwise walk or bike for the entire trip or even lower trip-level physical activity of those choosing to use public transport. This debate, however, is far from closed as others have argued that depending on the e-micromobility vehicle chosen, and thanks to the electrical assistance provided, longer distances can be travelled, with increased distance, duration, and frequency potentially compensating for the reduced PA exertion (Bourne et al., 2018, 2020; Castro et al., 2019).

Additionally, it is important to consider what is behind micromobility schemes, including shared bike programs, as these often have both public policy and commercial aspects. These schemes are often implemented as part of governmental initiatives to promote active transportation and improve public health (Woodcock et al., 2014). However, many micromobility schemes are also operated by private companies with the goal of generating revenue (Fitt and Curl, 2020). These companies may offer services such as bike or scooter sharing to tap into consumer demand and take advantage of behavioural tendencies towards more convenient forms of transportation. This mix of public policy and commercial interests can create challenges and controversies in the implementation and operation of micromobility schemes (Abduljabbar et al., 2021; Latinopoulos et al., 2021). For example, there may be tensions between the goals of promoting active transportation and improving public health, and the goals of maximizing profits and minimizing costs from private operators. Overall, it is important to consider the public policy and commercial aspects of micromobility schemes when evaluating their impact on active transportation and public health, and to consider the potential trade-offs and challenges that may arise.

In terms of PA, to date, most of the evidence linking PA levels with e-micromobility are focused on e-bike use (Castro et al., 2019; Gojanovic et al., 2011; Peterman et al., 2016; Sperlich et al., 2012). Previous studies have commonly presented Metabolic Equivalent of Task (MET) values of about 4–7 METs for the e-bike, depending on the assistance mode chosen, terrain covered, and the rider's intrinsic PA motivation (Alessio et al., 2021; Bini and Bini, 2020; Bourne et al., 2018). According to international standards, 3–5.9 METs correspond to moderate and >6 METs correspond to vigorous intensity PA (World Health Organization, 2020), which would mean that e-cycling falls under moderate-to-vigorous intensity PA, and if performed regularly, would lead to compliance with PA guidelines, and the maintenance and improvement of health status (Bernstein and McNally, 2017; De Geus and Hendriksen, 2015; Hoj et al., 2018; Langford et al., 2017).

Furthermore, several studies have found that e-bikes strongly appeal to groups with little interest in PA, a behaviour most likely explained by motivations of hedonism, as individuals who score high on hedonism are found to be less likely to engage in physical activity or travel by active mobility (Sundfor et al., 2017), and therefore, resulting in a positive net effect of e-bike use from a public health perspective (Fyhri et al., 2017; Jahre et al., 2019; Van Cauwenberg et al., 2018). Because of this combination of longer and more sustained travelling and the high rate of adoption among low-PA population groups, some authors have concluded that e-biking can, in fact, serve as a gateway to active transportation (and PA) for sedentary individuals (Langford et al., 2017; Mildestvedt et al., 2020; Sperlich et al., 2012).

While the evidence on PA levels associated with e-bike use is quite solid, little evidence exists on the PA levels associated with e-scooter use. The debate in this regard focuses on both the exact PA derived from e-scooter use, and on how this PA would replace the PA gained from the mode of transport used before switching to the e-scooter (Sanders et al., 2022). As such, some e-scooter operators argued that e-scooters offer a low-intensity workout that can help increase core strength, and exercise the legs by putting a positive demand on the muscles to stabilise the body on the vehicle. A recent study using objective PA data found a potential increase in PA resulting from standing in comparison to sitting when using the car or public transport (Glenn et al., 2020). The study by Ognissanto et al. (2018) found that e-scooter users reported perceiving that they were increasing their PA levels when replacing short car journeys for e-scooter rides. A consensus seems to exist that switching to an e-scooter from a car would generate a net PA gain. However, studies on travel behaviour and travel mode change suggest that e-scooters are seldomly replacing car use, and are actually replacing active travel modes. Most new e-scooter users are former pedestrians, or public transport users, which would have potentially negative effects on overall PA levels (Christoforou et al., 2021; Felipe-Falgas et al., 2022; Glenn et al., 2020; Kopplin et al., 2021; Sanders et al., 2020, 2022)..

