UAB
Universitat Autònoma de Barcelona

On the links between electric micromobility and health in Barcelona. A focus on physical activity

Alexandra Bretones Diaz

On the links between electric micromobility and health in Barcelona. A focus on physical activity

Alexandra Bretones Diaz

GEMOTT
Grupo de Estudios de Movilidad Transporte y Territorio
Departament de Geografia
UAB
Universitat Autònoma de Barcelona

Illustrations by Aitana Giráldez

Tesi Doctoral

ON THE LINKS BETWEEN ELECTRIC MICROMOBILITY AND HEALTH IN BARCELONA. A FOCUS ON PHYSICAL ACTIVITY

Alexandra Bretones Diaz

Co-Directora i Tutora:

Dra. Carme Miralles Guasch

(Departament de Geografia, Universitat Autònoma de Barcelona)

Co-Director:

Dr. Oriol Marquet Sardà

(Departament de Geografia, Universitat Autònoma de Barcelona)

Programa de Doctorat en Geografia

Departament de Geografia

Universitat Autònoma de Barcelona

Bellaterra, maig de 2024

GEMOTT Grupo de Estudios de Movilidad Transporte y Territorio

Departament de Geografia

UAB Universitat Autònoma de Barcelona

Modern societies have become healthier in almost every other respect, but there is a significant exception—humans move less than ever before.

Physical activity is the front-page story here because the health costs of inactivity are so large, and because there are few downsides.

(Woodward & Wild, 2020)

PREFACE

This thesis adheres to the guidelines set forth by the Academic Committee of the Doctoral Program (CAP) within the Department of Geography at Universitat Autònoma de Barcelona (UAB), as outlined in RD 99/2011 and the transitional provision ratified by CAP on October 13th, 2022.

In accordance with the specific stipulations of RD 99/2011, all article-based dissertations must comprise a minimum of three scientific contributions authored by the candidate, either published in academic journals or in the form of books or book chapters, among other formats. These contributions must be either published or at least accepted prior to submission.

Conforming to this regulation, as depicted in Figure 1, the structure of this dissertation is as follows:

- Part I introduces the research, establishes the general theoretical framework, and outlines the research methodology.
- Part II presents the thesis findings, which are derived from three studies published in academic journals.
- Part III encompasses the discussion and conclusionS.
- Part IV contains the references and any annexes.

This doctoral dissertation is founded upon three scientific articles published in international journals. The titles of these papers are provided below:

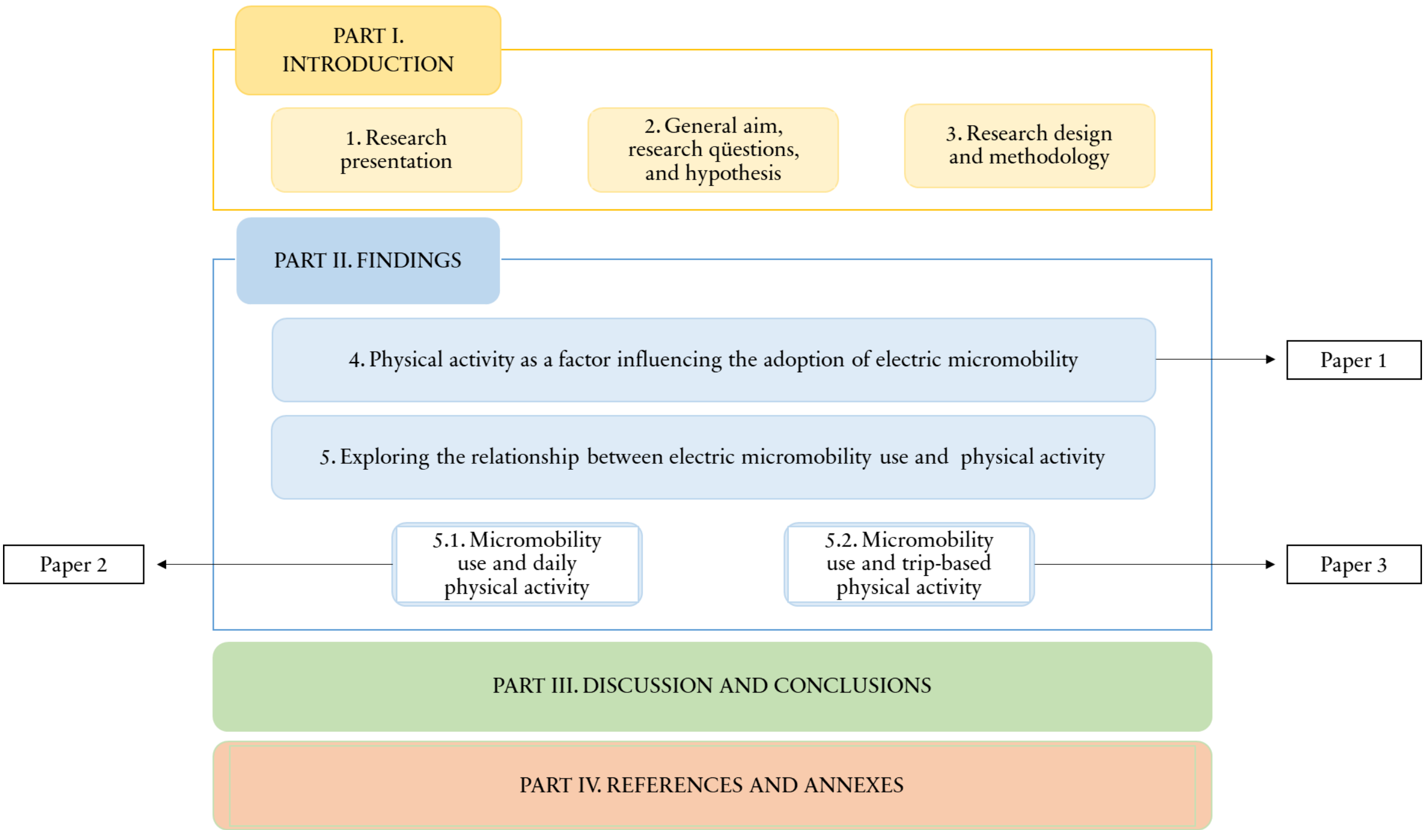
1) **Bretones, A.**, & Marquet, O. (2022). Sociopsychological factors associated with the adoption and usage of electric micromobility. A literature review. *Transport Policy*, *127*, 230–249. https://doi.org/10.1016/j.tranpol.2022.09.008 JCR (2022): Impact Factor = 6.8 / Journal Citation Indicator (JCI) = 1.91 / Journal Ranking by JCI = Q1 (Transportation) and Q1 (Economics)

2) **Bretones, A.**, & Marquet, O. (2023). Riding to health: Investigating the relationship between micromobility use and objective physical activity in Barcelona adults. Journal of Transport & Health, 29, 101588. https://doi.org/10.1016/j.jth.2023.101588

JCR (2022): Impact Factor = 3.6 / Journal Citation Indicator (JCI) = 0.85 / Journal Ranking by JCI = Q2 (Transportation) and Q2 (Public, Environmental and Occupational Health)

3) **Bretones, A.**, Miralles-Guasch, C., & Marquet, O. (2024). Real-world and traffic-adjusted physical activity levels of micromobility modes in Barcelona. Journal of Transport & Health, 34, 101732. https://doi.org/10.1016/j.jth.2023.101732
JCR (2022): Impact Factor = 3.6 / Journal Citation Indicator (JCI) = 0.85 / Journal Ranking by JCI = Q2 (Transportation) and Q2 (Public, Environmental and Occupational Health)

Figure 1 Thesis Structure



Source: own production

This dissertation received support from the Generalitat de Catalunya via an AGAUR-FI grant (2021FI_B 00085), facilitating a dedicated full-time research period of 3 years. Additionally, this doctoral dissertation received support from research projects within the Research Group on Mobility, Transportation, and Territory (GEMOTT) at the UAB:

- **New mobility in the city (NEWMOB). 19S01360 -006. Convocatòria Pla Barcelona Ciencia 2019.** Institut de Cultura, Ajuntament de Barcelona. Period: 01/01/2020- 31/01/2022. Lead researcher: Dr. Oriol Marquet (Universitat Autònoma de Barcelona).
- **Electric, light and shared. The rise of micromobility in Spain and its environmental, social and Health consequences. A multimethod study using GIS, tracking and accelerometry (MICROMOV). PID2019-104344RB-I00. Convocatoria 2019 - «Proyectos de I+D+i».** Ministerio de Ciencia, Innovación y Universidades. Period: 01/06/2020 – 01/06/2023. Lead researcher: Dr. Carme Miralles-Guasch (Universitat Autònoma de Barcelona).
- **Inclusiva, sostenible, saludable i resilient. La mobilitat i la ciutat en l'escenari postpandèmia (PANDÈMIES). 2020 PANDE 00023. Convocatòria Replegar-se per créixer: l'impacte de les pandèmies en un món sense fronteres visibles (Pandèmies 2020)**. AGAUR, Generalitat de Catalunya. Period: 14/05/2021-13/11/2022. Lead researcher: Dr. Carme Miralles-Guasch (Universitat Autònoma de Barcelona).
- **Territorios para la movilidad activa en España. Atlas Movactes 1.0 (MOVACTES). PDC2021-120820-I00. Convocatoria Pruebas de Concepto 2021.** Ministerio de Ciencia, Innovación y Universidades. Period: 01/02/2021 – 30/11/2023. Lead researcher: Dr. Carme Miralles-Guasch (Universitat Autònoma de Barcelona).
- **La transición ecológica en la movilidad y el transporte. El papel de la proximidad urbana (ECOMOV). TED2021-129280B-I00. Convocatoria Proyectos estratégicos orientados transición ecológica y transición digital 2021.** Ministerio de Ciencia, Innovación y Universidades. Period: 01/12/2022 – 30/11/2024. Lead researchers: Dr. Carme Miralles-Guasch and Dr. Oriol Marquet (Universitat Autònoma de Barcelona).
- **Urban Mobility (SGR). 2021 SGR 00577. Convocatòria SGR-Cat 2021.** AGAUR, Generalitat de Catalunya. Lead researcher: Dr. Carme Miralles-Guasch (Universitat Autònoma de Barcelona).
- **Herramientas cartográficas para la gestión sostenible de la movilidad urbana (MOBITOOLS). PDC2022-133212-I00. Convocatoria Pruebas de Concepto 2022.** Ministerio de Ciencia, Innovación y Universidades. Period: 01/12/2022 – 01/12/2024. Lead researcher: Dr. Carme Miralles-Guasch (Universitat Autònoma de Barcelona).

- **Transforming Mobility through Proximity Planning and 15 minute-cities in Spain. Implications for acceptability, social equity, and the environment (Mobififteen). PID2022-136314OB-I00. Convocatoria 2022 - «Proyectos de I+D+i».** Ministerio de Ciencia, Innovación y Universidades. Period: 01/09/2023 – 31/08/2026. Lead researchers: Dr. Carme Miralles-Guasch and Dr. Oriol Marquet (Universitat Autònoma de Barcelona).

AGRAÏMENTS

Aquesta tesi doctoral és fruit de la inquietud i l'esforç personal, d'hores de dedicació a la recerca, del voler saber-ne cada dia una mica més i sempre amb aquella il·lusió quasi infantil de fer que el món sigui una mica millor. També ha sigut possible gràcies a estar obsessionada des de ben petita en ser bona en tot allò que em queia entre mans, a ser bona estudiant, filla, amiga, persona. I això em va portar a tenir l'oportunitat de dedicar uns anys de la meva vida a desenvolupar aquesta recerca, la qual no vaig deixar escapar. Jo, que no sabia que era fer un doctorat, però que fer-me dir doctora sempre m'havia semblat una meta interessant. I per descomptat, tot aquest procés no hagués estat possible sense el recolzament de moltes persones que han estat al meu costat tot aquest temps, i a les quals m'agradaria dedicar les següents paraules.

Primer de tot voldria donar les gràcies a la meva directora de tesi, la Carme Miralles, per haver-me deixat formar part d'aquest gran grup de recerca que lidera, per veure el meu potencial des d'un principi, i motivar-me a millorar constantment. Per ensenyar-me els entrellats de la recerca, a ser forta davant els conflictes, a no tenir por a equivocar-me i sobretot a fer preguntes. Gràcies per la confiança i la dedicació.

Gràcies a l'Oriol Marquet, per ser molt més que el meu tutor i supervisor de tesi, per ser un guia, i per ensenyar-me tant i tant. Va ser ell qui em va mencionar per primer cop la possibilitat de fer un doctorat, per tant, qui em va obrir la porta després d'haver sigut el meu professor al màster, i tutor del treball final de màster, el que constitueix la meva primera contribució a la recerca. Agraeixo sincerament totes les hores de dedicació, les respostes ràpides inclús a les inquietuds més banals, a fer-me sentir vàlida, capaç i independent en la recerca. Admiro molt la teva capacitat com a acadèmic i professional, sempre amb la resposta oportuna a la boca, com si ho sabessis tot. I això m'ha donat molta tranquil·litat durant tot aquest procés, saber que sempre estaves a l'altra banda d'un correu, un slack o una passejada fins al teu despatx per aclarir-me allò que m'inquietés en aquell moment. Gràcies també per contribuir a que la meva recerca sigui de més qualitat, per les infinites correccions, consells i discrepàncies que m'han fet créixer com a investigadora. I per facilitar-me el poder anar més enllà del despatx i compartir la meva recerca fora, participar en altres projectes interessants i fer-me un forat en aquest petit món.

Vull agrair també formar part del GEMOTT (Grup d'Estudis en Mobilitat, Transport i Territori), ja que comptar amb un grup de recerca unit ha sigut clau en el desenvolupament de la meva tesi. No seré jo la persona més sociable del món però sí que necessito de l'energia de socialitzar per seguir funcionant. I l'entorn laboral no n'és una excepció. De fet, des d'un primer moment he sentit que he caminat acompanyada, i que conjuntament formaven un tot del que poder estar orgullosa. És un privilegi haver compartit espai amb totes vosaltres, les que estan des del principi i les que s'han anat incorporant darrerament. Hem fet una bona *pinya* i no canviaria les converses del grup *the office* per res del món. De fet, som afortunades de tenir un grup com el nostre, on tots els dijous a les dues del migdia ens reunim per compartir avenços, recerques que estem iniciant o simplement debatre, xerrar i menjar dolços. Tenir amb qui anar a dinar els dies que estem a la oficina, i a qui demanar consell per qualsevol cosa. Començo agraint a les meves companyes de despatx, a la Jerònia, que ja ens coneixíem del màster i a la que considero una bona amiga i admiro plenament per les seves capacitats, i per mai dir-me que no quan he necessitat que m'ajudés. A la Irene, que sempre et pregunta com estàs, que té consells i solucions per tot, que viu la recerca amb una passió que és contagiosa, i la que vaig tenir l'oportunitat de conèixer molt millor estant de congrés a París, i a la que trobaré molt a faltar ara que marxa a fer el post doctorat. A l'Oriol Roig, etern company de treballs de camp i una de les persones amb més humanitat que conec, entregat i amb qui es pot parlar de qualsevol cosa. A la Serena, que tot i que fa poc que ens coneixem ens entenem molt bé, compartim vivències i receptes de rebosteria. A la Marta, que sempre et treu un somriure amb la seva ànima alegre. I també al Pablo, el Jaime, la Judith i l'Enric, que tot i que s'han incorporat en els últims mesos agraeixo molt haver conegut i que formin part del grup. Vull fer una menció especial també a les companyes més sèniors amb les qui comparteixo o he compartit moments, començant per la Zeynep, una companyia sempre molt agradable, qui m'ha servit de referent en aquesta etapa final de la tesi; la Jimena, amb tota la seva saviesa i amabilitat; el Samuel, de qui sempre aprens alguna cosa i té el comentari just per fer-te reflexionar; la Monika, que ara ha tornat i amb qui he anat coincidint intermitentment, i és una maquíssima persona; el Xavi Delclòs, que tot i no haver coincidit en el mateix moment al grup aprecio molt; i el Guillem, a qui vaig tenir la sort de conèixer breument i ja no està amb nosaltres. No puc deixar d'agrair a la Laia la seva dedicació i constància, i el haver-me cuidat durant aquest temps, escoltant-me i compartint inquietuds. Els detalls que té amb nosaltres i les maneres de demostrar-nos que és aquí, per si la necessitem. Finalment, altres persones que sempre recordaré com la Nati, l'Stephanie, el Juan, i el Tom.