Most past research has relied on self-reported instruments to assess PA, such as questionnaires and ad hoc surveys among micromobility users, mainly due to their advantages in terms of cost and post-processing. Questionnaires can provide valuable information in terms of contextual socioeconomic conditions of the person travelling, along with self-assessed reports of time spent travelling in each mode of transport and type of PA (Troiano et al., 2014). However, they also entail some measurement challenges and misclassifications, including reporting biases, variability in perception, reliability and validity issues, and difficulties when aiming at consistently report time spent in each mode of transport (Matthews et al., 2012; Shephard, 2003; Sylvia et al., 2014). Aiming at overcoming part of these limitations, recent studies have started to use accelerometers as these dedicated wearable devices provide objective and more precise measures of PA (Plasqui et al., 2013; Rowlands, 2018, 2018van Hees et al., 2011; White et al., 2016, 2019; Wijndaele et al., 2015). One advantage of dedicated accelerometers is that they provide accurate measures of daily PA (Murphy, 2008), while they are also valid and reliable predictors of the total amount of PA, and energy expenditure (Liu et al., 2021). Transport and travel studies have incorporated accelerometers in an attempt to relate PA levels with daily commuting and different travel modes, thus numerous studies have relied on these devices to derive objective measures of PA associated with active travel (Brondeel et al., 2016; Delclòs-Alió et al., 2019; Duncan et al., 2016; Marquet et al., 2018, 2022; Mendinueta et al., 2020; Miller et al., 2015; Oliver et al., 2010; Pizarro et al., 2016; Yang et al., 2012).

Despite the fact that accelerometer-based studies are becoming increasingly more present in transport research, there still exists little evidence of PA related to micromobility use. Furthermore, most of the existing literature focuses exclusively on conventional bikes and shared bike services whereas, to our knowledge, almost no study has focused on PA derived from e-scooter use. This limited available evidence needs to be acknowledged, as PA levels may strongly vary depending on the micromobility mode used, the presence or not of electric assistance, and the user's personal characteristics and fitness conditions. For that aim, this study examines the daily PA of different micromobility users in Barcelona, northeast Spain. By comparing accelerometer-based daily PA levels of conventional shared bike, electric shared bike, and electric scooter users with those of a control group composed of non-micromobility users, we intend to contribute valuable evidence on the real effects of these modes on the PA of the population. Additionally, we also test the likelihood of each group of users complying with PA health guidelines and recommendations.

2. Materials and methods

2.1. Study sample

In 2020, the NEWMOB study surveyed 902 micromobility users in the city of Barcelona, northeast Spain. The aim of this project was to examine the travel behaviour of micromobility users residing or working in Barcelona, as well as the impact of COVID-19, in terms of their adoption and usage of micromobility. Between September 15th and October 1st of 2020, 8 pollsters were distributed in strategic points of the city of Barcelona during working days between 9 a.m. and 8 p.m. Through a Computer Assisted Personal Interviewing (CAPI) technique, private e-scooter and bike sharing (both in conventional and electric modality) users were randomly stopped and asked to answer a questionnaire that took 10–15 min. Because of Barcelona City Council ban prohibiting e-scooter companies to operate within the city boundaries, only private e-scooter users were eligible as questionnaire respondents. Participants were intercepted just before they would start a trip, during an ongoing trip or immediately after finishing a trip. At the end of the two-week survey, the sample was composed of 326 electric scooter users, 251 moped scooter users, 217 traditional bike users, and 108 electric bike users (Roig-Costa et al., 2021). Survey responses were restricted to individuals living and/or working in Barcelona and reporting their age as 16 years or over. The age was set at 16 years mainly for two reasons: firstly, the minimum age allowance to drive an electric scooter in Barcelona is 16 years; secondly, Barcelona's public bike sharing system allows people over 16 years of age to use the service. The survey included blocks of questions on socio-demographic characteristics, basic information, the use of transport systems, relation to other modes of transport and multimodality, and the use of public space and mobility.

From this initial sample, a subsample of participants, called the experimental group, was further selected to participate in a tracking study using dedicated GPS and accelerometer devices. We randomly selected a representative subsample from the baseline survey that was formed by 204 micromobility users (65 e-scooters, 28 moped scooters, 74 conventional bikers, and 37 e-bike users). An additional control group consisting of 43 non-micromobility users was formed for comparison purposes. This control group consisted of individuals that did not use any micromobility mode, therefore, they are users of the remainder available modes (i.e., active modes, public transport, private transport). The control group was designed to mirror the composition of the study group in terms of age, gender and socioeconomic status. A total of 247 individuals participated in the tracking study. After signing an informed consent, participants were administered a baseline questionnaire regarding their basic sociodemographic characteristics, along with their self-reported health and PA habits. At that stage, participants were also provided with an accelerometer device (GT3X-BT; ActiGraph LLC, Pensacola, FL, USA) and a GPS device (BT-Q1000X; QStarz, Taiwan, R.O.C.) along with instructions on how to wear the devices for 7 days, starting on the day of recruitment. Both devices had to be worn over the right side of the hip during the day, except when having contact with water (showering, swimming), during contact sports, and night-time sleeping. Participants were also asked to fill in a daily travel diary, administered at the end of each participated day through smartphone messages, in order to facilitate posterior cross-check and transport-mode attribution of their trips, and to facilitate interpretation of accelerometer-recorded PA levels.

The study setting was the municipality of Barcelona, which is dominated by continuous and compact urban areas with constant high densities and mixed land uses (Marquet and Miralles-Guasch, 2018). Overall, Barcelona's built environment and specific conditions made it popular in terms of micromobility usage, as well as representative of historical European cities characterized by dense and compact urban environments where these new modes are in a competitive situation over space with pedestrians, bike users, and cars (Esztergár-Kiss and Lopez Lizarraga, 2021).

2.2. *Physical activity variable*

Objective PA was measured by a triaxial Actigraph wGT3X-BT. Participants' daily data were considered valid if they had worn the device for a minimum of 8 h each day. Non-wearing time was defined as intervals of 90 min without recorded activity data, and sleeping hours were not considered. Accelerometer raw data were uploaded to ActiLife software (https://actigraphcorp.com/actilife/), from which activity intensities were obtained in terms of daily minutes of sedentary, light, moderate, vigorous, and very vigorous activity levels. For the present analyses, a composite measure reflecting moderate-to-vigorous physical activity (MVPA) was created, including the total time spent in moderate, vigorous, and very vigorous activity intensity levels. Following the standard practice in the field, the present analysis uses a three-level PA classification: sedentary, light, and MVPA activity levels (Hajna et al., 2019; Marquet et al., 2018, 2019, 2020; Pizarro et al., 2016; Vich et al., 2021).

Self-report PA data were obtained through the baseline questionnaire administered on the recruitment day using the International Physical Activity Questionnaire (IPAQ) short form. The IPAQ is formed by open-ended questions surrounding individuals' last 7-day recall of physical activity, and has been rigorously tested for reliability and validity (Craig et al., 2003). Additionally, the daily travel diary gave us information about the number of trips taken by each participant, and the specific travel mode(s) used. Other contextual information in the analysis included the sociodemographic characteristics of the participants: age (categorised from 16 to 29 years; from 30 to 44 years; 45 years and older), sex (male, female), educational level (primary school, high school, college/university) and professional status (student, active, retired). Moreover, Body Mass Index (BMI) was calculated, based on self-reported height and weight. Participants were further categorised as underweight, regular weight, overweight, or obese based on BMI values (Giné-Garriga et al., 2020; Mendinueta et al., 2020; National Center for Chronic Disease Prevention and Health, 2022; White et al., 2016).

2.3. *Data analysis*

Firstly, a descriptive analysis of our sample was conducted. Sample characteristics were assessed regarding age, sex, occupation, education, and BMI category. Participants were asked to self-identify which was the mode of micromobility that they used the most. This information was used to group participants into e-bike, bike, or e-scooter users. Secondly, we used daily travel logs to identify the use of any micromobility mode during any participated day. This double classification process was needed because self-identified e-scooter users might also use shared bikes or e-bikes on a particular day, or even not use any micromobility device during a whole day. Thus, all valid participated days were classified, based on whether or not the user had actively used a specific micromobility mode. That created 5 categories grouping participated days as days on which they had used (1) electric scooter, (2) conventional shared bike, (3) electric shared bike, (4) a combination of two or more micromobility modes, and (5) no micromobility vehicle used.

Thirdly, we assessed whether each participated day had met the PA guidelines set by the WHO in terms of MVPA (World Health Organization, 2020). We also calculated the daily minutes of sedentary, light, and MVPA physical activity, and used a one-way ANOVA

Table 1
Characteristics of the study population, overall and by type of user.