Vull estendre el meu agraïment al Departament de Geografia de la Universitat Autònoma de Barcelona que ha fet possible que desenvolupi aquesta tesi en una institució de reconegut prestigi. Aquest programa no seria possible sense una bona coordinació, per això agraeixo tant a l'Antònia Caselles com a la Mireia Baylina la seva tasca com a coordinadores del Programa de Doctorat, sempre disposades a resoldre dubtes i ajudar-te. També agrair a la resta de membres del departament, amb qui intercanvies bon dies als passadissos, especialment l'Oriol Nel·lo, que ha format part de les meves comissions de seguiment i sempre ha tingut bons consells per fer-me avançar la tesi; l'Àngel Cebollada, que m'ha assignat tasques de docència que m'han fet sortir de la meva zona de confort, i per referència, el Pau Avellaneda, amb qui he compartit part d'aquestes tasques docents. No puc deixar de mencionar a la secretaria del departament, que m'ha ajudat molt en temes administratius i a que tot funcioni correctament.

Durant el procés d'aquesta tesi també he tingut l'oportunitat de sortir del despatx i compartir la meva recerca amb altres grups i institucions. És per això que vull agrair a la Carolyn Daher i la Natalie Mueller, de l'Institut de Salut Global de Barcelona, per permetre'm conèixer-les, i treballar amb elles. Són dues dones que admiro molt i que m'han mostrat una altra cara de la recerca. També la Lucinda Cash, de la Universitat Pompeu Fabra, per la feina que hem fet plegades i el seu coneixement. I finalment, al James Woodcock, i tot el seu equip del Public Health Modelling group, per acollir-me a Cambridge durant una estada de recerca, integrant-me a les dinàmiques del grup, i fent-me partícip de *workshops*, tasques de recerca, activitats i cursos. A tota la gent que vaig trobar-me allà i em van fer sentir una mica menys lluny de casa, la Lei, la Kelly, el Lambed, el Yuchen, l'Ali, el Corin, la Haneen, l'Annie i la Meelan.

I per acabar, no puc deixar de dedicar unes paraules a totes aquelles persones que no formen part d'aquest món acadèmic ni de la recerca, però que són vitals per a mi. Primer vull agrair el recolzament incondicional que sempre he tingut de la meva família, tant en aquesta etapa com en etapes anteriors. Els meus pares, que sempre m'han donat suport en tot el que he fet, m'han deixat independència i han alimentat els meus somnis, tot i sempre posar-me els peus a terra. La meva mare, pilar indispensable en la meva vida, amb qui no podria concebre no poder compartir les meves ànsies, preocupacions i alegries. El meu pare, per animar-me a aspirar alt, ser ambiciosa i lluitar pel que vull. El Joan, per també fer-me de pare tots aquests anys i estar present en tots els moments. A l'Olga, que encara em fa de mare de tant en tant. Els meus avis, que són la llum dels meus dies, que m'han criat i m'han vist créixer com a persona. La meva àvia, de qui he tret el cul inquiet, que no sé que faria sense ella, sense les nostres llargues converses, i les seves carmanyoles. El meu avi, amb qui no cal paraules per entendre'ns. També el meu altre avi, que tot i no ser tant propers sempre es mostra orgullós i interessat per tot el que faig. La meva àvia, que ja fa uns anys que no hi és. I els meus petits, els meus tres germans. La Marta, amb qui amb l'edat ens hem anat entenent cada cop més i que més que una germana és una amiga essencial. I l'Ernest i el Bernat, els meus dos tresors, que ja són dos homes, que es preocupen i a qui abraçar quan ens veiem és un regal. També a la resta de la meva família, els meus tiets i tietes reals i postissos, els que m'han fet d'avis, el meu cosí, i tots els demés que ja sigui en dinars familiars o més de tant en tant ens hem anat trobant. I no puc deixar de mencionar la meva nova família, aquella que no ve donada de sèrie però que un dia hi aterres, i tot hi haver sigut només fa uns anys, m'han fet sentir sempre com a casa.

L'altra família, la que sí escollim i formem amb els anys, a qui també vull agrair haver estat tot aquest temps, és la meva família d'amigues, que no són pas poques. L'Andrea, aquella amiga de tota la vida a qui li pots explicar les pors més profundes, qui m'ha escoltat pacientment tots aquests anys, i amb qui no imagino no seguir compartint-ho tot. El meu trio preferit, la Sílvia, la Júlia i la Judith, que sent tant diferents ens hem fet inseparables, sempre disposades a parlar de la vida, de llibres, de receptes, i d'ampliar la llista interminable de plans a fer. L'Anna, que des que ens vam conèixer el primer dia d'universitat he sentit com una germana. La Mireia, amiga de la infància, amb qui mantinc converses interminables per notes de veu. La Clara i la Laura, el meu gran regal del màster. No sé què faria sense elles. La Ingrid, que tot i estar a l'altra punta del món sap fer-se present. I no em puc deixar les meves companyes i família d'equip, les meves *ladies*, que junt amb els meus entrenadors, m'han ensenyat a treballar en equip, superar-me, creure en mi mateixa, i ser forta. Els agraeixo tots els moments viscuts i el haver disposat d'un espai on oblidar-me de tot i lliurar-me a l'exercici físic, que com defenso en aquesta tesi, és font de salut i benestar. Altrament, donar les gràcies a amics i amigues que no he mencionat explícitament però que han estat presents en tot aquest procés.

I vull dedicar aquetes últimes paraules a la persona més especial, el meu estimat Sergi. Gràcies per absolutament tot, tot el que fas per mi cada dia. Per ser el meu màxim recolzament, per escoltar els meus monòlegs interns, les meves preocupacions i dubtes, ajudar-me a confiar i a saber valorar-me, a fer-me millor persona. Gràcies per estimar-me com soc, donar-me ales i empènyer-me a trobar allò que vull ser. Per les petites coses del dia a dia que han fet que aquests anys siguin molt fàcils. Gràcies per ser-hi i per fer-me ser.

Finalment, acabar agraint a totes aquelles persones que d'alguna forma han estat vinculades a aquest procés, i que s'han interessat per la meva recerca. Gràcies a totes.

Alexandra.

ABSTRACT

In recent years, urban transportation systems have undergone significant transformations driven by technological advancements and changing societal preferences. Among these changes, the rise of electric micromobility has emerged as a promising solution to address the challenges associated with urban mobility while promoting sustainability and public health. Electric micromobility refers to small-scale, lightweight vehicles powered by electric motors, including e-scooters, e-bikes, and other similar modes of transportation. These vehicles offer convenient alternatives to traditional modes of transport, such as cars and public transit, particularly for short-distance trips within urban environments. However, their adoption can hold profound implications for urban transportation systems and public health outcomes, in a context where cities grapple with congestion, pollution, and the adverse effects of sedentary lifestyles, promoting active modes of transportation becoming increasingly crucial. Understanding the links between electric micromobility and health is therefore paramount for policymakers, urban planners, and public health professionals. Hence, this dissertation investigates the relationship between electric micromobility and health outcomes, with a particular focus on physical activity patterns in the urban landscape of Barcelona. Drawing upon a combination of literature review and empirical studies, the research examines how the adoption and usage of electric micromobility modes, such as e-scooters and e-bikes, influence individual health and well-being.

The first study established a foundation for the research by conducting a literature review exploring the existing research landscape. This review provides a comprehensive overview of the factors shaping the adoption intention and usage of electric micromobility, identifying if the promise of physical activity and potential health benefits are valued by individuals deciding to use these devices. The two subsequent empirical analyses delve into the patterns of physical activity associated with electric micromobility usage in Barcelona. Using objective measurements obtained through GPS and accelerometer devices, the research evaluates the levels of physical activity across the different micromobility modes.

The findings strongly supported the hypothesis presented in this dissertation by demonstrating that physical activity and health are considered relevant factors when

deciding to adopt and use electric micromobility and that there exists a significant relationship between the e-micromobility mode used and the level of physical activity. The results of the empirical studies revealed distinct associations between electric micromobility modes and daily as well as trip-related physical activity levels. Moreover, the studies examine the implications of electric micromobility usage for public health outcomes, shedding light on the potential benefits and challenges associated with promoting active transportation modes in urban environments. It discusses the role of electric micromobility in facilitating active lifestyles and its implications for mitigating the adverse health effects of sedentary behaviour.

The outcomes of this dissertation contribute to our understanding of the relationship between electric micromobility and health outcomes, particularly in urban environments like Barcelona. By examining the physical activity patterns associated with different modes of electric micromobility, the research provides valuable insights into the potential health benefits and risks of these emerging transportation solutions. These findings have significant implications for policymakers, urban planners, and public health professionals seeking to promote sustainable urban development and improve public health outcomes. By highlighting the importance of promoting mainly cycling and e-cycling as viable alternatives for enhancing physical activity levels, this dissertation offers evidence-based recommendations for guiding future urban mobility policies and initiatives.

Overall, this research contributes to a better understanding of the complex relationship between a mode of transport and the implied physical activity, and consequent effect on health. By elucidating the potential benefits and challenges associated with promoting electric micromobility for enhancing physical activity levels and mitigating sedentary behaviour, this dissertation can help policymakers, urban planners, and public health stakeholders to devise evidence-based strategies aimed at fostering healthier and more sustainable urban environments.

RESUM

En els últims anys, els sistemes de transport urbà han experimentat transformacions significatives impulsades pels avenços tecnològics i el canvi de les preferències socials. Entre aquests canvis, l'auge de la micromobilitat elèctrica ha sorgit com una solució prometedora per abordar els reptes associats a la mobilitat urbana alhora que es promou la sostenibilitat i la salut pública. La micromobilitat elèctrica es refereix a vehicles lleugers i de petita escala impulsats per motors elèctrics, inclosos els patinets elèctrics, les bicicletes elèctriques i altres mitjans de transport similars. Aquests vehicles ofereixen alternatives convenients als mitjans de transport tradicionals, com els cotxes i el transport públic, especialment per a viatges de curta distància dins dels entorns urbans. No obstant això, la seva adopció pot tenir profundes implicacions per als sistemes de transport urbà i la salut pública, en un context en què les ciutats s'enfronten a la congestió, la contaminació i els efectes adversos dels estils de vida sedentaris, sent cada vegada més crucial promoure modes de transport actius. Entendre els vincles entre la micromobilitat elèctrica i la salut és, per tant, primordial per als responsables polítics, urbanistes i professionals de la salut pública. Per això, aquesta tesi investiga la relació entre la micromobilitat elèctrica i la salut, amb un enfocament particular en els patrons d'activitat física en l'entorn urbà de Barcelona. Basant-se en una combinació de revisió bibliogràfica i estudis empírics, la investigació examina com l'adopció i l'ús de modes de micromobilitat elèctrica, com ara els patinets i les bicicletes elèctriques, influeixen en la salut i el benestar individuals.

El primer estudi estableix una base per a la investigació mitjançant la realització d'una revisió bibliogràfica que explora la recerca existent. Aquesta revisió proporciona una visió general completa dels factors que configuren la intenció d'adopció i l'ús de la micromobilitat elèctrica, identificant si la promesa d'activitat física i els beneficis potencials per a la salut són valorats pels individus que decideixen utilitzar aquests dispositius. Les dues anàlisis empíriques posteriors aprofundeixen en els patrons d'activitat física associats a l'ús de la micromobilitat elèctrica a Barcelona. Utilitzant mesures objectives obtingudes a través de GPS i acceleròmetres, la investigació avalua els nivells d'activitat física a través dels diferents mitjans de micromobilitat.

Els resultats recolzen les hipòtesis presentades en aquesta tesi demostrant que l'activitat física i la salut es consideren factors rellevants a l'hora de decidir adoptar i

utilitzar la micromobilitat elèctrica i que existeix una relació significativa entre el mode de micromobilitat utilitzat i el nivell d'activitat física. Els resultats dels estudis empírics revelen diferents associacions entre els modes de micromobilitat elèctrica i els nivells d'activitat física diària i a nivell de viatge. A més, els estudis examinen les implicacions de l'ús de la micromobilitat elèctrica per a la salut pública, aportant llum sobre els possibles beneficis i reptes associats a la promoció dels modes de transport actius en entorns urbans. Es discuteix també el paper de la micromobilitat elèctrica en la facilitació d'estils de vida actius i les seves implicacions per mitigar els efectes adversos en la salut del sedentarisme.

Els resultats d'aquesta tesi contribueixen a entendre la relació entre la micromobilitat elèctrica i la salut, especialment en entorns urbans com Barcelona. En examinar els patrons d'activitat física associats a diferents modes de micromobilitat elèctrica, la investigació proporciona informació valuosa sobre els possibles beneficis per a la salut i els riscos d'aquestes solucions de transport emergents. Aquestes troballes tenen implicacions significatives per als responsables polítics, urbanistes i professionals de la salut pública que busquen promoure el desenvolupament urbà sostenible i millorar la salut pública. En destacar la importància de promoure principalment l'ús de la bicicleta i la bicicleta elèctrica com a alternatives viables per millorar els nivells d'activitat física, aquesta tesi ofereix recomanacions basades en l'evidència per guiar futures polítiques i iniciatives de mobilitat urbana.

En general, aquesta recerca contribueix a una millor comprensió de la complexa relació entre un mitjà de transport i l'activitat física implicada, i el conseqüent efecte sobre la salut. En dilucidar els beneficis potencials i els reptes associats a la promoció de la micromobilitat elèctrica per millorar els nivells d'activitat física i mitigar el comportament sedentari, aquesta dissertació pot ajudar els responsables polítics, urbanistes i agents de salut pública a dissenyar estratègies basades en l'evidència destinades a fomentar entorns urbans més saludables i sostenibles.

RESUMEN

En los últimos años, los sistemas de transporte urbano han experimentado transformaciones significativas impulsadas por los avances tecnológicos y el cambio de las preferencias sociales. Entre estos cambios, el auge de la micromovilidad eléctrica ha surgido como una solución prometedora para abordar los retos asociados a la movilidad urbana a la vez que se promueve la sostenibilidad y la salud pública. La micromovilidad eléctrica se refiere a vehículos ligeros y de pequeña escala impulsados por motores eléctricos, incluidos los patinetes eléctricos, las bicicletas eléctricas y otros modos de transporte similares. Estos vehículos ofrecen alternativas convenientes a los medios de transporte tradicionales, como los coches y el transporte público, especialmente para viajes de corta distancia dentro de los entornos urbanos. Sin embargo, su adopción puede tener profundas implicaciones para los sistemas de transporte urbano y la salud pública, en un contexto en que las ciudades se enfrentan a la congestión, la contaminación y los efectos adversos de los estilos de vida sedentarios, siendo cada vez más crucial promover modas de transporte activos. Entender los vínculos entre la micromovilidad eléctrica y la salud es, por lo tanto, primordial para los responsables políticos, urbanistas y profesionales de la salud pública. Por eso, esta tesis investiga la relación entre la micromovilidad eléctrica y la salud, con un enfoque particular en los patrones de actividad física en el entorno urbano de Barcelona. Basándose en una combinación de revisión bibliográfica y estudios empíricos, la investigación examina como la adopción y el uso de modos de micromovilidad eléctrica, como por ejemplo los patinetes y las bicicletas eléctricas, influyen en la salud y el bienestar individuales.

El primer estudio establece una base para la investigación mediante la realización de una revisión bibliográfica que explora la investigación existente. Esta revisión proporciona una visión general completa de los factores que configuran la intención de adopción y el uso de la micromovilidad eléctrica, identificando si la promesa de actividad física y los beneficios potenciales para la salud son valorados por los individuos que deciden utilizar estos dispositivos. Los dos análisis empíricos posteriores profundizan en los patrones de actividad física asociados al uso de la micromovilidad eléctrica en Barcelona. Utilizando datos objetivos obtenidos a través

de GPS y acelerómetros, la investigación evalúa los niveles de actividad física a través de los diferentes modos de micromovilidad.

Los resultados apoyan las hipótesis presentadas en esta tesis demostrando que la actividad física y la salud se consideran factores relevantes a la hora de decidir adoptar y utilizar la micromovilidad eléctrica y que existe una relación significativa entre el modo de micromovilidad utilizado y el nivel de actividad física. Los resultados de los estudios empíricos revelan diferentes asociaciones entre los modos de micromovilidad eléctrica y los niveles de actividad física diaria y a nivel de viaje. Además, los estudios examinan las implicaciones del uso de la micromovilidad eléctrica para la salud pública, aportando luz sobre los posibles beneficios y retos asociados a la promoción de los modos de transporte activos en entornos urbanos. Se discute también el papel de la micromovilidad eléctrica en la facilitación de estilos de vida activos y sus implicaciones para mitigar los efectos adversos en la salud del sedentarismo.

Los resultados de esta tesis contribuyen a entender la relación entre la micromovilidad eléctrica y la salud, especialmente en entornos urbanos como Barcelona. Al examinar los patrones de actividad física asociados a diferentes modas de micromovilidad eléctrica, la investigación proporciona información valiosa sobre los posibles beneficios para la salud y los riesgos de estas soluciones de transporte emergentes. Estos hallazgos tienen implicaciones significativas para los responsables políticos, urbanistas y profesionales de la salud pública que buscan promover el desarrollo urbano sostenible y mejorar la salud pública. Al destacar la importancia de promover principalmente el uso de la bicicleta y la bicicleta eléctrica como alternativas viables para mejorar los niveles de actividad física, esta tesis ofrece recomendaciones basadas en la evidencia para guiar futuras políticas e iniciativas de movilidad urbana.