Sample characteristics (n = 129)	Overall	Experimental group			Control group
		Electric scooter	Conventional shared bike	Electric shared bike	
N	*129*	*36*	*44*	*24*	*25*
Demographics					
Male	73 (56.59%)	21 (58.33%)	24 (54.55%)	15 (62.50%)	13 (52.00%)
Age, years (mean (SD))	33.43 (10.58)	33.25 (11.68)	30.77 (10.51)	35.54 (9.45)	36.36 (9.38)
Age, years					
16–29	52 (40.31%)	17 (47.22%)	23 (52.27%)	6 (25.00%)	6 (24.00%)
30–44	58 (44.965)	13 (36.11%)	17 (38.64%)	15 (62.50%)	13 (52.00%)
45+	19 (17.73%)	6 (16.67%)	4 (9.09%)	3 (12.50%)	6 (24.00%)
Education level					
< High school	5 (3.88%)	1 (2.78%)	2 (4.55%)	2 (8.33%)	–
High school	48 (37.21%)	22 (61.11%)	12 (27.27%)	10 (41.67%)	4 (16.00%)
College/University	76 (58.91%)	13 (36.11%)	30 (68.18%)	12 (50.00%)	21 (84.00%)
Professional status					
Student	12 (9.30%)	1 (2.78%)	9 (20.45%)	1 (4.17%)	1 (4.00%)
Active	115 (89.15%)	33 (91.67%)	35 (79.55%)	23 (95.83%)	24 (96.00%)
Retired	2 (1.55%)	2 (5.56%)	–	–	–
BMI (kg/m^2)					
Mean (SD)	23.56 (4.28)	23.97 (4.22)	23.69 (5.35)	24.42 (3.23)	21.91 (2.58)
Low weight (<18.5)	3 (2.33%)	1 (2.78%)	1 (2.27%)	–	1 (4.00%)
Regular weight (18.5–25)	91 (70.54%)	25 (69.44%)	32 (72.73%)	13 (54.17%)	21 (84.00%)
Overweight (25–30)	30 (23.26%)	8 (22.22%)	9 (20.45%)	10 (41.67%)	3 (12.00%)
Obesity (≥30)	5 (3.88%)	2 (5.56%)	2 (4.55%)	1 (4.17%)	–

Note. SD = standard deviation; BMI = body mass index.

on a bivariate analysis between the PA levels and the type of participated day. This preliminary analysis was aimed at finding statistically significant differences in PA levels between the modes of transport used.

Finally, we used a multilevel linear regression to examine the association between objective measures of PA and the mode of transport used during the participated day, while controlling for a wide set of individual confounders (age, sex, educational level, professional status, and BMI index). We used 3 Fit Linear Mixed-Effect Models from the lme4 package in R software v. 1.4.1717 (Bates et al., 2015) with subject ID acting as a random effect. This modelling design has often been used in similar transportation studies (Kang et al., 2017; Koohsari and Oka, 2020; Seto et al., 2016) in order to account for the nested nature of the data: participated days belonging to the ID of specific subjects.

3. Results

3.1. Descriptive characteristics

The definitive data set used for the analysis consisted of 386 days that belonged to 129 individuals distributed between 36 electric scooter users, 44 conventional shared bike users, 24 electric shared bike users and 25 from the control group (non-micromobility users). Characteristics of the study population are presented in Table 1. In brief, participants were, on average, 33.43 years of age and with regular weight (mean BMI of 23.56 kg/m^2), although 23% were overweight. Slightly more than half of the participants were men (57%), and college/university-educated (59%). Overall, 89% of participants were employed. Compared with other user groups, electric shared bike users were more likely to be men (63 vs. 58, 55, and 52%), between 30 and 44 years of age (63 vs. 36, 39, and 52%), and overweight (42 vs. 22, 20, and 12%). In terms of education level, electric scooter users were more likely to be low educated (i.e., high school level) (61 vs. 27, 42, and 16%), while the control group (i.e., non-micromobility users) were more likely to have a college or university education (84 vs. 36, 68, and 50%).

The classification of valid days according to the type of mode used and how the participants defined themselves is presented in Table 2. According to the table, self-defined electric scooter users used this mode on 76% of the days reported, and on the remaining days they did not use any micromobility mode. Contrarily, conventional bike users only used the bike on half of the reported days (52%), the rest of the days using the electric bike (7%), combining different micromobility modes (8%), or not using any micromobility mode (33%). In the case of electric bike users, they only used this mode on 19% of the days, reporting having used the conventional bike even more (31%). These users also report days when they did combine micromobility modes (8%) and not used them (36%). All of these modes account for 301 valid reported days, to which reported days by the control group were added for the analysis. In total, 386 days were used.

3.2. Physical activity analysis

For the aims of the statistical analyses, we used the average mean times that were accumulated per participant and per day. These mean times were classified according to the different PA intensity levels (moderate-to-vigorous (MVPA), light, and sedentary), and in relation to the total daily wearing time of each participant (Table 3). With this approach, we were able to compare the PA time of participants with different numbers of participated and valid days.

Participants that had used an e-scooter during the day were found to have the lower MVPA levels, accumulating 7% of their logged time in MVPA, but they also presented lower levels of sedentary behaviour (65% of daily wearing time). Also, it appears that e-scooter use was associated with more light PA during the day (28% of the time). This contrasts with days on which participants had used either the conventional or shared bike, associated with higher MVPA daily levels (9 and 11% of the time, respectively). However, sedentary behaviour was also found to be as high (68 and 70%). Therefore, there is a consistent low level of light PA among bike and e-bike users, especially in the case of the e-bike. When combining two or more micromobility modes during the same day, high levels of MVPA are found (10%), as well as the lowest time spent in sedentary activities (58%). Consequently, much time is also spent in light PA (32%), compared to the rest of the modes. Further, low levels of MVPA are present when any micromobility mode is used (9%), along with a considerable amount of time dedicated to sedentary activities (70%). Finally, the low levels of MVPA in the control group are in line with those days when e-scooter is used (in both cases 7% of the time). But, in that case, a longer time is allocated to sedentary

Table 2
Valid days (wearing time of at least 8 h/day) by transport mode used [a].

Days on which mode was used	Self-reported preferred main mode			
	Electric scooter	Conventional shared bike	Electric shared bike	Total days
Electric scooter	64 (76.19%)	0 (0.00%)	0 (0.00%)	64
Conventional shared bike	0 (0.00%)	69 (51.88%)	26 (30.95%)	95
Electric shared bike	0 (0.00%)	9 (6.77%)	16 (19.05%)	25
Mixed modes	1 (1.19%)	11 (8.27%)	12 (14.29%)	24
No micro modes	19 (22.62%)	44 (33.08%)	30 (35.71%)	93
Control group	–	–	–	85
Total	**84 (100.00%)**	**133 (100.00%)**	**84 (100.00%)**	**386**

[a] Values are reported as n (%).

Table 3

Average amount (in %) of daily time spent in MVPA, light, and sedentary activity (of the total wearing time), by mode of transport used, expressed by Mean, SD, Median, and ANOVA (p-value).

Average daily time spent (in %)	MVPA				Light				Sedentary			
	Mean	SD	Median	p-value	Mean	SD	Median	p-value	Mean	SD	Median	p-value
Electric scooter	7.09 [a]	5.32	6.11	0.025*	28.19	11.29	26.25	<0.01***	64.72	12.64	64.54	0.025*
Conventional shared bike	9.46	4.83	8.47	0.044*	22.77	9.33	21.13	0.172	67.77	10.69	69.54	0.834
Electric shared bike	10.75	5.75	8.61	0.032*	19.69	4.20	19.69	0.023*	69.57	7.38	67.50	0.35
Mixed modes	10.29	4.94	10.20	0.094	31.64	13.54	30.72	<0.01***	58.07	13.52	59.48	<0.01***
No micro modes	8.72	6.25	7.19	0.629	21.68	7.69	20.52	<0.01**	69.59	9.85	72.64	0.042*
Control group	7.09	4.71	5.77	<0.01**	23.66	8.84	23.65	0.754	69.37	10.13	68.88	0.096
Total	**8.49**	**5.44**	**7.26**	**<0.01*****	**23.96**	**9.74**	**21.93**	**<0.01*****	**67.56**	**11.08**	**68.48**	**<0.01*****

Note. MVPA = moderate-to-vigorous physical activity; SD = standard deviation.

[a] Values are reported as a percentage (%). Total wearing time represents 100%.

behaviour (69%), and not to light PA (24%).

3.3. *Adherence to physical activity guidelines*

With regards to the PA guidelines compliance, and according to Table 4, days on which participants had used the electric bike, the conventional bike, or a mix of two-or-more micromobility modes resulted in always recording PA above the guidelines. On the other hand, the lowest scores are linked to the use of electric scooters, as only 58% of participated days that an e-scooter had been used met the PA guidelines. Overall, all the micromobility modes and combinations, except for the e-scooter, were more likely to meet PA recommendations than the control group (65%).

3.4. *Multivariate results*

In Table 5, Models 1, 2, and 3 examine the associations between the different modes used and the levels of physical activity (MVPA, light, and sedentary) in terms of daily time spent out of the total wearing time. All three models are adjusted by age, gender, educational level, professional status, and BMI. Additionally, the models presented were used to obtain adjusted daily time estimates at the three different activity levels, in relation to the mode used (Fig. 1).

In Model 1, the MVPA daily time (in relation to the control group that is the reference group in the model) was positively associated with the use of both shared conventional (coefficient = 0.023, p = .032) and shared electric bikes (coefficient = 0.047, p = .001), the use of mixed modes (coefficient = 0.038, p = .01), and not using any micromobility mode (coefficient = 0.024, p = .03). However, it was not associated with the use of electric scooter (coefficient = 0.007, p = .56). The adjusted estimates calculated at mean values of the covariates show that the highest MVPA levels were found among those days on which participants chose to use the electric shared bike (13%) or a combination of two-or-more micromobility modes (12%). E-scooters where the micromobility modes associated with a lower MVPA amount even when adjusting for the gender, age, education level and professional status of their users. In terms of light PA, mixed modes (27%) and electric scooters (26%) present the higher percentages, as opposed to electric bikes (20%) and the no usage of micromobility modes (21%). Finally, more time is spent in sedentary activities by the control group (69%) and when not using micromobility modes (68%). Indeed, days when modes are combined present the less amount of time (62%) dedicated to sedentary activity.