En general, esta investigación contribuye a una mejor comprensión de la compleja relación entre un medio de transporte y la actividad física implicada, y el consiguiente efecto sobre la salud. Al dilucidar los beneficios potenciales y los retos asociados a la promoción de la micromovilidad eléctrica para mejorar los niveles de actividad física y mitigar el comportamiento sedentario, esta disertación puede ayudar los responsables políticos, urbanistas y agentes de salud pública a diseñar estrategias basadas en la evidencia destinadas a fomentar entornos urbanos más saludables y sostenibles.

CONTENTS

FIGURES

TABLES

ABBREVIATIONS

EMM: Electric MicroMobility

PA: Physical Activity

MET: Metabolic Equivalent of Task

MVPA: Moderate-to-Vigorous Physical Activity

WHO: World Health Organization

ITF: International Transport Forum

PRISMA: Preferred Reporting Items for Systematic reviews and Meta-Analyses

GPS: Global Positioning System

GIS: Geographic Information System

RWE: Real-World Energy Expenditure

TAE: Traffic-Adjusted Energy Expenditure

LIST OF TERMINOLOGY

Electric micromobility: The definition of EMM followed throughout this dissertation is smaller, lightweight vehicles powered by electricity and capable of operating at speeds of up to 25 km/h, primarily utilized for short trips, typically covering distances of up to 10 km, and that can either be privately owned or accessed through shared services. Therefore, the vehicles considered EMM are electric bikes and electric scooters.

Functional and non-functional factors: Functional values encompass tangible attributes and utilitarian functions, such as product variety, pricing, convenience, and quality. On the other hand, non-functional values pertain to the intangible aspects of a product, addressing social and emotional needs. In the context of this dissertation, functional values are associated with the conventional needs that consumers consider when selecting a mode of transportation, primarily including price, operating costs, performance, range, comfort, convenience, and charging time, along with the distinctive characteristics of the service or product. Conversely, non-functional values are linked to the perceptions individuals form regarding EMM, encompassing values related to social, emotional, and epistemic needs, such as environmental consciousness, innovative tendencies, and social beliefs.

Physical activity: According to the WHO, physical activity is defined as any movement of the body's skeletal muscles that necessitates energy expenditure. It encompasses all forms of movement, whether during leisure time, transportation, or work-related activities. Both moderate- and vigorous-intensity physical activities contribute to improved health. Common ways to engage in physical activity include walking, cycling, participating in sports, engaging in active recreation and play, and can be enjoyed by individuals of all skill levels. Regular physical activity is scientifically proven to aid in the prevention and management of noncommunicable diseases like heart disease, stroke, diabetes, and various cancers. Additionally, it helps to prevent hypertension, maintain a healthy body weight, and can enhance mental health, overall quality of life, and well-being.

Metabolic Equivalent of Task: The metabolic equivalent of task (MET) is a physiological measurement that represents the ratio of the metabolic rate during a specific physical activity to the metabolic rate at rest. One MET corresponds to the amount of oxygen consumed while sitting quietly at rest, which is approximately 3.5 milliliters of oxygen per kilogram of body weight per minute. MET values are used to quantify the intensity of various physical activities, with higher MET values indicating greater energy expenditure and intensity levels (Jetté et al., 1990).

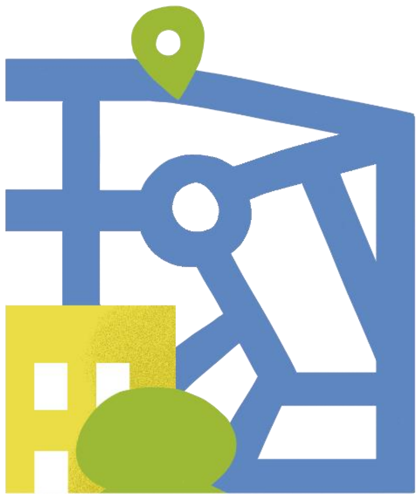
Health and well-being: The WHO describes health as "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". The WHO recognizes health as an essential human entitlement, advocating for universal access to fundamental health resources. In the realm of health promotion, health is viewed as an asset enabling individuals to live productive lives on personal, social, and economic levels. Well-being is defined as "Well-being is a positive state experienced by individuals and societies. Similar to health, it is a resource for daily life and is determined by social, economic and environmental conditions." Well-being encompasses both the quality of life and the capacity of individuals and communities to make meaningful contributions to the world (World Health Organization, 2021).

Trip: In mobility and transport research, a "trip" refers to a unidirectional journey undertaken for a singular primary purpose, regardless of whether one or multiple modes of transportation are utilized. It is important to note that transitioning to another mode of transport during the journey does not constitute a separate trip.

Real-World Energy Expenditure: RWE is a scenario defined for the aims of one of the case studies of this dissertation that captures all physical activity from the start to the end of the trip, inclusive of sedentary time (e.g., at intersections, traffic lights, etc.). Factors such as the local street layout, driving conditions, and infrastructure availability significantly impact this scenario.

Traffic-Adjusted Energy Expenditure: TAE is the other scenario defined that focuses solely on trip segments during which the individuals are actively engaged, thereby excluding sedentary time. This measurement is designed to consider stops and driving conditions influenced by the local context, offering a more accurate estimation of the physical activity generated during motion, enhancing its suitability for comparisons between cities.

PART I. INTRODUCTION



1. Research presentation

1.1. Electric micromobility and health: a research exploration

Electric micromobility (EMM) has experienced a significant surge in recent years, reshaping urban transportation and establishing itself as a distinct niche with its unique user dynamics, opportunities, risks, and impacts. This upward trajectory is propelled by a diverse array of factors, such as the potential for reducing greenhouse gas (GHG) emissions (de Bortoli, 2021; Hollingsworth et al., 2019; Requia et al., 2018), mitigating congestion while enhancing accessibility (Milakis et al., 2020; Yanocha & Allan, 2021), and addressing first- and last-mile mobility challenges (S. Shaheen & Chan, 2016). Beyond these benefits, EMM also has the potential to revolutionize the user travel experience, presenting a joyful alternative to move around, while having an impact in health and well-being (McQueen et al., 2021). Then, as cities actively pursue sustainable, zero-carbon futures, the incorporation of these innovative transport modes becomes increasingly pivotal in discussions surrounding urban mobility. A particularly intriguing domain of study centres around the relation between EMM and physical activity (PA). Against the backdrop of escalating urbanization and the concurrent rise in sedentary lifestyles, some suggest that EMM modes have emerged as potential remedies to these challenges. In this sense, it is imperative to comprehend how these modes impact PA levels, given that PA is directly linked to health benefits.

In this context, encouraging daily PA at the population level is increasingly associated with the promotion of active travel, as it offers manifold health advantages. Apart from fulfilling PA guidelines, daily PA confers specific health benefits, including enhancements in cardiovascular fitness, a reduction in the risk of heart disease, stroke, and other cardiovascular conditions, calorie burning for weight loss or maintenance, stress reduction, mood improvement, decreased risk of depression and anxiety, enhanced cognitive function, and a decreased risk of chronic diseases such as type 2 diabetes, certain cancers, and osteoporosis, among others (Doorley et al., 2015; I. M. Lee et al., 2012; Mueller et al., 2015; Raustorp & Koglin, 2019; Rojas-Rueda, Nazelle, et al., 2016; Saunders et al., 2013). However, global evidence indicates that 23% of adults fall short of meeting the World Health Organization (WHO) recommendations on PA (World Health Organization, 2013), spending most of their waking time inactive. At the national level (Spain), according to a survey conducted in 2022, 27.4% of individuals aged 16 and older reported being sedentary in their leisure time (Instituto Nacional de Estadística (INE), 2022). This physical inactivity escalates the risk of mortality and morbidity attributed to chronic non-communicable diseases (NCDs), which constitute 60% of all deaths worldwide (Lee et al., 2012). Given this situation, the adoption and proliferation of EMM as a new mode of transport introduces intriguing questions about their impact on active travel and, subsequently, populations' daily PA levels (Abduljabbar et al., 2021; Castro et al., 2019; Sanders et al., 2022). In the light of these, this dissertation aims to contribute to the understanding of daily PA levels associated with different micromobility modes, including conventional shared bikes, electric shared bikes, and electric scooters, in the city of Barcelona, northeast Spain.

Existing literature on EMM primarily examines their potential impacts on various fronts, including the potential positive and negative effects arising from the implementation of an EMM fleet (Bieliński et al., 2020; Oeschger et al., 2020; Zagorskas & Burinskiene, 2020), associated technical and operational aspects (Gojanovic et al., 2011; Shaheen et al., 2020; Shaheen & Cohen, 2019), health benefits and impacts on PA (Bourne et al., 2018; Castro et al., 2019; De Geus & Hendriksen, 2015; Glenn et al., 2020; Gojanovic et al., 2011; Hoj et al., 2018; Sperlich et al., 2012), safety, injuries and security concerns (Brownson et al., 2019; Kobayashi et al., 2019; Panwinkler & Holz-Rau, 2021; Qian et al., 2020; Siebert et al., 2021; Stoermann et al., 2020; Verstappen et al., 2021), economic implications such as fuel and congestion costs (Adler et al., 2019; Button et al., 2020; Compostella et al., 2020; Pavlenko et al., n.d.; Pietrzak & Pietrzak, 2021), and environmental impacts like air pollution, congestion or noise (Hollingsworth et al., 2019; Hsieh et al., 2018; Hulkkonen et al., 2020; López-Dóriga et al., 2022; Nematchoua et al., 2020). Notably, there is also a growing focus on the social dimension, with studies exploring the factors influencing the adoption EMM, aiming to understand the motivations behind individuals choosing to embrace these innovative alternatives, as well as the reasons why some may be hesitant to do so, while also focusing on user characteristics, modal shift, the built environment's role, accessibility and connectivity issues, and socio-demographic characteristics (Almannaa et al., 2021; Bieliński & Wa\.zna, 2020; Campbell et al., 2016; Edge et al., 2018; Fyhri et al., 2017; Jones et al., 2016; Kaplan et al., 2018; McQueen et al., 2021; Van Cauwenberg et al., 2019).

As mentioned, a specific area of focus revolves around the relation between EMM and PA. Existing research has already proven the positive link between conventional bikes and PA levels, proving that increased uses of cycling for utilitarian trips is correlated with increased levels of physical activity (Castro et al., 2019; Oja et al., 2011; Raustorp & Koglin, 2019; Woodcock et al., 2014). In the case of EMM, some have hypothesized that even though EMM can generate less PA than bikes or walking, the popularization of these new modes may generate a more active modal split, as a number of motorized trips can be converted into EMM trips generating a net benefit in terms of PA at the population level. Some authors, however, have raised concerns regarding the potential reductions in PA levels due to electric assistance. This concern arises from the possibility that, if EMM ends up replacing mainly traditional active modes of transport like walking and cycling, it could eventually result in a decline in the population's PA levels (Glenn et al., 2020; López-Dóriga et al., 2022; Sanders et al., 2020, 2022; Şengül & Mostofi, 2021). This issue is particularly pertinent in the case of e-scooters, with some asserting that they could serve as a replacement for walking or biking, especially on shorter journeys, and/or might be employed to cover the "last mile" of a trip, discouraging walking or biking for that segment of the journey (Glenn et al., 2020; Kazemzadeh & Sprei, 2024; Sanders et al., 2020, 2022; Weschke et al., 2022). This could lead to a potential reduction in the PA levels of individuals who might otherwise choose to walk or bike for the entire trip, or even decrease the PA associated with trips for those opting for public transport. However, this debate remains open, as others argue that depending on the chosen EMM vehicle and the provided electrical assistance, longer distances, durations, and frequencies might compensate for the reduced PA exertion (Bourne et al., 2018, 2020; Castro et al., 2019).

From a methods point of view, most research to date has predominantly relied on self-reported measures to assess PA associated with travel. However, this approach has several well-known limitations such as reporting biases, variability in perception, reliability and validity issues. These limitations have prompted a shift toward more objective measures using accelerometers and GPS devices to provide accurate insights into daily PA levels associated with different transport modes (Chaix et al., 2019;

Duncan et al., 2016; Marquet et al., 2020; Matthews et al., 2012; Shephard, 2003; Sylvia et al., 2014; White et al., 2019).

Furthermore, it is crucial for both researchers and policymakers to delve into the underlying motivations of micromobility initiatives, including shared programs, as they often intertwine both public policy and commercial dimensions. Frequently, these schemes are integrated into governmental strategies aiming to encourage active transportation and enhance public health (Woodcock et al., 2014). However, numerous micromobility programs are also offered by private enterprises with the primary objective of revenue generation (Fitt & Curl, 2020). These companies may provide bike or scooter sharing services to cater to consumer demand and capitalize on preferences for more convenient transportation options. The coexistence of public policy and commercial interests can give rise to challenges and disputes in the planning and execution of micromobility schemes (Abduljabbar et al., 2021; Latinopoulos et al., 2021). For instance, tensions may emerge between the aspirations of promoting active transportation and enhancing public health, and the profit-maximizing and cost-minimizing objectives of private operators.

1.2. General aim, research questions, and hypothesis

The general aim of this thesis is to comprehensively investigate the intersection between EMM and health, with a particular focus on PA. Specifically, this dissertation seeks to provide nuanced insights into the real-world effects of these modes' popularization and increased use on the PA levels of Barcelona adults, considering the unique characteristics of users and the different micromobility modes. The main hypothesis is that *the use of EMM significantly influences the level of daily physical activity of Barcelona adults, across the different EMM modes, which can have direct effects on individual's health (H0)*. Therefore, this research aligns with the broader exploration of EMM impact on PA, filling gaps in the existing literature and informing future policy and interventions aimed at promoting active transportation in urban environments.

Expanding on this foundation, the dissertation has formulated a series of research questions (RQ1-RQ4) and their associated hypotheses (H1-H4). Although briefly outlined here, each of these questions will undergo comprehensive exploration in Sections 4 and 5 of Part II.

RQ1: Does the provision of physical activity serve as a sociopsychological factor influencing the adoption and use of EMM?

H1: The potential for physical activity is perceived by individuals as a positive sociopsychological factor when deciding to adopt and use EMM. Therefore, this provision of exercise is an important determinant of travel behaviour. Individuals recognize the potential for physical activity as a significant and positive aspect when evaluating the adoption of EMM. The hypothesis suggests that the perceived link between EMM and physical activity plays a pivotal role in influencing individuals to choose and incorporate EMM into their transportation habits, thereby contributing to the broader understanding of sociopsychological factors in the adoption of micromobility modes.

RQ2: How do daily and trip-specific physical activity levels vary across different micromobility modes?

H2: The different micromobility modes (shared bike, shared e-bike, private es-cooter) are associated to different levels of daily and trip-related PA. Specifically, the levels of PA associated with biking and e-biking are anticipated to be higher than those linked to e-scooter usage. The hypothesis posits that different micromobility modes contribute to varying amounts of PA, with a particular focus on shared and private modes. This exploration aims to shed light on the potential disparities in PA patterns across micromobility options, thereby enhancing our understanding of the health-related implications associated with these modes of transportation.

RQ3: How do the daily physical activity levels of micromobility users compare to those of non-users?

H3: Micromobility users present higher levels of daily PA than non-users. The hypothesis is grounded in the assumption that individuals engaging in micromobility are more likely to incorporate regular PA into their daily routines, mainly resulting from the active involvement required by these modes. This would be particularly true in the case of using the bike or e-bike, but with less impact when using the e-scooter. This hypothesis also implies that choosing micromobility as a mode of transport could *be associated with a lifestyle that prioritizes PA, potentially offering health-related benefits compared to non-users with less physically active transportation habits.*

RQ4: How do variations in micromobility modes impact individuals' compliance with the physical activity recommendations established by the World Health Organization (WHO)?

H4: The utilization of shared bikes and e-bikes demonstrates a higher adherence to the physical activity recommendations outlined by the WHO compared to other modes. Individuals engaging in biking and e-biking as part of their transportation choices are more likely to achieve and sustain the recommended levels of daily PA, thereby promoting their overall health and well-being. This higher compliance is attributed to the nature of these modes, involving greater physical effort and exertion, leading to improved cardiovascular fitness and a reduced risk of chronic diseases.