Additionally, two goodness-of-fit measures, including Akaike Information Criterion (AIC) and R-squared were employed to test the data fitting performance of the three models presented. As well, to test the residuals of the models, we used Root Mean Squared Error (RSME) as the evaluation metric. The results of the RSME for the different models are as follows: 0.04 for Model 1, 0.05 for Model 2, and 0.07 for Model 3.

4. Discussion and conclusions

This study aimed to assess the associations between transport mode used for daily trips by micromobility users and daily time spent in different PA intensities, in the city of Barcelona. To do so we used moderate-to-vigorous (MVPA), light, and sedentary PA obtained through accelerometer assessments. The analysis combined objective data on PA, and self-reported data on the daily mode used. The relationships we have found contribute to a better understanding of the PA levels of micromobility users and the importance that the daily modal choice has in complying with health guidelines.

To the best of our knowledge, this study is one of the first to assess the daily PA levels of micromobility users. Further, the strength of this study is in: (1) the use of both objective and self-reported data to assess PA levels; (2) the reliability of accelerometry-based determination; and (3) the specificity of our sample regarding micromobility modes of transport.

Our results find that, in general, micromobility users are more active than the control group, even when adjusting by socio-demographic characteristics of individuals. Also, a clear distinction is established between the PA levels gained by those using shared bikes, shared e-bikes, and e-scooters. While shared bikes and e-bikes dedicate 10% of their daily time to MVPA, electric scooters account for only 7%, on average. These results are consistent with previous research showing that the use of electric scooters cannot be considered as active travel (Glenn et al., 2020; Sanders et al., 2022). The recent study by Sanders et al. (2022), for example, compared the PA gained from e-scooter trips with that of auto trips, and found that e-scooter trips were approximately as active as auto trips. In our study, PA gained in days on which the e-scooter was used was significantly lower than that gained by those who used other

Table 4
Days meeting MVPA World Health Organization guidelines by mode of transport used (MVPA ≥30 min/day).

Transport mode used		Number of days meeting PA guidelines	Number of days NOT meeting PA guidelines	Total days
Experimental group	**Electric scooter**	37 (57.81%) [a]	27 (42.19%)	64 (100.00%)
	Conventional shared bike	88 (92.63%)	7 (7.37%)	95 (100.00%)
	Electric shared bike	24 (96.00%)	1 (4.00%)	25 (100.00%)
	Mixed modes	22 (91.67%)	2 (8.33%)	24 (100.00%)
	No micro modes	71 (76.34%)	22 (23.66%)	93 (100.00%)
Control group		55 (64.71%)	30 (35.29%)	85 (100.00%)

[a] Values are reported as n (%).

Table 5

Fit Linear Mix Effects Models: Linear associations of Mode Used with PA (all kinds).

	Model 1				Model 2				Model 3			
	Moderate-to-vigorous physical activity				Light physical activity				Sedentary physical activity			
	Coeff.	Std. Err.	t value	P > |z |	Coeff.	Std. Err.	t value	P > |z |	Coeff.	Std. Err.	t value	P > |z |
Mode Used Control group (REF)												
Electric scooter	0.007	0.012	0.583	0.560	0.030	0.023	1.334	0.182	−0.040	0.026	−1.549	0.121
Shared bike	0.023	0.011	2.144	**0.032***	−0.004	0.020	−0.209	0.834	−0.018	0.023	−0.777	0.437
Shared e-bike	0.047	0.014	3.293	**0.001*****	−0.027	0.025	−1.091	0.275	−0.018	0.029	−0.631	0.528
Mixed modes	0.038	0.015	2.576	**0.010****	0.035	0.025	1.423	0.155	−0.078	0.029	−2.676	**0.007****
No micro modes	0.024	0.011	2.175	**0.030***	−0.019	0.020	−0.927	0.354	−0.004	0.023	−0.170	0.865
Age 16–29 (REF)												
30–44	−0.011	0.009	−1.209	0.227	0.001	0.017	0.051	0.959	0.011	0.019	0.603	0.546
45 +	−0.010	0.013	−0.745	0.456	0.013	0.025	0.523	0.601	0.001	0.028	0.029	0.977
Gender **Female (REF)**												
Male	0.005	0.008	0.626	0.531	−0.033	0.015	−2.220	**0.026***	0.028	0.017	1.683	0.092
Occupation Active (REF)												
Student	−0.000	0.015	−0.003	0.998	−0.047	0.028	−1.650	0.099	0.047	0.032	1.484	0.138
Retired	0.022	0.035	0.641	0.521	0.049	0.065	0.740	0.460	−0.079	0.074	−1.071	0.284
Education University (REF)												
< High school	0.019	0.015	1.270	0.204	0.024	0.029	0.843	0.399	−0.042	0.031	−1.333	0.183
High school	−0.005	0.009	−0.529	0.597	0.028	0.018	1.606	0.108	−0.021	0.020	−1.033	0.302
BMI Low weight (REF)												
Regular weight	−0.009	0.029	−0.321	0.748	0.016	0.052	0.313	0.755	−0.006	0.059	−0.102	0.919
Overweight	−0.014	0.028	−0.470	0.638	0.034	0.055	0.620	0.535	−0.020	0.061	−0.325	0.745
Obesity	−0.036	0.034	−1.054	0.292	0.016	0.065	1.506	0.132	−0.052	0.072	−0.719	0.472