1.3. Overview of the dissertation structure

This dissertation revolves around three distinct studies (a literature review and two empirical studies) that constitute the primary focus of the research project. Considering the stated general objectives and specific hypothesis and research questions, the structure of the dissertation is outlined as follows:

After this introductory section (Section 1) delineating the context of the dissertation, as well as the main aims and hypothesis, Section 2 provides a synthesis of theoretical concepts essential for understanding the objectives and significance of the studies. Section 3 delves into research design and methodologies, starting with the overarching research design and then detailing the methodologies applied in the three studies. This includes information on the setting, sample, data collection, measures, key definitions, and main statistical analyses.

The studies are divided into two sections within Part II. The first study, that is the systematic literature review, is presented in Section 4, serving as the foundation for the thesis and empirical studies by offering background knowledge on the field. This systematic review explores the adoption intention and usage of these modes, allowing us to understand what is behind the success of EMM and if potential PA benefits are a reason to become a regular user. On the other hand, the two empirical studies are introduced in Section 5, both exploring the impacts that the different micromobility modes have on daily and trip-related PA levels. These two studies analyse the real PA associated with the use of EMM devices in the city of Barcelona, and using objective measures of PA, coming from GPS and accelerometer devices, contributing to this blurred knowledge in current research.

Moving on to Part III, a comprehensive discussion of findings from all presented studies, an exploration of strengths and limitations, potential future research areas and policy implications (Section 6), and final reflections (Section 7) are provided. Finally, Part IV encompasses all the references used in this research (Section 8). Figure 1, previously presented, shows the structure of the dissertation.

2. Theoretical framework

This section is dedicated to the general theoretical framework with the aim to enhance the comprehension of the research findings presented throughout this dissertation. With this in mind, the definition of EMM is examined, along with the relationship between EMM and health, further developing more in detail the specific implications for PA. Moreover, different theories and concepts are explored in order to understand what determines travel behaviour, and concretely the adoption and use of EMM.

2.1. Electric micromobility definition and conceptual framework

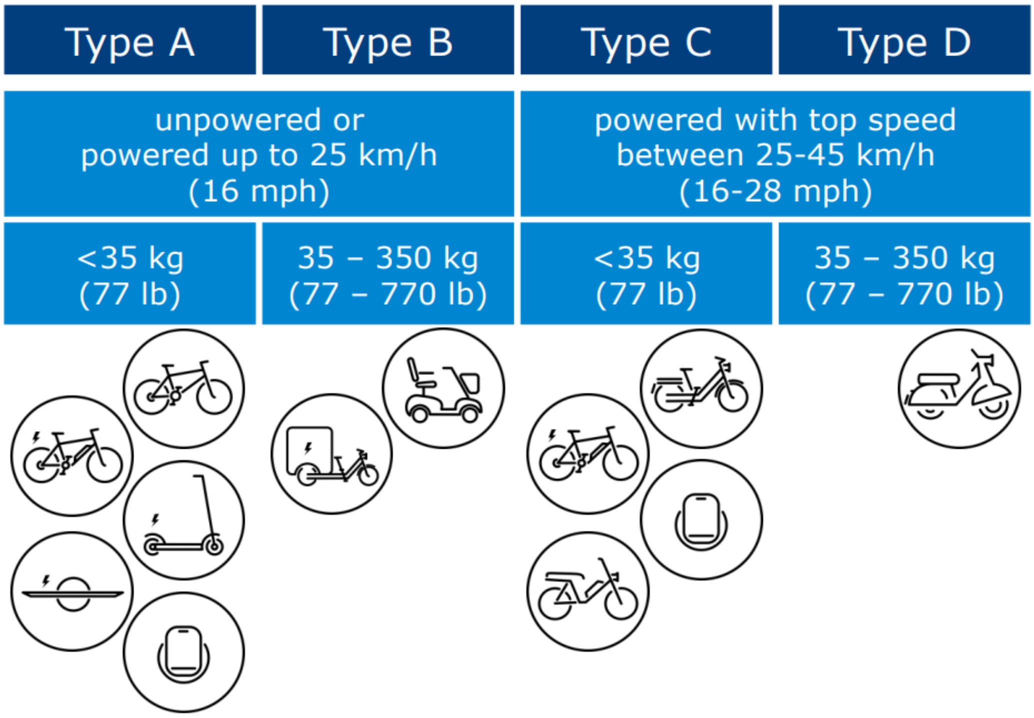
Transportation is recognised as been one of the key elements of cities, significantly affecting their economic, environmental, and social development, while facilitating the movement of people and goods. In this context, the prevailing car-centric transport planning is adversely affecting urban environments, encompassing a decline in physical activity levels, elevated levels of air and noise pollution, environmental deterioration, heat island effects, and traffic congestion (Mueller et al., 2017; Nieuwenhuijsen et al., 2017). Therefore, a change in the current transportation paradigm is essential to offer sustainable and health-promoting modes of travel. Over the last years, cities worldwide have started to introduce new measures and initiatives to shift to more sustainable forms of transportation, including the development of new mobilities. EMM emerged then as one of these transformative mobility modes, quickly gaining a considerable share in the mode distribution of cities and addressing a yet undefined niche regarding its user demographics, prospects, hazards, and consequences. In European settings, EMM vehicles can typically transport one or two passengers, and occasionally cargo, while operating at low speeds (i.e., 25 km/h), but also sometimes up to moderate speeds (i.e., 45 km/h) (The European Parliament and the Council of the European Union, 2013), and they can be accessed through sharing systems or be privately owned. E-bikes, e-trikes, or e-cargo bikes, as well as different models of e-scooters and e-rickshaws, as well as one-wheeled and two (or more)-wheeled balancing boards, such as Segways and e-skateboards, are examples of vehicles that frequently fit the rather broad definition of EMM.

The term electric micromobility encompasses a broad category of lightweight vehicles positioned between pedestrians and cars (Bahrami & Rigal, 2021). However, it lacks a universally accepted definition and remains subject to ongoing debate and refinement as new vehicles and services emerged in urban environments worldwide. Various terms have been used in the literature to describe this concept. Gitelman et al. (2020) refer to it as "alternative transport means," while Milakis et al. (2020) characterize EMM as a sustainable mobility solution, offering flexibility, personal mobility, low environmental impact, and high social inclusion potential. The term "micromobility" initially gained prominence in describing the early trends in shared bicycle usage (Clewlow & Mishra, 2017), while "e-micromobility" now encompasses both private and shared docking-station and dockless e-scooters, e-bikes, and other emerging e-micro vehicles (Bai et al., 2021; McQueen et al., 2021; Reck et al., 2021). Moreover, according to insights gathered from stakeholder interviews by EIT Urban Mobility (2020), micromobility can be classified as a device, a mode of transport, or a service, with the "e-" prefix denoting electric propulsion. Thus, the categorization of EMM presents a complex challenge, partly due to the legal definitions that dictate the classification of each vehicle. Moreover, these classifications vary significantly across countries and local jurisdictions. Consequently, EMM taxonomy and classifications have defied conventional categorization and are typically defined based on a combination of vehicle weight, maximum speed, and capacity.

In fact, the European Union regulation N°168/2013 (The European Parliament and the Council of the European Union, 2013) introduced the L-category for vehicles as a reference for member countries in 2013. This classification included L1e-A for powered cycles with a maximum speed of 25km/h and a net power between 250 watts and 1000 watts, and L1e-B for two-wheeled mopeds with up to 45km/h and 4000 watts net power. However, this categorization excluded human-powered vehicles like bicycles or skates, as well as standing scooters. In consequence, various international bodies have attempted to provide definitions that encompass the diverse range of personal mobility vehicles and devices. According to a publication by the Society of Automotive Engineers, powered micromobility vehicles should meet three main criteria: (1) be fully or partially powered, (2) have a curb weight of less than 227kg (50lb), and (3) a top speed of 48km/h (30m/h) (SAE International, 2019). Also, the International Transport Forum proposed a micromobility definition as the use of micro-vehicles with a mass of no more than 350kg and a design speed no higher than 45km/h (Santacreu et al., 2020). However, they acknowledge the difficulty in reaching consensus on an international level and the risks associated with treating vehicles with significantly different kinetic energies under the same umbrella, suggesting a 4-level categorization (see Figure 2).

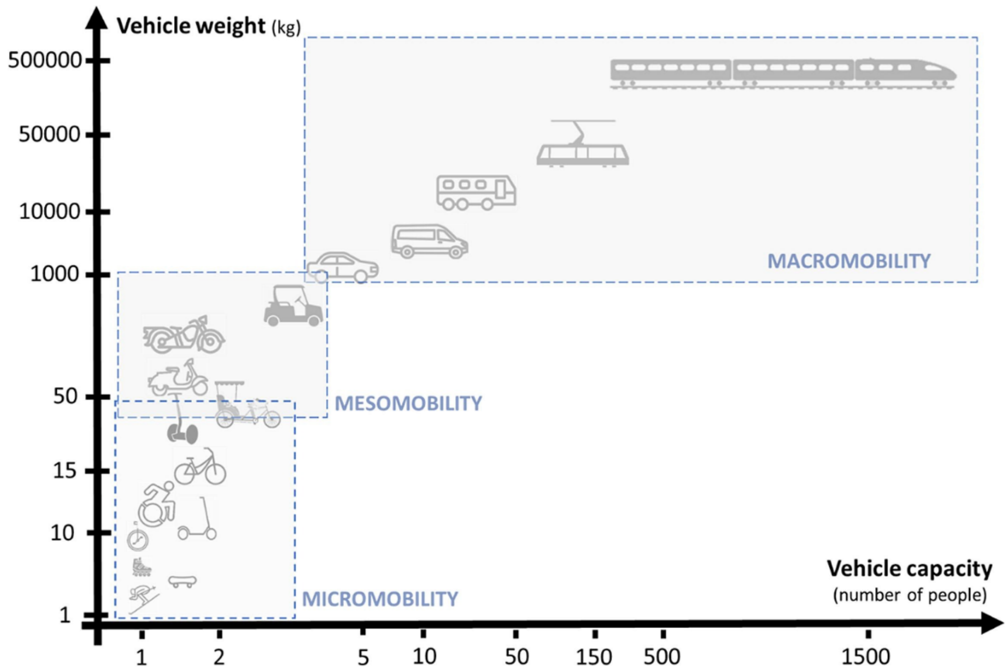
A different interpretation that diverges from the conventional emphasis on speed and vehicle weight/capacity is offered by Christoforou et al. (2021). They propose a mobility-centric definition, defining micromobility as encompassing all transportation modes that enable users to transition fluidly between pedestrian and vehicular behaviour based on situational needs (e.g., dismounting to navigate through intersections or adopting pedestrian-like behaviour at crosswalks). This adaptable behaviour, referred to as hybridity, has also been observed by Kjærup et al. (2021). Notably, Christoforou et al. (2021) perceive this range of vehicles as representing a novel dimension of mobility, distinct from traditional macromobility and mesomobility modes, as represented in Figure 3.

Figure 2 Proposed micromobility definition by the International Transport Forum



Source: https://www.itf-oecd.org/safe-micromobility

Figure 3 Proposed classification of vehicles at the micro-, meso-, and macro- scales



Source: Christofotoru et al. (2021)

For the aim of this dissertation, this last definition provided by Christoforou et al. (2021) is used, excluding larger vehicles such as e-moped scooters and e-motorcycles, which likely fall within the mesomobility category instead.

2.2. Health pathways of electric micromobility

In the pursuit of sustainable and zero-carbon urban futures, the consideration of these novel transportation modes could hold heightened significance within discourses concerning urban mobility and ecological sustainability. EMM is posited to possess the potential for mitigating greenhouse gas (GHG) emissions, ameliorating air quality, and alleviating traffic congestion. Simultaneously, it is expected to enhance accessibility, connectivity, and facilitate first- and last-mile mobility (Johnson, 2018; May et al., 2010; Metz, 2017; S. A. Shaheen et al., 2011; S. Shaheen & Chan, 2016). Furthermore, these innovative modes might have the capacity to elevate the user travel experience, providing a more immersive engagement with the travel environment, offering a pleasurable alternative for commuting, and potentially influencing health and well-being outcomes (Jones et al., 2016; Pettersson et al., 2016; Porcelli et al., 2014). In fact, a 5–10% increase in the EMM modal share is estimated in the European Region by 2030 as a result of the growing popularity of these new e-powered micro-vehicles in cities across the globe (Heineke et al., 2020).

Given the predicted increase in EMM usage and the acknowledged relationship between transport modal choice and health (Glazener et al., 2021; Khreis & Nieuwenhuijsen, 2019), it is necessary to understand the potential impacts that the use of EMM can have on public health outcomes. A variety of pathways and mechanisms exist through which EMM can impact health, although research on EMM and health is still limited. We posit that many of the established connections between traditional transportation and health are applicable to EMM as well (Glazener et al., 2021; Glenn et al., 2020). Below, the main direct and indirect pathways that relate EMM and health are presented (see Figure 4), as well as a summary on the main findings that current research presents about the direct associations between EMM and health (see Table 1). The link between EMM adoption and PA levels is further developed in section NN, as being the particular health effect of interest for this dissertation.

Figure 4 EMM and health direct and indirect pathways

Source: own production

Table 1 Summary of research findings in relation to the direct pathways of EMM and health

	Main findings	Sources
Physical activity	• Physical inactivity as a leading risk factor	(Katzmarzyk et al., 2022; Lee et al., 2012; World Health Organization, 2013)
	• Small evidence compared to other forms of transport, and mainly focused on e-bikes	(Alessio et al., 2021; De Geus & Hendriksen, 2015; Gojanovic et al., 2011; Louis et al., 2012; Peterman et al., 2016; Sanders et al., 2022; Sperlich et al., 2012)
	• Potential to replace more active forms (walking and cycling), so previous transport mode determines the gain/loss of PA.	(Glenn et al., 2020; Kazemzadeh & Sprei, 2024; Krier et al., n.d.; Kroesen, 2017; Roig-Costa et al., 2021; Sun et al., 2020)

	• Travel longer distances may compensate the lack of PA	(Bourne et al., 2020; Castro et al., 2019; Jahre et al., 2019; Van Cauwenberg et al., 2018)
Air pollution	• Potential positive impact in reducing motor vehicle combustion-related air pollution and greenhouse gas emissions	(de Bortoli, 2021; Winslott Hiselius & Svensson, 2017)
	• Impacts shift from vehicle use to vehicle manufacturing, end-of-life treatment, and electricity generation	(de Bortoli, 2021; Weiss et al., 2015)
	• Emissions will most likely occur at locations outside densely populated areas substantially decreasing exposure rates and associated health risks	(Weiss et al., 2015)
	• Negative impact from short life span of e-scooters	(Hollingsworth et al., 2019; Severengiz et al., 2020)
	• Related to sharing systems, impact caused by the vehicles collection and relocation	(de Bortoli, 2021; Gössling, 2020)
	• The lower physical activity intensity will result in less inhalation of air pollutants	(De Geus & Hendriksen, 2015; Tran et al., 2021)
Noise	• Battery-operated engines are essentially silent, leading to reduced road traffic noise exposure	(Glenn et al., 2020; Weiss et al., 2015)
	• Decreases in vehicle-associated noise exposure evokes traffic safety concerns as approaching vehicles might not be heard	(Weiss et al., 2015)
Safety and injury risk	• Single-vehicle accidents are much more common than collisions, but less likely to be reported	(Bekhit et al., 2020; Bloom et al., 2021; Campbell et al., 2019; Glenn et al., 2020; Hertach et al., 2018; Lavoie-Gagne et al., 2021; Liew et al., 2020; Pétursdóttir et al., 2021; Weber et al., 2014)
	• Looking at collisions, users mostly conflict with pedestrians on shared paths and with motorized vehicles at intersections	(Cicchino et al., 2021; Dozza et al., 2016; MacArthur et al., 2018; Petzoldt et al., 2017)

• Regarding injury severity, women, elderly, and inexperienced riders present increased risk to suffer a serious injury	(Cicchino et al., 2021; Coelho et al., 2021; DiMaggio et al., 2019; Fyhri et al., 2019; Glenn et al., 2020; Hertach et al., 2018; Kiewiet et al., 2017; King et al., 2020; Weber et al., 2014)
• Male and young and middle-aged riders seem to be more prone to risk taking behaviours	(Gitelman et al., 2018; Kim et al., 2021; Trivedi et al., 2019; Wu et al., 2019)
• Alcohol consumption, lack of helmet use, high speeds and red-light crossing are the main risky behaviors associated with accidents	(Anderson-Hall et al., 2019; Bai et al., 2013; Beck et al., 2020; Bekhit et al., 2020; Blomberg et al., 2019; Bloom et al., 2021; Brownson et al., 2019; Chi et al., 2019; de Guerre et al., 2020; Faraji et al., 2020; Gitelman et al., 2018; Glenn et al., 2020; Kobayashi et al., 2019; Moftakhar et al., 2021; Panwinkler & Holz-Rau, 2021; Qian et al., 2020; Savitsky et al., 2021; Trivedi et al., 2019; Verstappen et al., 2021)
• When EMM is inappropriately used (riding in sidewalks) or parked, can create safety conflicts with pedestrians and other users	(Bloom et al., 2021; Glenn et al., 2020; Gössling, 2020; Sikka et al., 2019)
• Reports of fire-related incidents and burns resulting from explosions of e-scooter batteries during charging or riding	(Commission, 2020; Glenn et al., 2020; Liew et al., 2020)
• Inadequate infrastructure, uneven surfaces, poor road conditions and physical barriers are a major concern when riding a vehicle with small wheels, especially e-scooters	(Haustein & Møller, 2016; Hertach et al., 2018; Ognissanto et al., 2018; Panwinkler & Holz-Rau, 2021)

Source: own production

2.2.1. Physical activity

Based on the fact that transport and physical activity are directly related, encouraging active travel is seen as crucial to promoting physical activity at the population level. In fact, daily physical activity, especially through active travel practices such as walking and cycling, has been found to provide significant health benefits, including enhancing cardiovascular fitness and mitigating the likelihood of heart disease, stroke, and other cardiovascular ailments (Gordon-Larsen et al., 2009; Hamer & Chida, 2008; Henriques-Neto et al., 2020; Lorenzo et al., 2020; Saunders et al., 2013); burning calories and encouraging weight loss or maintenance (de Haas et al., 2021; Laverty et al., 2015; Millett et al., 2013; Mueller et al., 2015); lowering stress, elevating mood, and lowering the risk of depression and anxiety (Greaves et al., 2024; Knott et al., 2018; Rissel et al., 2014); and lowering the risk of chronic illnesses like type 2 diabetes, specific cancers, and osteoporosis, among others (Brinks et al., 2015; Doorley et al., 2015; Jarrett et al., 2012; Laverty et al., 2015; Millett et al., 2013; Saunders et al., 2013). Aside from this numerous health benefits, the potential of active transportation modes becomes even more important when 23% of adults worldwide do not meet the World Health Organization's recommendations for PA (World Health Organization, 2013, 2020) and instead spend most of their waking hours inactive, which its consequential increase in the risk of mortality and morbidity from chronic non-communicable diseases (Lee et al., 2012). The literature has repeatedly highlighted the positive association between conventional bike usage and the maintenance of an active lifestyle, coupled with enhanced mental health and well-being (Castro et al., 2019; Ma et al., 2021; Oja et al., 2011; Otero et al., 2018; Raustorp & Koglin, 2019; Woodcock et al., 2014).

In this particular context, the popularity of EMM brings new inquiries to the table when questioning its relation to physical activity levels. As a matter of fact, in present discussions on active travel, there is a growing debate surrounding the inclusion of these emerging e-micromobilities such as e-bikes and e-scooters. Traditionally, active travel has been narrowly defined as walking and (pedal) cycling, with a primary focus on the physical activity involved. However, some scholars, exemplified by Cook et al. (2022), challenge this conventional classification, proposing a more inclusive definition based on sustained physical exertion directly contributing to motion. While they extend the inclusion criteria to encompass e-bikes under "assisted active travel" micromobility, e-scooters and similar modes find themselves categorized as "non-active" modes. Despite this, there is a growing body of authors who argue for a reconsideration of this classification. They suggest that labelling e-scooters as "non-active" overlooks the active engagement required by their use, such as maintaining posture and balance. These advocates propose a re-evaluation to more accurately reflect the physical involvement inherent in operating e-scooters and related devices (Grant-Muller et al., 2023; Jones & Chatterjee, 2023; Kazemzadeh & Sprei, 2024). With this in mind, we argue for a need of empirical data to really challenge or confirm such classifications, acknowledging the multifaceted and potential active aspects of EMM, becoming imperative to broaden the discourse on active travel to accommodate these evolving forms of mobility.

However, there is a notable lack of evidence concerning the relationship between EMM and PA. The inclusion of electrical assistance in these modes raises concerns about possible reduced PA levels, particularly if travel conditions and routes remain unchanged. Some researchers have expressed apprehensions that the substitution of active modes of transport, like walking and traditional cycling, could lead to an overall decrease in the population's PA levels (Glenn et al., 2020; Sanders et al., 2020, 2022). This concern is particularly true for e-scooters, with some suggesting that they are already replacing walking, especially for shorter trips, thereby diminishing the population's overall physical activity levels (Glenn et al., 2020; Sanders et al., 2020, 2022). However, the ongoing debate has yet to reach a consensus, as some argue that depending on the chosen e-micromobility vehicle and the provided electrical assistance, longer distances may be covered, potentially compensating for the reduced PA exertion in terms of increased distance, duration, and frequency (Bourne et al., 2018, 2020; Castro et al., 2019).

In this limited body of existing evidence on EMM and PA, we find predominantly studies about e-bike use (Castro et al., 2019; Gojanovic et al., 2011; Peterman et al., 2016; Sperlich et al., 2012). Studies often report Metabolic Equivalent of Task (MET) values ranging from 4 to 7 for e-bikes, depending on factors such as the chosen assistance mode, terrain characteristics, and the rider's inherent motivation for physical activity (Alessio et al., 2021; Bini & Bini, 2020; Bourne et al., 2018). According to international standards, these MET values correspond to physical activity of moderate (values between 3 and 5.9) and vigorous (values exceeding 6) intensity (World Health Organization, 2020). This therefore implies that e-cycling would have to be considered as a moderate-to-vigorous mode of transport, suggesting that regular engagement in e-cycling would align with physical activity guidelines, maintaining and enhancing the individual health status (Bernstein & McNally, 2017; De Geus & Hendriksen, 2015; Hoj et al., 2018; Langford et al., 2017). Moreover, multiple studies have identified a strong appeal of e-bikes among groups with limited interest in PA, a behaviour often attributed to hedonistic motivations. Individuals with a high tendency toward hedonism are typically less prone to exercise or opt for active mobility in their travel choices (Sundfor et al., 2017). Surprisingly, this leads to a positive net effect of e-bike use from a public health perspective, particularly among population groups with lower levels of PA (Fyhri et al., 2017; Jahre et al., 2019; Van Cauwenberg et al., 2018). Given the combination of extended and more sustained travel facilitated by e-bikes and their widespread adoption among low-physical activity populations, some researchers have suggested that e-bikes could serve as a gateway to active transportation for sedentary individuals (Langford et al., 2017; Mildestvedt et al., 2020; Sperlich et al., 2012).

On the contrary, the existing literature on e-scooters and PA, although expanding, remains relatively limited in comparison to e-bikes. Given that e-scooters belong to the EMM category and share features with e-bikes, such as electric propulsion, there is a plausible assumption that they may offer some sort of PA engagement. However, the full extent and nature of this engagement are yet to be comprehensively understood. In this case, the research discussion revolves around the exact amount of PA derived from e-scooter use and how this activity may replace the PA gained by the previous mode of transport before switching to the e-scooter (Sanders et al., 2022). Some e-scooter operators claim that e-scooters provide a low-intensity workout, contributing to increased core strength and leg exercise by demanding muscle stabilization for body balance on the vehicle. A recent study utilizing objective activity data suggested a potential increase in physical activity when standing, compared to sitting, such as in a car or public transport (Glenn et al., 2020). The research by Ognissanto et al. (2018) reported that e-scooter users perceived an increase in their activity levels when substituting short car journeys with e-scooter rides. Although consensus seems to support the notion that the transition from car to e-scooter could result in a net PA gain, studies of travel behaviour and modal change indicate that e-scooters are less likely to replace car use but instead often replace active travel modes.

Most new e-scooter users were previously pedestrians or public transport users, potentially leading to adverse effects on overall PA levels (Christoforou et al., 2021; Felipe-Falgas et al., 2022; Glenn et al., 2020; Kopplin et al., 2021; Roig-Costa et al., 2021; Sanders et al., 2020, 2022).

Furthermore, it is crucial to consider the underlying dynamics of EMM programs, as these initiatives often combine political and commercial motives. While such programs are often integrated into government strategies to promote active transportation and improve public health (Woodcock et al., 2014), they are equally administered by private companies aimed at generating revenue (Fitt & Curl, 2020). These companies offer services such as bike or scooter sharing to meet consumer demands and exploit preferences for more convenient transportation options. The juxtaposition of public policy and commercial interests creates complexities and controversies in the implementation and functioning of these programs (Abduljabbar et al., 2021; Latinopoulos et al., 2021). Then, potential conflicts may arise between the objectives of promoting active transport and public health on the one hand and the objectives of maximizing profits and reducing costs by private operators on the other. For instance, private operators may prioritize areas with higher demand and profitability, resulting in an uneven distribution of services, with less profitable or underserved areas receiving limited or no coverage, causing social inequities (Mouratidis, 2022). Moreover, data privacy concerns arise as private companies may exploit user data for profit, conflicting with government interests in using such data for urban planning (Bruce, 2020; Vinayaga-Sureshkanth et al., 2020).

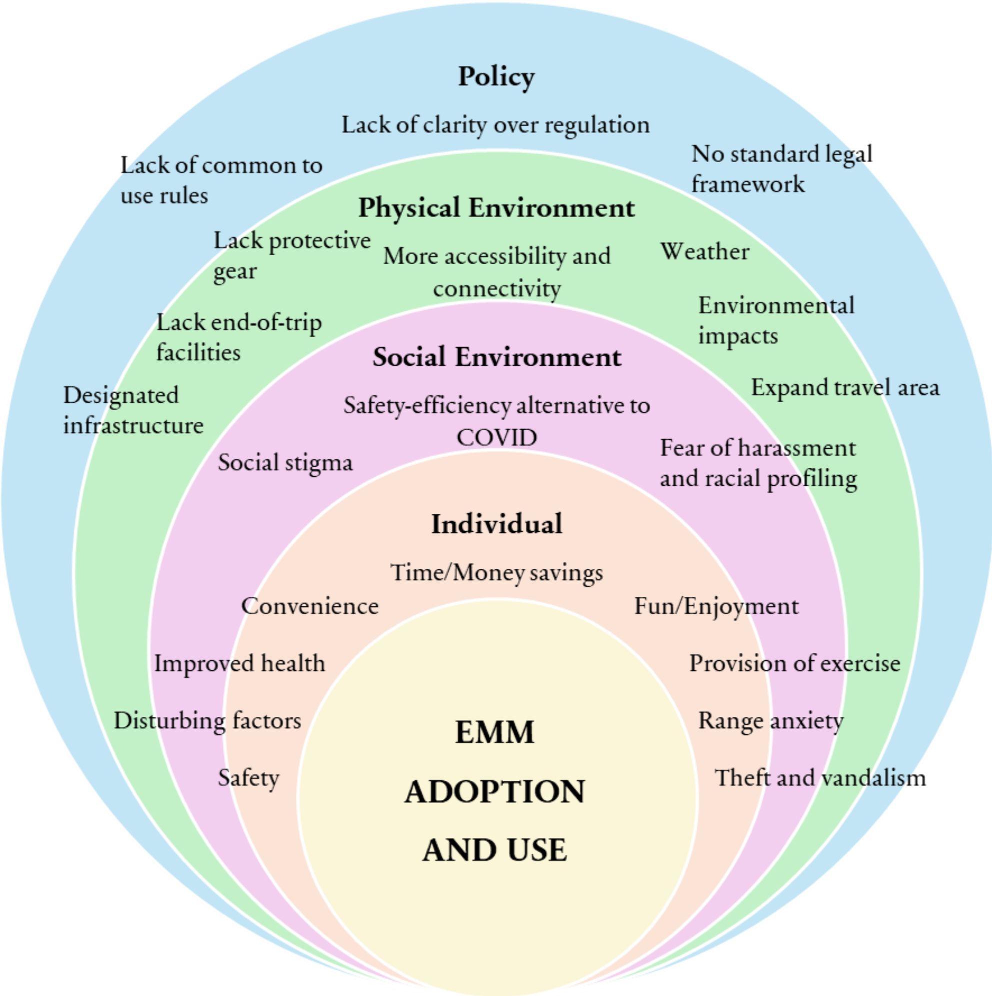
2.3. Adopting the socio-ecological model of active travel to EMM

When exploring active travel, research has mainly focused on answering to what are the health impacts associated with active travel, and to which are the main causes that contribute to the prevalence of active travel. In this sense, we can find several disciplines (e.g., epidemiology, transport, urban planning, environmental and other social sciences) collaborating to address these questions, resulting in extensive bodies of literature. As mentioned in the previous section, the main identified outcomes of active travel in terms of health are physical activity, diminished risk of several diseases, and improved psychological well-being, to mention some. On the other hand, when investigating the determinants of active travel, researchers mainly studied sociodemographic determinants (Barajas & Braun, 2021; Barnett et al., 2019; Chandrabose et al., 2023; Ferrari et al., 2020; Lawlor et al., 2021; Nehme et al., 2016) and the influence of the built environment (Aldred, 2019; Cerin et al., 2017; Clark et al., 2014; Haybatollahi et al., 2015; Liu et al., 2021). Additionally, psychological and social factors, including perceived environmental characteristics, attitudes, and preferences (Barnett et al., 2019; Bondemark, 2023; De Vos et al., 2019; Lades et al., 2020; Panter & Jones, 2010; Shaer et al., 2021; Stark et al., 2018), have been explored, albeit receiving comparatively less attention.

The promotion of active travel and health behaviours intersects with a variety of conceptual frameworks. Within this expansive landscape of behavioural theories and models, ecological models emerged as comprehensive frameworks. Socio-ecological models consider the psychological and social factors that influence a behaviour in addition to its environmental and policy context. The fundamental idea of the socio-ecological model is that numerous levels of factors, such as intrapersonal (biological, psychological), interpersonal (social, cultural), organizational, community, physical environment, and policy, can influence behaviour. Several authors based their behaviour analysis on this model, such as Götschi et al. (2017) with the conceptual framework for active travel, the active living framework by Sallis et al. (2006), the macro-micro-meso structure presented in Mattioli et al. (2016) study when assessing car-dependence, or the recent study by Sulikova and Brand (2021) that applies a multilevel socio-ecological model to active travel mode choice in seven European cities. What all these frameworks have in common is the targeting of various individual (socio-psychological) and environmental (ecological) factors to explain outcomes related to travel. Indeed, these models are commonly used in behavioural science, as considering both the environmental and individual-level factors offers us a better understanding of behaviour.

Therefore, it becomes evident that travel and mode choice is not a solitary endeavour but intricately connected to individual perceptions, societal norms, environmental cues, and policy contexts. In this sense, I have updated the Socioecological model framework in relation to EMM adoption and use as summarised by Figure 5, following a socio-ecological approach, contributing to a holistic comprehension of the role of EMM in shaping travel behaviour.

Figure 5 Socio-Ecological Model Adapted for EMM Adoption and Use



Source: own production

In the following subsections, the four levels (i.e., individual, social, physical and policy) of the socio-ecological model will be conceptualised in more detail, while relating them to travel behaviour and specifically, to the factors identified by individuals as key to adopt and use EMM.

2.3.1. The individual level

The individual level incorporates the personal determinants that may influence a behaviour, such as sociodemographic characteristics but also individuals' skills, attitudes and beliefs, among others.

Various socio-cognitive theories exist in the literature and certain strands of transport research conceptualize commuting within the framework of rational choice, as exemplified by Metz (2008). According to this perspective, individuals make decisions based on the rational goal of minimizing the time and associated costs of travel. This rational choice framework is also integral to the psychological Theory of Planned Behaviour (TPB) (Ajzen, 1991) and the Theory of Reasoned Action (TRA) (Fishbein & Ajzen, 1975). They delve into motivational factors, predicting behaviour through intentions influenced by attitudes (individual's subjective response or judgement toward the behaviour), subjective norms (whether others believe the behaviour should be carried out or not), and perceived behavioural control (possessing the necessary skills, capability, and control). Nonetheless, other non-reasoned actions were also incorporated into these theories, like habit, visibility and self-identity (Bird et al., 2018; de Bruijn et al., 2009; Sniehotta et al., 2014).

As seen in the socio-ecological model illustration before, individual attitudes play a really important role when determining the adoption intention and use of EMM. For instance, it was significant for individuals to safe money and time, have fun and enjoy the ride, improve their physical health and well-being, among others. Actually, some reseach highlights how attitudes and other psychological factors have more influence that the actual built environment (Arroyo et al., 2020; Dill et al., 2014; Hunecke et al., 2010; Lemieux & Godin, 2009) in determining travel behaviours, underlining then the importance of considering them when assessing and promoting active travel and travel-related health behaviours.

2.3.2. The social environment

The social environment encompasses the influence exerted by an individual's close social circle, including family and friends, as well as the broader societal context on their behaviour.