***: $p < .001$; **: $p < .01$; *: $p < .05$.

Akaike's Information Criterion (AIC): 1176.47 (Model 1); −857.32 (Model 2); −683.77 (Model 3).

R-squared: 0.35 (Model 1); 0.63 (Model 2); 0.50 (Model 3).

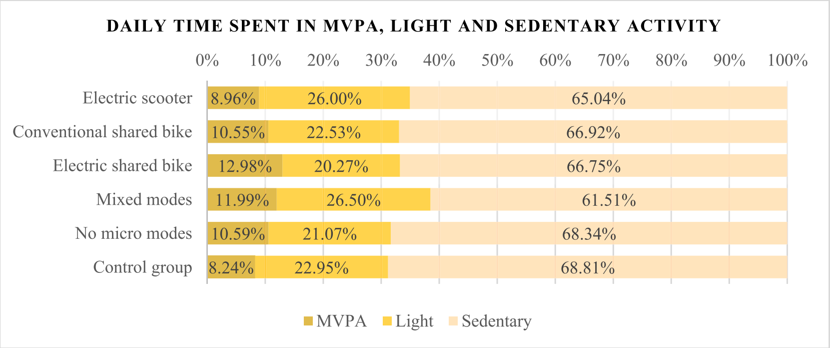

Fig. 1. Model estimates of daily time spent in PA (all kinds) by mode used.

micromobility devices, and only slightly higher (in terms of light PA) than that gained by the control group consisting of non-micromobility users. E-scooter usage was associated with lower levels of higher intensity PA, but also with lower levels of sedentary behaviour. This finding clearly suggests that e-scooter users are spending more time being active, albeit in less physically intense activity than other modes. In comparison, shared bikes and shared e-bikes registered more intense physical activity patterns, but fewer overall daily minutes of activity (MVPA + light), and thus more sedentary time.

On the other hand, shared e-bikes presented slightly higher levels of MVPA than shared bikes (11 versus 9% of daily time, on average). This may be caused by a rebound effect, as the electric assistance of e-bikes makes them easier to ride, so that users could cover longer distances and thus spend more time e-biking (Bourne et al., 2020; Castro et al., 2019). It also may be a measurement error, in the sense that accelerometers do not really distinguish activity coming from pedalling assistance, hence they may not be accurately assessing the physical exertion that is carried out by the individual wearing it. Further research will be needed in this area, in order to test the sensitivity capacity of accelerometers with respect to accurately detecting PA while e-biking. More research will also be needed to understand significant differences in how conventional and electric bikes travel around the city (speeds, acceleration, distances, routes, etc.); and furthermore, to comprehend the way users perceive the PA gained by means of the conventional and electric bike (Roig-Costa et al., 2021).

Surprisingly, logged levels of light PA were low for both shared bikes and e-bikes. This result is somewhat unexpected in a city like Barcelona, where the shared bike system is based on a docked scheme that makes it necessary for users to walk to/from the station. We found no evidence that walking might be resulting in more light PA, which might suggest that cycling has such a high degree of efficiency, that even considering this light PA at the beginning and end of the trip, total PA levels are lower than other modes.

From our results, we also found an association between using a micromobility mode during the day and meeting daily WHO PA health guidelines. Setting the reference at the minimum requirement of time of 30 min of MVPA daily, more than 90% of days when conventional and electric bikes, as well as mixing modes, are used, fulfils this activity goal. Interestingly, this diverges from the percentage of complying days when the electric scooter is used, which slightly achieves 60%, accounting for the lowest scores from the whole sample included in the analysis. Finally, results from the goodness-of-fit and adjusted models also suggest that all types of modes, except electric scooter, were positively associated with higher daily time spent in MVPA, compared to the control group.