The extensive body of literature exploring the connections between the built or physical environment and travel behaviour, which will be explained in the following subsection, contrasts with the limited number of studies that investigate the impact of the social environment. In terms of theories, we find the social influence theory, that posits that social influence predominantly affects individual's behaviour through two dimensions: normative and informational (Kaplan & Miller, 1987). The normative dimension implies that individuals adopt behaviours akin to those in their surroundings due to pressure, fearing exclusion if their behaviours deviate from the norm. On the other hand, the informational dimension suggests that individuals seek more information sources during decision-making, letting information provided by others to shape their own behavioural decisions.

Similarly, available research mentions social cohesion, social interaction, social networks, and role models as factors influencing travel behaviour. Social cohesion plays an important role, specifically at the neighbourhood level (Landolfi & Dragan, 2018; McDonald, 2007; Mendes de Leon et al., 2009; van den Berg et al., 2017), as it can exert a profound influence by fostering a sense of connection and shared identity within a community. When social cohesion is strong, individuals may be more inclined to adopt similar behaviours, influenced by the norms and values of their close social groups. Furthermore, social cohesion can foster collaborative decision-making, and influence the adoption of more active and sustainable travel behaviours. Social interaction and social networks also play a pivotal role in shaping individuals' behaviour through various mechanisms (Arentze & Timmermans, 2008; Luo et al., 2022; Páez & Scott, 2007; Pike & Lubell, 2018). Norms and peer influence within these networks can lead individuals to adopt behaviours aligned with prevailing behaviours, fostering conformity, while information and recommendations shared within social circles can also influence decisions. Social events and group dynamics further impact decisions, as collaborative planning and group travel can influence transportation modes and routes. Additionally, cultural, and social identity within these networks play a role in shaping behaviour, aligning choices with shared values and identity. Social media platforms amplify these influences, providing a space for feedback and shared experiences that impact perceptions and decisions. Finally, regarding role models, they can exert a significant influence by serving as examples that individuals look up to and may seek to emulate (Brown & Treviño, 2014; Darlow & Xu, 2011; Seemüller et al., 2023). Role models can contribute to the normalization of certain behaviours, creating a positive influence on attitudes and choices within communities.

Looking at the socio-ecological model figure, and in the backdrop of the COVID-19 pandemic, studies indicated that EMM was perceived as a secure transport alternative, providing individuals with the means to uphold physical and social distancing, especially during those periods when there was reluctance to use public transportation (Bateman et al., 2021; Campisi et al., 2021; Dias et al., 2021; Glavić et al., 2021; Oeschger et al., 2020). Another common social factor is the presence of perceived social stigma, often manifesting as social shaming. E-bikes are sometimes, albeit erroneously, seen as a form of "cheating" and are not considered genuine bicycles by some cycling enthusiasts (Bjornara et al., 2017; Boland et al., 2020). Similarly, EMM vehicles are sometimes perceived as mere "toys," leading to riders being labelled as "lazy," "overweight," or engaging in "cheating" behaviour (Dill & Rose, 2012; Edge et al., 2018; Jones et al., 2016; Ognissanto et al., 2018; Van Cauwenberg et al., 2018). Moreover, restricted distribution and accessibility of sharing stations/vehicles, along with high access fees and user costs are seen as potential social barriers. Entry into the system often necessitates a credit or debit card and access to a smartphone with a supporting application, requirements potentially resulting in the exclusion of socioeconomically disadvantaged or elderly individuals who may lack the necessary resources or technological proficiency to access sharing systems (Bateman et al., 2021; Cao et al., 2021; McQueen et al., 2021).

2.3.3. The built environment

The built or physical environment refers to both natural and built elements of urban areas, encompassing transportation infrastructure, land use patterns, and geographical variations. Transportation infrastructure includes elements like road networks, sidewalks, bike lanes, public transit networks, and parking availability.

As mentioned, the impact of the built environment on behaviour stands as one of the most extensively researched topics in travel behaviour studies, as exemplified by numerous theoretical and empirical contributions (Cao et al., 2009; Ewing & Cervero, 2001, 2010; Feng, 2017; Gehrke & Wang, 2020; Handy et al., 2005; Nasri & Zhang, 2012; Sharma & Jain, 2023; Thao & Ohnmacht, 2020; Tracy et al., 2011; Zhang & Zhang, 2020). Some studies highlight significant characteristics such as density, diversity, design, destination accessibility, and distance to transit shaping travel patterns (e.g., mode choice, vehicle miles travelled, trip frequency and travel time) (Cervero, 2006; Cervero & Kockelman, 1997; De Vos et al., 2021; Ding & Cao, 2019; Ewing & Cervero, 2001; Liu et al., 2021; Thao & Ohnmacht, 2020; Zhou et al., 2022), while others yield mixed or inconclusive results (Eldeeb et al., 2021; Ewing & Cervero, 2010; Hong et al., 2014).

In terms of EMM, as shown in the socio-ecological model, the main characteristic of the built environment affecting its adoption and usage is the infrastructure. However, it is important to acknowledge that the urban morphology plays also a crucial role in enabling EMM adoption and usage, as the built environment needs to offer destinations within a reasonable distance, and a minimum level of density, land use mix, and accessibility, among other factors, Moving back to infrastructure, an insufficient infrastructure, including the absence of designated and segregated paths, as well as the poor conditions of existing infrastructure elements such as uneven pavement and gravel surfaces directly affect individual's travel behaviour (Almannaa et al., 2021; Arsenio et al., 2018; Bateman et al., 2021; Bourne et al., 2020; Dill & Rose, 2012; Fyhri et al., 2017; Glavić et al., 2021; Jones et al., 2016; Nikiforiadis et al., 2021; Söderberg f.k.a. Andersson et al., 2021). Similarly, the widespread deficiency in end-of-trip facilities, such as secure and adequate parking or storage areas, and charging stations are found to negatively affect its usage (Bourne et al., 2020). Additionally, individuals mention the impact of adverse weather conditions such as rain, wind, snow, cold, or heat, along with traveling in darkness (Almannaa et al., 2021; Bjornara et al., 2017; Edge et al., 2018; Jones et al., 2016; Noland, 2019; Söderberg f.k.a. Andersson et al., 2021; Weiss et al., 2015). Concerning sharing systems, studies find the accessibility of docking-system stations and the availability, as well as the uneven distribution, of non-docked vehicles throughout the city to affect EMM travel behaviour (Bateman et al., 2021; Bieliński et al., 2020; Cao et al., 2021; McQueen et al., 2021).

2.3.4. The policy level

Finally, the policy level involves interventions and strategies implemented at the governmental or institutional level to address issues related to human behaviour, environmental factors, and their interactions.

According to Pucher (1988), urban transportation systems and travel behaviours are largely shaped by public policy rather than solely by individual choices or consumer preferences. Indeed, the impact of policies on travel behaviour is multifaceted as they can shape the built environment, influence transportation options, and incentivize certain modes of travel over others. For example, urban planning policies can determine the layout of cities, the availability of public transportation, and the accessibility of amenities, which in turn affect how people choose to travel (De Vos, 2015; Shiftan, 2008). Investments in public transportation infrastructure, such as expanding bus or rail networks, can make using public transit more convenient and attractive, leading to an increase in public transit ridership (Beaudoin et al., 2015; Padeiro et al., 2019). Similarly, policies that promote walking and cycling infrastructure, such as bike lanes and pedestrian-friendly streets, can encourage more active modes of transportation (Winters et al., 2017).

Economic policies also play a role in shaping travel behaviour. For instance, taxes on gasoline or emissions can influence the cost of driving and encourage people to use alternative modes of transportation or choose more fuel-efficient vehicles (Klier & Linn, 2015; Meireles et al., 2021; Wang et al., 2015). Subsidies for public transit or incentives for electric vehicle purchases can also influence travel behaviour by making certain modes of transportation more affordable and appealing (Börjesson et al., 2020; Muehlegger & Rapson, 2022; Shen & Feng, 2020; Song et al., 2020; Yang et al., 2020). Furthermore, regulatory policies, such as speed limits, parking regulations, and zoning ordinances, can affect travel behaviour by influencing the ease and convenience of driving versus other modes of transportation (Albalate & Gragera, 2020; Cleland et al., 2021).

Regarding EMM and other means of transport, regulation is seen as necessary to cover several key areas: 1) ensuring self-protection through requirements such as helmet use and the presence of lights and reflectors; 2) governing riding behaviours, including limits on the number of riders and restrictions on using electronic devices while riding; 3) establishing traffic rules, such as guidelines for infrastructure use and setting maximum speeds; and 4) managing parking, including the provision of designated parking spaces and preventing obstruction of pedestrian pathways, crosswalks, doorways, or driveways (Feng et al., 2021).

Indeed, the proliferation of EMM in urban areas supposed a regulatory challenge for policymakers worldwide, due to the unprepared regulatory environment, and the existent ambiguity between local and national jurisdictions (Fearnley, 2020; Gössling, 2020). A significant challenge in many cities is the division of authority between national jurisdictions and local city councils regarding key transport policies

(Gössling, 2020). For example, regulations pertaining to helmet use, maximum speeds, sidewalk usage, or minimum age requirements for vehicle use may fall outside the purview of city councils. Additionally, the classification of EMM vehicles as motorized or non-motorized can have implications for insurance requirements, leading to uncertainty and potential liability issues in cases of accidents, damage, or injuries occurring on city infrastructure (Glenn et al., 2020; Gössling, 2020). Another aspect of regulation pertains to addressing misuse, particularly concerning sharing systems, which also impacts the vehicles' lifespan and environmental footprint (Hollingsworth et al., 2019). Moreover, cities may encounter issues that are specific to their local context but may not be problematic in other cities, necessitating targeted intervention strategies. In fact, EMM users often lack familiarity with local use and safety regulations (Glenn et al., 2020; James et al., 2019; Wood et al., 2019), but they have indicated willingness to change their behaviours if they were aware of the expectations, such as riding in the street instead of on sidewalks (Glenn et al., 2020). Given all of the above, it is not surprising that city councils had to navigate trial-and-error phases and continually adjust legislation.

In essence, and according to the abovementioned levels of influence, it seems that individuals positively value several aspects that these new modes offer. EMM is presented as a mean to improve accessibility and connectivity for specific social groups, give people a quick, easy, and reasonably priced way to get around, while having significant equity implications for the choices they make about how they travel (Sikka et al., 2019). Convenience, freedom, flexibility, and overcoming car dependence are also among the benefits of EMM that have been reported in a number of studies (Berge, 2019; McQueen et al., 2021). Further, other benefits include the exercise potential offered (Bjornara et al., 2019; Rérat, 2021; Söderberg f.k.a. Andersson et al., 2021), the ability to move around for users with physical limitations (Jones et al., 2016; MacArthur et al., 2018), a reduction in travel time (Bozzi & Aguilera, 2021; Christoforou et al., 2021; Glavić et al., 2021), financial savings (Christoforou et al., 2021; Glavić et al., 2021), respect for the environment (Glavić et al., 2021; Rérat, 2021), enjoyment, fun, and an enhanced travel experience (Christoforou et al., 2021; Söderberg f.k.a. Andersson et al., 2021), as well as a general contribution to increased well-being (Söderberg f.k.a. Andersson et al., 2021).

However, not only benefits are perceived from the introduction of EMM in urban settings. A number of obstacles and deterrents have also been identified, including safety concerns (Almannaa et al., 2021; Bateman et al., 2021; Cao et al., 2021; Glavić et al., 2021), inadequate infrastructure, bad road conditions, a lack of end-of-trip facilities (Almannaa et al., 2021; Bateman et al., 2021; Nikiforiadis et al., 2021; Söderberg f.k.a. Andersson et al., 2021), the cost of purchasing and maintaining the vehicle (Bieliński et al., 2020; Wikstrøm & Böcker, 2020), the vehicle's limited carrying capacity (Edge et al., 2018; McQueen et al., 2021), theft and vandalism fears (Bourne et al., 2020; Jones et al., 2016; Ognissanto et al., 2018), as well as technical failure and weakness fears (Jones et al., 2016; Söderberg f.k.a. Andersson et al., 2021). Still, different contextual settings, transportation needs, routines and habits, personal perceptions, and past experiences can all have a significant impact on these positive and negative determinants.

At the individual level, and regarding the aim of this dissertation, is important to notice how improving health and doing exercise are perceived as determinants of EMM adoption and use. This is a common reason cited by users of conventional active travel modes (walking and cycling), which shows that in some sense EMM is also perceived as being active living and promoting healthy behaviours.

3. Research design and methodology

This chapter serves the purpose of presenting the diverse methodologies employed for this thesis. In the context of an article-based thesis, each case study features an in-depth exposition of the chosen methodologies along with their respective justifications. To mitigate redundancy and provide a comprehensive overview, this chapter offers a broader perspective on the research design and methods.

3.1. General research design

All academic research activities, regardless of discipline, begin with building your research on and connecting it to existing knowledge. A proper literature review is thus a crucial first step in any research. According to Tranfield et al. (2003), a literature review is essentially a methodical process of gathering and combining prior research, and a well-executed review establishes a solid basis for knowledge advancement and helps with theory production (Webster & Watson, 2002). Furthermore, a literature review is also a great method to identify areas that require further investigation. Because not much is known about the sociopsychological factors that are driving EMM adoption, this dissertation begins with a systematic literature review exploring the sociopsychological factors affecting the adoption and usage of EMM. Once I had understood what factors were inducing certain population groups to adopt EMM, I wanted to fully explore what were the implications in terms of health of that adoption, especially regarding PA. As a result, the literature review is followed by two empirical analyses completely focused on understanding the relation between these new mobilities and physical activity levels.

Examining some of the promise and potential of these novel forms of mobility has been one of the main focuses of the EMM literature to date. In addition, the research also focused on the social dimension by examining user characteristics and travel patterns, their potential for modal shift and their interaction with the built environment. In this social dimension of travel, adoption intention and further usage are usually examined, as they allow us to understand the specificities (tangible or intangible) of a particular travel mode. People's decisions and preferences are influenced by social and psychological factors, which have been found to be reliable indicators of behaviours like consumer purchase or adoption intentions in transportation research (Galdames et al., 2011; Hunecke et al., 2010; Levin et al., 1977). Thus, a systematic review was carried out in accordance with PRISMA (Preferred Reporting Items of Systematic Review and Meta-Analysis) guidelines in order to obtain insights into the various sociopsychological factors influencing EMM adoption intention and usage (see Section 4). After the study selection stage, the papers underwent two phases of review: one for their titles and abstracts, and the other for their complete texts. The content analysis, which concerned the identification of factors, their categorization as functional or non-functional, and the type of relationship—categorized as positive, mixed, or negative—between the factor and adoption and use intention, covered 67 papers in total (see Section 4.1.4. for more detailed information). This review serves as a pivotal step in attaining a comprehensive understanding of the factors influencing individuals' adoption and utilization of EMM. It not only sheds light on what individuals prioritize and value in their decision-making process but also underscores the significance of physical activity as a health-related factor impacting their behaviour. Moreover, this thorough examination contributes to the refinement of the research questions posed in this dissertation, ensuring their alignment with the two empirical studies.

As discussed in the previous section, research indicates that EMM, notably e-cycling, has the potential to contribute to increased PA levels (Castro et al., 2019; Chabanas et al., 2019; Fyhri & Fearnley, 2015; Gojanovic et al., 2011; Sundfør & Fyhri, 2017; Wild & Woodward, 2019). However, the current body of literature concerning e-scooters and PA remains relatively limited. Nevertheless, considering that e-scooters share similarities with e-bikes, particularly in terms of electric propulsion, it is plausible to infer that they could similarly promote some PA engagement. Consequently, ongoing discussions focus on accurately measuring the PA generated by various micromobility modes, particularly e-scooter usage, and comparing these activity levels with those achieved through traditional modes of transportation (Glenn et al., 2020; Sanders et al., 2022). To explore the relationship between a travel mode and PA, much of the prior research has leaned on self-reported instruments, such as questionnaires and ad hoc surveys, a choice primarily driven by their cost-effectiveness and ease of post-processing. In fact, questionnaires offer valuable insights into the contextual socioeconomic factors influencing an individual's travel habits and provide self-assessed accounts of time spent using different modes of transportation and engaging in various forms of physical activity (Troiano et al., 2014). However, questionnaires are not without their measurement challenges and shortcomings, including issues related to reporting biases, variability in perception, reliability, validity concerns, and difficulties in consistently reporting the time allocated to each mode of transport (Matthews et al., 2012; Shephard, 2003; Sylvia et al., 2014).

In an effort to address some of these limitations, recent studies have embraced the use of accelerometers and/or Global Positioning Systems (GPS) devices to provide more objective and precise measures. These tracking tools have significantly improved the monitoring of human movement, particularly within the context of daily travel (Batista Ferrer et al., 2018; Chaix et al., 2019; Duncan et al., 2016; Marquet et al., 2020; Plasqui et al., 2013; Rowlands, 2018; White et al., 2019). Dedicated accelerometers excel in providing precise assessments of daily PA (Murphy, 2008), allocating time to active or sedentary activities, as well as categorizing the data based on the intensity level of activities (from sedentary to very vigorous energy expenditure). On the other hand, GPS devices can pinpoint an individual's location with high precision, often within a few meters at any given moment. They also generate mobility indicators that provide insights into a person's daily movement patterns.

However, for distinguishing specific transportation-related activities like cycling, the combined use of GPS and accelerometers proves to be more advantageous than relying on each sensor independently. In fact, when it comes to discriminating between active and passive modes of transportation, the integration of GPS data, such as speed, with accelerometer data has been found to enhance the accuracy of transport mode detection (Allahbakhshi et al., 2020; Brondeel et al., 2015; Ellis et al., 2014; Lee & Kwan, 2018). Consequently, these wearable devices not only provide accurate measurements of daily PA and energy expenditure but also serve as valid and reliable predictors of overall PA levels (Liu et al., 2021).

These methodologies were utilized in the two empirical studies carried out within this dissertation. The primary aim of these studies was to investigate the relationship between the use of EMM and PA. After this introductory section, which has outlined the overall research design beginning with the literature review and followed by the quantitative methods employed, the subsequent sections will delve into more comprehensive details regarding the two empirical studies. These sections will offer insights into the data collection techniques, the composition of the sample, the study's setting, the measurements utilized, and the statistical analyses employed to conduct the studies.

3.2. Characterisation of the study area

The two empirical studies included in this dissertation were conducted in the municipality of Barcelona, situated on the northeastern coastline of Spain, and serving as the capital and largest city of the autonomous community of Catalonia (see Figure 6). Barcelona is home to 1.6 million residents, its urban area sprawling into numerous neighbouring municipalities, forming the Metropolitan Region of Barcelona. Nestled between the mouths of the rivers Llobregat and Besòs, Barcelona stands as one of the largest metropolises on the Mediterranean Sea, flanked to the west by the Serra de Collserola mountain range. Covering an area of 101.4 square kilometres, the city of Barcelona is distinguished by its densely populated urban layout, a well-integrated mix of urban services and functions, and a comprehensive public transportation network that is evenly distributed across the area (Miralles-Guasch & Tulla Pujol, 2012).

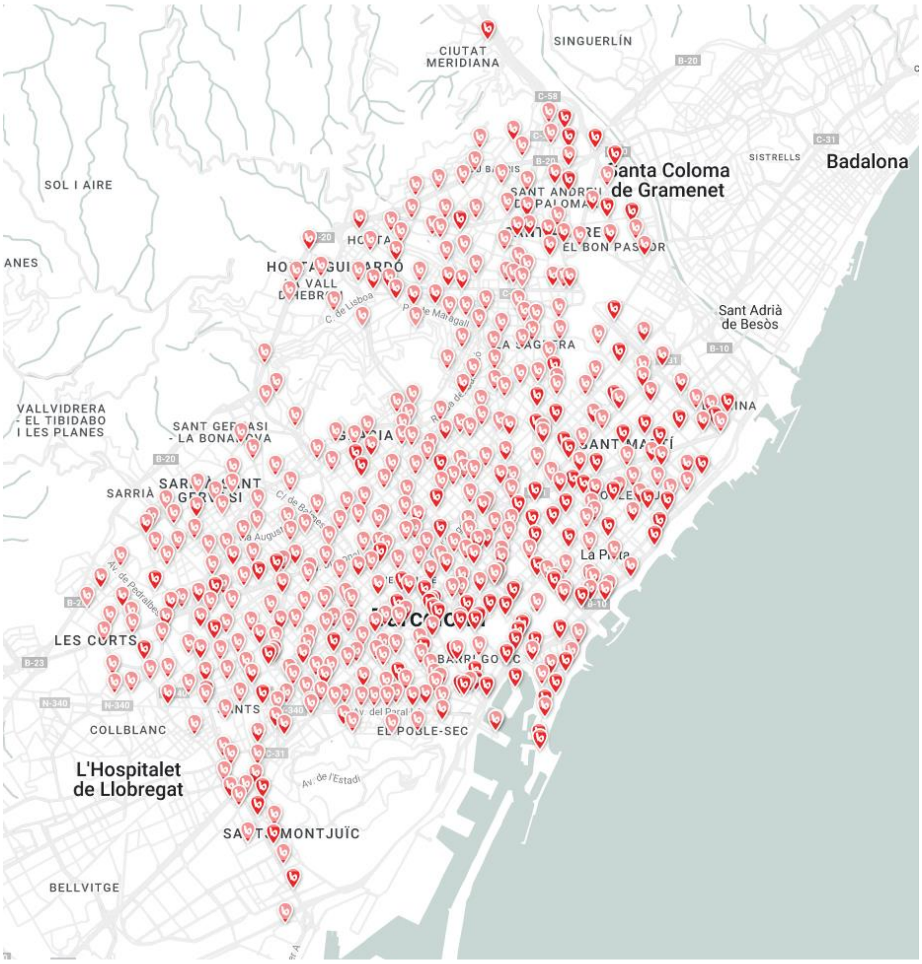
Figure 6 Location and boundaries of Barcelona

Source: own production

3.2.1. The micromobility model in Barcelona

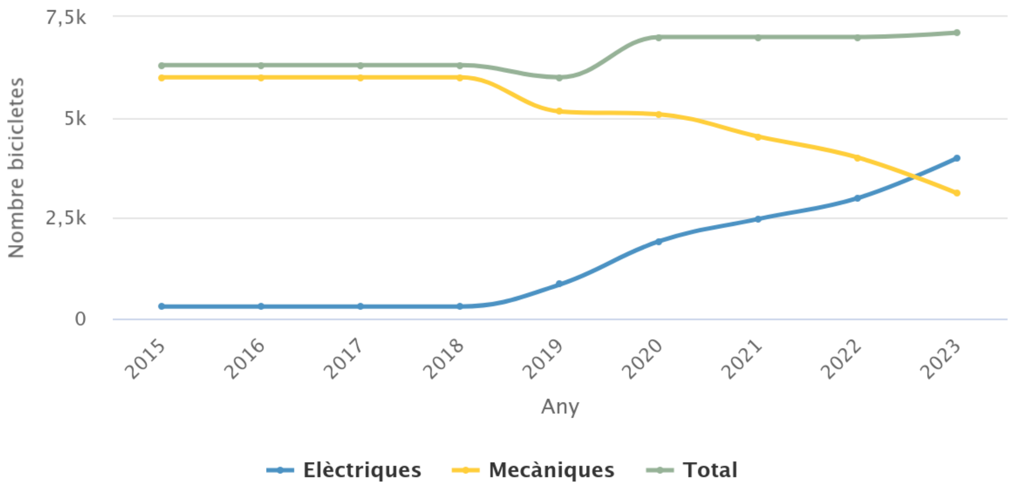
The particular urban characteristics of Barcelona makes it a perfect location for the use of micromobility devices, embodying the essence of traditional European cities with dense, compact urban areas where these new modes of transportation compete for public space with pedestrians, cyclists, and cars (Esztergár-Kiss & Lopez Lizarraga, 2021). In fact, in 2022 bicycle trips accounted for a total of 174,900, and e-scooter trips for 69,960 (representing a 3.5 and 1.4% of total internal trips, respectively) (IERMB, 2023). In accordance with the definition provided in Section 2, our analysis focused on conventional and electric bicycles from the public bike-sharing system along with privately owned e-scooters. The public bike-sharing system, operated under the name Bicing, offers both conventional and electric shared bicycles, with almost 150,000 users, more than 500 docking stations and a fleet of 7,100 vehicles (see https://bicing.barcelona/). Figure 7 shows the location of Bicing docking stations, and Figure 8 shows the evolution in the number of bikes (both electric and conventional) offered by this service. The graph clearly illustrates the gradual integration of e-bikes into the system over time, coinciding with a broader expansion of the fleet in response to the growing demand within the city. Regarding electric scooters, at the moment, the legislative framework in Barcelona does not allow the use of shared electric scooters, so the analysis is limited to the study of private electric scooters.

Figure 7 Locations of Bicing stations in Barcelona



Source: https://bicing.barcelona/

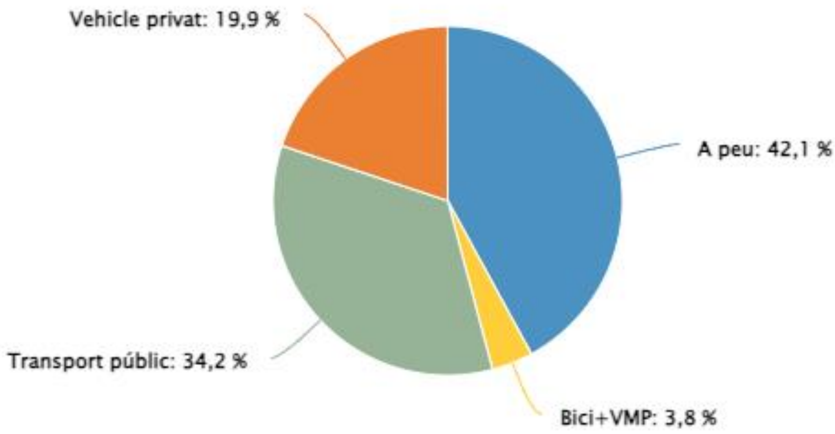
Figure 8 Evolution of the number of bicycles offered by the Bicing system over time



Source: https://dades.ajuntament.barcelona.cat/dades-basiques-de-mobilitat/

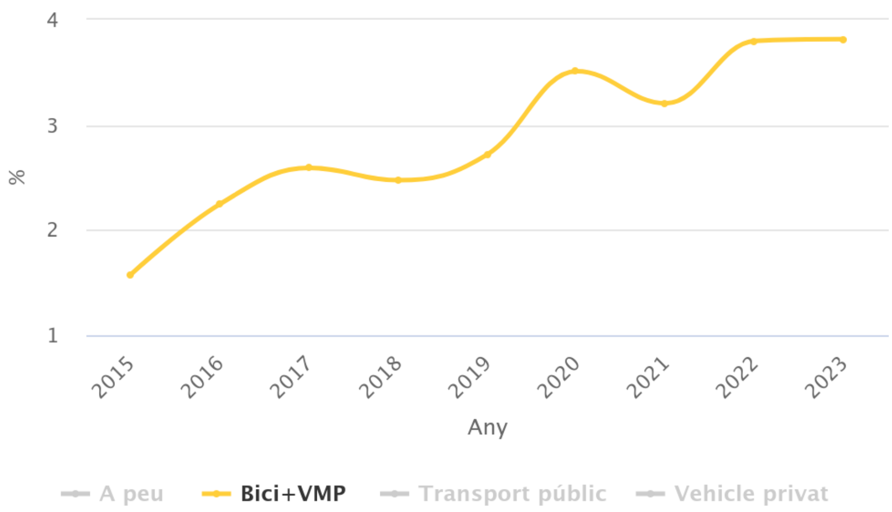
Indeed, at the end of 2023, micromobility represented a 3.8% of Barcelona modal split (see Figure 9), accounting for a notable increase since 2015, when it was of 1.6% (see Figure 10).

Figure 9 Total modal split (provisional estimates as of December 2023)



Source: https://dades.ajuntament.barcelona.cat/dades-basiques-de-mobilitat/

Figure 10 Evolution of the % of total modal split



Source: https://dades.ajuntament.barcelona.cat/dades-basiques-de-mobilitat/

3.3. Overview of the data collection process: the NewMob Project

In 2020, the NewMob study was conducted in Barcelona, Spain, involving a survey of 902 micromobility users. The primary objective of the study was to gain insights into the travel behaviour of individuals using micromobility options and to assess the impact of the COVID-19 pandemic on the adoption of these modes of transportation.

The survey was carried out over the period from September 15th to October 1st and employed eight trained pollsters who were strategically stationed at various locations throughout the city of Barcelona. The data collection took place on working days between 9 a.m. and 8 p.m. Utilizing a Computer Assisted Personal Interviewing (CAPI) technique, individuals using private e-scooters and the public bike-sharing system Bicing (including conventional and electric modes) were randomly approached and requested to participate in a questionnaire, which typically took around 10 to 15 minutes to complete. The questionnaire included questions related to the frequency of utilization, motives behind the use of micromobility vehicles, and the contentment level experienced by riders when using such vehicles. It also aimed to investigate the rationale behind the adoption of micromobility vehicles and the modes of transportation they were replacing. Supplementary questions were incorporated into the questionnaire to ascertain the socio-demographic attributes of respondents and to gauge the extent to which the travel behaviours of users had been altered by the COVID-19 pandemic.

To be eligible for participation, individuals had to either live or work in Barcelona and be over 16 years old, as this is the minimum age requirement for operating an electric scooter and using the public bike-sharing system. The survey sample encompassed 326 electric scooter users, 251 moped scooter users, 217 traditional bike users, and 108 electric bike users (Roig-Costa et al., 2021).

The table below (see Table 2) summarises the socio-demographic profile of the micromobility users surveyed in terms of gender, age, professional status, educational level and frequency of use.

Table 2 Socio-demographic characteristics and frequency of use of micromobility users

	Conventional shared bike	**Electric shared bike**	**Electric scooter**	**Shared moped scooter**	**Total**
Sample (N)	217	108	326	902	902
Gender (%)					
Female	48.4	39.8	35.9	29.9	37.7
Male	51.2	59.3	63.5	69.3	61.6
Age (%)					
16 – 24	30.9	38.9	33.1	45.8	36.9
25 – 34	35.9	27.8	31.9	27.5	31.2
35 – 44	15.7	12.0	23.9	15.5	18.2
45 – 54	9.2	14.8	7.7	9.6	9.4
> **54**	8.3	6.5	3.1	1.6	4.3
Professional status (%)					
Employed	69.6	60.2	78.2	67.3	71.0
Unemployed	5.1	5.6	5.8	1.6	4.4
Student	23.5	33.3	13.5	31.1	23.2
Education level (%)					
< High school	6.9	6.5	9.5	1.2	6.2
High school	30.0	40.7	49.1	51.0	44.0
College/University	61.8	50.9	38.6	47.4	48.1
Frequency of use (%)					
Occasional	1.8	32.4	5.5	49.8	20.2
Weekly	27.2	35.2	12.0	33.5	24.4
Daily	71.0	32.4	82.5	16.7	55.4

Source: own production adapted from Roig-Costa et al. (2021)

In terms of socio-demographic characteristics, the predominant group among the survey respondents comprised males, accounting for 61.6% of the total. This gender disparity is especially pronounced in the case of shared moped scooter users, with nearly 69.3% of users identifying as men. In contrast, the gender gap is less pronounced among shared conventional bicycle users, with women constituting 48.4% of those surveyed. Regarding the distribution of age groups, it is noteworthy that the sample exhibits a discernibly youthful composition. A substantial majority, comprising 68.1% of the surveyed individuals, falls within the age bracket of under 34 years, with over half of this subgroup being under 25 years of age (36.9%). Apart from that, there is a pronounced prevalence of young individuals utilizing shared moped scooters, with 45.8% falling within the under-25 age category. Contrarily, a noteworthy 21.3% of respondents who identify as electric bike-sharing users are aged over 45 years.

In terms of occupation, it is pertinent to highlight that a significant majority of micromobility users were employed at the time of participating in the survey. This observation is particularly salient in the context of electric scooter users, where 78.2% of respondents were found to be employed. In contrast, a considerable proportion of users of shared electric bicycles and moped scooters, amounting to 33.3% and 31.3% respectively, were under educational activities. Significant disparities are also found in the educational level of the respondents. A notable 61.8% of shared conventional bicycle users possess a university education, whereas a relatively lower proportion (38.6%) of electric scooter users have completed university studies.

Lastly, most participants assert regular usage of micromobility, with 55.4% indicating daily utilization. However, it is noteworthy that the frequency of daily use is different among the distinct categories of micromobility users. Electric scooter and conventional bike users present the highest percentages of daily usage, being of an 82.5% and 71.0%, respectively. In contrast, only 32.4% of electric bike-sharing users and a mere 16.7% of moped scooter users indicate daily usage patterns.

3.3.1. Tracking Living Labs

Apart from the questionnaires, the NewMob project also included a tracking phase, to explore the travel behaviour and PA outcomes resulting from the use of micromobility devices. Therefore, from the initial sample, a specific subset of individuals was chosen to partake in a tracking study utilizing dedicated GPS and accelerometer devices. This selection process involved a random sampling method to ensure the representation of the broader survey population. Consequently, the final subset comprised 204 micromobility users (65 e-scooter users, 74 conventional bike riders, 37 e-bike users and 28 moped scooters). For comparison purposes, an additional control group comprising 43 individuals who did not use any micromobility mode was formed. These individuals utilized other available modes of transportation, including active modes, public transport, and private transport. The control group was carefully structured to match the study group in terms of age, gender, and socioeconomic status. In total, 247 individuals participated in the tracking study.