Our findings confirm that micromobility users in Barcelona are gaining more daily PA than our non-micromobility control group. However, a clear divide seems to exist between micromobility modes. While shared bikes and e-bikes are clearly associated with higher levels of MVPA, our results demonstrate that e-scooter cannot be considered as an active mode of transport as e-scooter users are accumulating fewer minutes of MVPA, and are significantly less likely to meet PA recommendation guidelines. These findings have implications for policy makers and transport policy, especially with respect to those planning initiatives that incorporate health and PA criteria. Overall, PA levels are strongly determined by the mode of transport which individuals decide to use (Castro et al., 2019; Dons et al., 2018; Hajna et al., 2019; Miller et al., 2015; Raza et al., 2020; Vich et al., 2019; Woodward and Wild, 2020) and, according to our results, conventional and electric bikes need to be clearly identified as the only active micromobility modes. While e-scooter use is becoming increasingly popular worldwide, cities should still prioritise the promoting of modal shifts towards bike and e-bike. Transport planners should be aware that shifts towards increased e-scooter use will only represent a health net benefit (NHB) when they replace the most sedentary modes of transport, such as the car, as any transfer from walking or biking towards e-scootering will represent a net loss in terms of PA. Overall, travel behaviour, including the modal choice and the amount of physical activity it generates, can have a significant impact on health outcomes as in as cardiovascular health, weight management, mental health, cognitive function and chronic diseases. While substantial research has demonstrated how encouraging active travel can be an effective way to improve public health and reduce the risk of chronic disease, promoting micromobility modes can only be expected to generate similar benefits when a significant share of new micromobility users effectively replace car use for e-scooter or bike sharing.

4.1. Limitations

This study is not without limitations. Firstly, the sample used for this analysis is limited in size and may be biased, in the sense that those who accepted to participate may present better general health conditions and PA levels than the ‘average’ adult population.

Probably, this may have led to an overestimation of the actual fulfilment of the PA recommendations. Moreover, reported valid days were lower in number than expected, considering that participants were told to wear the accelerometer for 7 days, therefore, diminishing the available data for this study. Secondly, PA levels were not limited to trips, but rather to the whole daily accelerometer wearing time. In fact, participants were asked to wear the device the whole day, except at night when sleeping, when doing contact sports/exercise, or when in contact with water, which is common practice in similar studies. Therefore, not all reported PA levels are associated with activity when travelling by a particular mode, but rather with daily activity that is associated with an individual, and influenced by the mode that is used to travel on that day. Thirdly, self-report data from travel diaries were used to classify days according to the mode(s) used, which might be less reliable than if it could be objectively identified. Similarly, we calculated BMI scores using self-reported height and weight data. Finally, as indicated in the methods section, the accelerometers were asked to be worn in the hip when we explained to the participants how to use and wear them. Then, it is worth noting that hip-worn accelerometers may not be as accurate as other methods when assessing physical activity specifically related to cycling or electric scooter use, as these activities involve complex movements of the body that may not be captured as well by a device worn on the hip. In the specific case of assessing physical activity associated with cycling, it is recognized that accelerometers worn on the thigh may provide a more accurate measurement of physical activity. However, these devices may not be as effective at measuring other types of physical activity such as scootering. In fact, hip-worn accelerometers may be more accurate at measuring physical activity compared to, for instance, waist-worn accelerometers, as they are closer to the centre of mass and may be less influenced by movements of the upper body. Overall, we consider that hip-worn accelerometers are a useful tool for assessing daily physical activity in terms of their wide range of applicability, the easy data processing, their cost-effectiveness, and their accessibility, as other transport and health studies indicate (Brondeel et al., 2019; Kerr et al., 2016; Voss et al., 2016; Yang et al., 2012). Still, the limitations of hip-worn accelerometers in the assessment of physical activity associated with micromobility use should be acknowledged, but also considered as an opportunity for research to further advance the field of study.

To conclude, and in order to strengthen the understanding of this matter, future studies should deepen the analysis of PA and micromobility usage, limiting the data to PA exertion while using these modes, and while using larger samples for the analysis. Likewise, it is also important to recognize that pioneering research in these areas has the potential to expand the field of knowledge and contribute to the development of more accurate and efficient measurement tools in the future. And, finally, new studies should be developed in other cities and semi-urban areas, where micromobility is having an important presence in modal share, in order to confirm the findings that are presented in this study.

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CRediT authorship contribution statement

Alexandra Bretones: Conceptualization, Methodology, Validation, Investigation, Resources, Writing - Original Draft, Visualization, Oriol Marquet: Conceptualization, Methodology, Validation, Resources, Writing - Review & Editing, Supervision, Project Administration.

Declaration of competing interest

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