Before commencing the tracking study, participants were required to provide informed consent. They also completed a baseline questionnaire that gathered information about their demographics, self-reported health, and PA habits. This questionnaire used the International Physical Activity Questionnaire (IPAQ) short form. The IPAQ consists of open-ended questions about individuals' PA over the past 7 days and has undergone rigorous testing to ensure reliability and validity (Craig et al., 2003a). Following the IPAQ questionnaire, each participant was equipped 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. These devices were asked to be worn during a week (7 continuous days), on the right side of the hip throughout the day, except for activities like showering, swimming, contact sports, and nighttime sleeping.

In addition to wearing the devices, participants were tasked with maintaining a daily travel diary. This diary was sent to them via WhatsApp or E-mail at the end of each day and served as a tool for cross-referencing their trips with the recorded physical activity levels from the accelerometers (see Appendix 1).

3.4. Accelerometer and GPS data processing

The accelerometer data were processed using Actilife software (https://actigraphcorp.com/actilife/), which summarized the data into 15-second intervals. Any periods of 60 minutes or more with zero values were categorized as "non-wear" and excluded from the analysis. To analyse mode and PA during commuting, participants were required to provide at least one day (8 hours) of valid accelerometer and GPS data from a typical workday. The GPS devices were set to record participants' locations every 15 seconds. The GPS data were analysed using the Human Activity Behaviour Identification Tool and Data Unification System (HABITUS) software. HABITUS employs a heuristic algorithm to identify trips from GPS trajectories and determine their mode of transportation by calculating the distance and speed between sequential GPS points (Berjisian & Bigazzi, 2022). Trips with a 90th percentile speed ranging from ≥10 km/h to <25 km/h were classified as "micromobility trips." As the HABITUS software cannot differentiate between e-scooter and bicycle trips, travel diaries were used to identify the specific mode of transportation for each micromobility trip. These travel diaries were designed to collect information on the number of trips and the micromobility mode used by participants daily.

3.5. Key measures and data analysis

This section is dedicated to explaining the diverse methodologies employed for the analysis of the data acquired through the various techniques outlined (questionnaires and TLL), in relation to the two case studies presented in this dissertation.

3.5.1. Physical activity variable

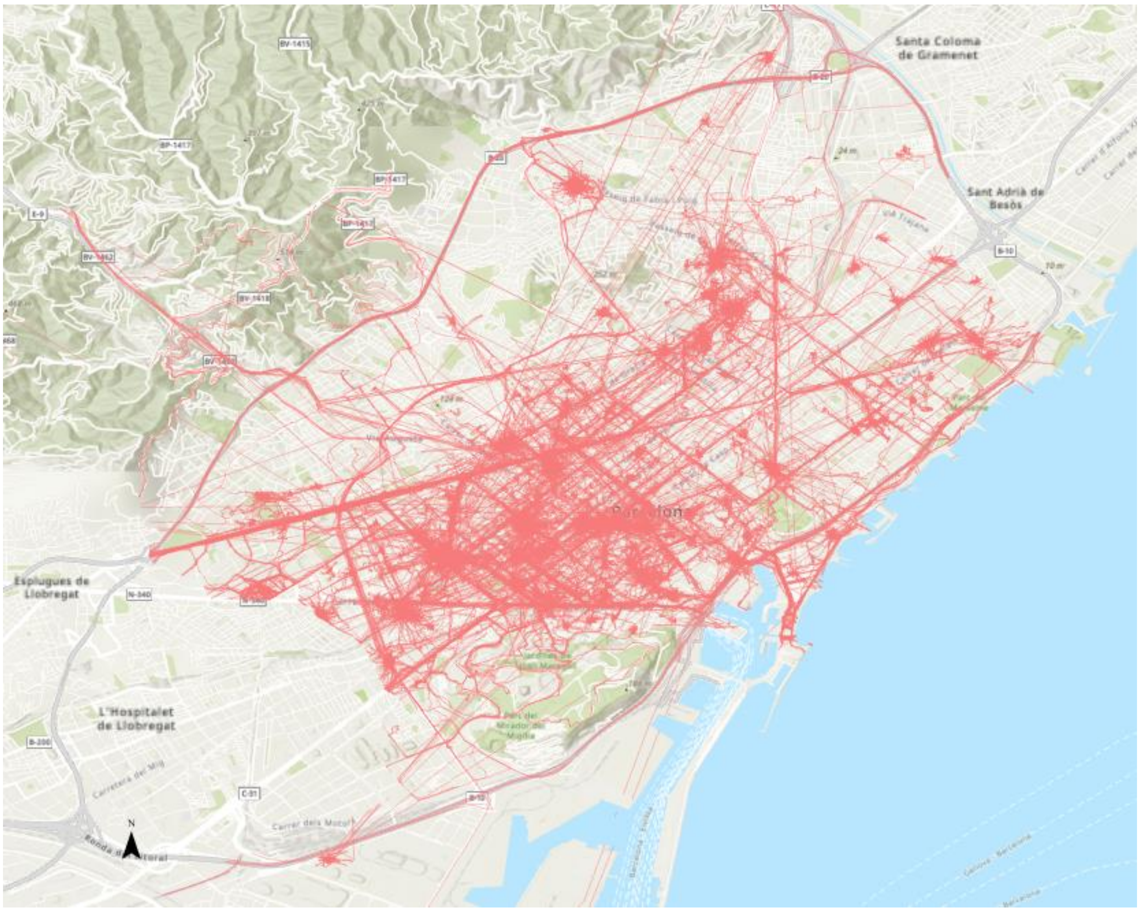
The first empirical study presented in this dissertation (see Section 5.1.) aimed at analysing the daily PA levels of EMM users. For this aim, objectively measured PA was a key variable for conducting the analysis, and it was obtained from the accelerometer device. The raw data was processed using the ActiLife software, which allow to classify the PA data into minutes spend at different activity intensities. Therefore, daily minutes of sedentary, light, moderate, vigorous, and very vigorous intensities were obtained from each participant and participated day (and considered as a valid day). For this specific case study, a new variable was created, reflecting moderate-to-vigorous PA (MVPA) by adding the time spent in these intensities. Consistent with standard procedures in the field, this analysis adopted a three-level classification for PA, comprising sedentary, light, and MVPA, as delineated in prior studies (Hajna et al., 2019; Marquet et al., 2018, 2019, 2020; Pizarro et al., 2016; Vich et al., 2021).

Apart from the objective PA data, self-reported data was also used, obtained from both the baseline questionnaire and the travel diaries. These data sources mainly provided sociodemographic and contextual information of the participants such as age (grouped into 16-29 years, 30-44 years, and 45 years and older), gender (male, female), education level (primary school, high school, college/university), and employment status (student, employed, retired). Body Mass Index (BMI) was also calculated based on self-reported height and weight, with participants categorized as underweight, normal weight, overweight, or obese according to BMI values (Giné-Garriga et al., 2020; Mendinueta et al., 2020; National Center for Chronic Disease Prevention and Health, 2022; White et al., 2016).

On the other hand, the second empirical study presented focused on assessing not the daily PA levels, but the trip-related PA levels. For this, GPS data needed to be combined with the accelerometer data, for every 15-second interval. These combined datasets were imported into ArcGIS Pro software (Esri, Redlands, California, USA), where trips occurring outside the boundaries of Barcelona municipality were visually identified and excluded (see Figures 11 and 12). Additionally, trips deemed too short (less than 2 minutes) or too long (more than 2 hours), as well as those with an average speed exceeding 60 km/h, were filtered out.

After identifying valid trips, Metabolic Equivalents of Task (METs) were used to quantify the intensity of PA, to facilitate comparison across different studies. MET is a unit measuring the rate of energy expenditure during PA (Mendes et al., 2018), where one MET equals the energy expended while sitting at rest, calculated as oxygen uptake per kilogram of body mass per minute (3.5 ml/O2/kg/min) (Hills et al., 2014). The total METs per route were computed using the Freedson equation (METS/min = 1.439008 + 0.000795 × count/min (vertical axis)) (Freedson et al., 1998). The average MET per minute for each trip was then determined by dividing the total estimated METs by the duration of the trip. Additionally, the PA data were aggregated into minutes spent at different activity levels for each trip, including sedentary, light, moderate, vigorous, and very vigorous, based on the cut points defined by Troiano et al. (2008) (<100 cpm for sedentary, 100–1951 cpm for light, 1952–5724 cpm for moderate, 5725–9498 cpm for vigorous, and >9488 cpm for very vigorous) (see an example of the database used in Appendix 2).

Figure 11 Geolocated datapoints collected during the tracking phase in Barcelona



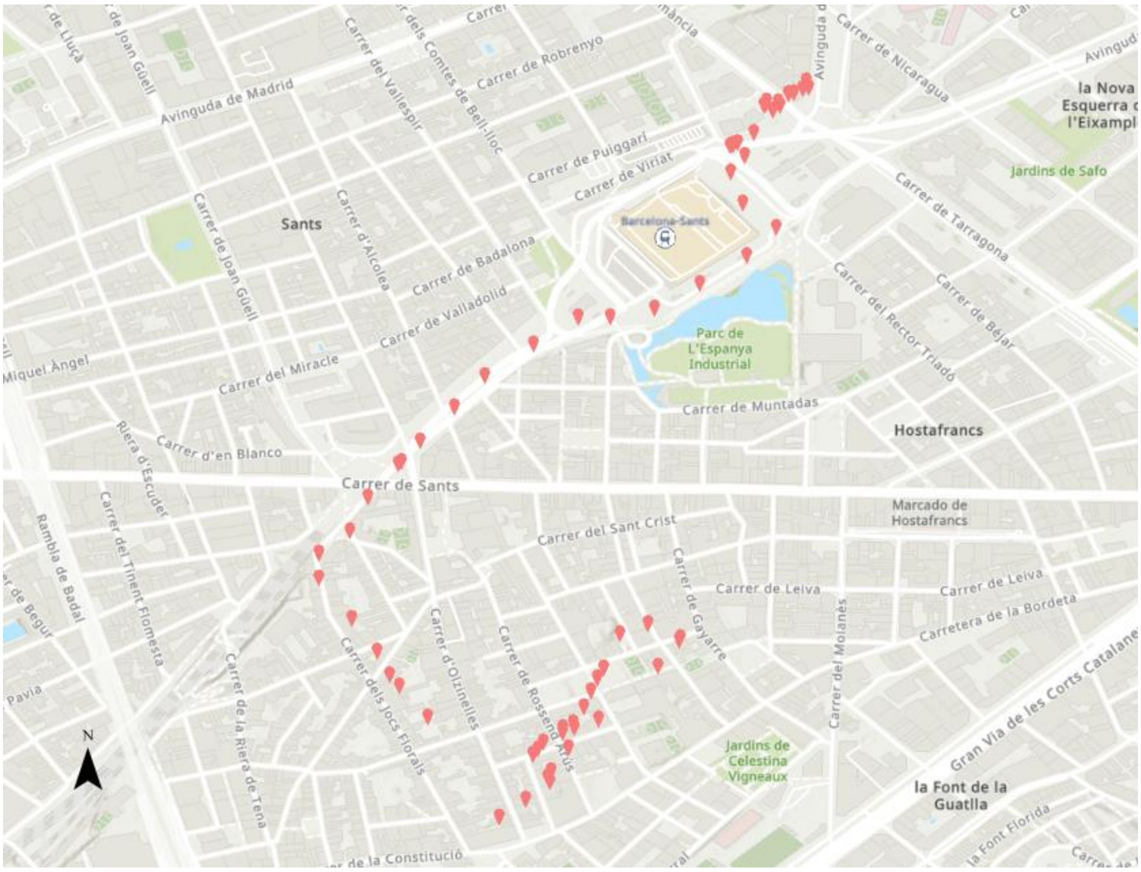
Source: own production

3.5.2. Descriptive and statistical analysis conducted

In both empirical studies a descriptive analysis of the sample was first conducted, assessing sample characteristics such as age, sex, occupation, education, and BMI category. Participants were also associated to a mode of micromobility, as they were asked to self-identify the mode they used most frequently. This information was utilized to categorize participants into e-bike, bike, or e-scooter users. Moreover, daily travel logs were examined to identify any use of micromobility mode on each participated day. This dual classification process was necessary because individuals self-identified as a specific mode users might also utilize other modes on certain days, or possibly not use any micromobility device throughout an entire day.

As statistical analyses, bivariate analysis and one-way ANOVA were employed in both studies to understand the relationship between the micromobility mode and the other variables, especially PA.

Figure 12 Example of tracking datapoints from one trip from one participant



Source: own production

In the first case study (see Section 5.1.), multilevel linear regression was employed to explore the relationship between objective measures of PA and the mode of transport used during each participated day, while controlling for various individual confounders such as age, sex, educational level, professional status, and BMI index. The specific methodology used was three Linear Mixed-Effect Models that were run using the lme4 package in R software version 1.4.1717 (Bates et al., 2015), with subject ID serving as a random effect. This modelling approach, commonly used in similar transportation studies (Kang et al., 2017; Seto et al., 2016), was adopted to address the nested structure of the data, where participated days are nested within the IDs of specific subjects.

In the second study (see Section 5.2.), the analysis examined energy expenditure (METs) when using micromobility modes by distinguishing between two different scenarios: Real-World Energy Expenditure (RWE) and Traffic-Adjusted Energy Expenditure (TAE). RWE captured all PA during the trip, including sedentary periods, while TAE focused solely on the active part of a trip, excluding sedentary periods. Both scenarios included as measurements the Total METs and METs per minute to account for variations in trip characteristics. To investigate the association between micromobility modes utilized during trips and the total METs and METs per minute produced, while adjusting for significant sociodemographic factors, the same methodology (multilevel linear mixed-effects models) as with the first case study was employed. These models included random effects for both user-specific and trip-specific factors to address any unobserved variability.

Moreover, to facilitate the interpretation of the models, marginal effects were computed using the R package "ggeffects" (Lüdecke, 2018). This method is useful to predict the total MET and MET per minute per trip for each transportation mode while keeping all other variables at their average values. More detail about the statistical analyses employed in both case studies can be found in Sections 5.1. and 5.2.

PART II. FINDINGS

4. Physical activity as a factor influencing the adoption of electric micromobility

4.1. Sociopsychological factors associated with the adoption and usage of electric micromobility. A literature review.

Transport Policy 127 (2022) 230–249

Contents lists available at ScienceDirect

Transport Policy

journal homepage: www.elsevier.com/locate/tranpol

Sociopsychological factors associated with the adoption and usage of electric micromobility. A literature review

Alexandra Bretones [a,*], Oriol Marquet [a,b]

[a] *Geography Department, Autonomous University of Barcelona, Spain*
[b] *Institute of Environmental Science and Technology (ICTA-UAB), Spain*

ARTICLE INFO

Keywords:
Micromobility
Sociopsychological factors
Electric mobility
Functional values
Non-functional values
Adoption intention

ABSTRACT

This paper aims to identify the main sociopsychological factors that individuals perceive as affecting their intention to adopt electric (e–)micromobility. Drawing from modal choice theory, the factors are classified into functional (money, time, and other convenience values) and non-functional (emotional, social, and epistemic values). Following a PRISMA systematic literature review of 67 papers, we observed the reported influence of several functional and non-functional factors over the decision on whether to use an e-micromobility mode of transport. Results indicate that non-functional factors such as environmental concern, innovativeness, and belonging can be even more influential for individuals than traditional functional factors such as speed, cost, and time savings. Users seem to perceive these services as socially beneficial, contributing to improved livability, equity of access, and diversity of choice. The present review contributes to our understanding of the complexity of modal choice, and the importance of accounting for the sociopsychological factors influencing user decisions regarding micromobility. Our findings can help improve the strategies and policies supporting e-micromobility adoption.

Bretones, A., & Marquet, O. (2022). Sociopsychological factors associated with the adoption and usage of electric micromobility. A literature review. *Transport Policy*, *127*, 230–249. https://doi.org/10.1016/j.tranpol.2022.09.008

JCR (2022): Impact Factor = 6.8 / Journal Citation Indicator (JCI) = 1.91 / Journal Ranking by JCI = Q1 (Transportation) and Q1 (Economics)

4.1.1. Introduction

Electric micromobility modes of transport (e-MM) are increasing their market share in cities around the world. The rise in the number of electric scooters, bicycles, and mopeds has been fuelled by the promise of solving some of the most prescient current urban problems such as congestion, air quality, and energy consumption (Hollingsworth et al., 2019; Moreau et al., 2020; Nematchoua et al., 2020). Cities are promoting these new modes because they offer positive outcomes for the environment and society (Shaheen & Cohen, 2019). However, the exact nature of these benefits is still unclear, especially regarding their actual impact on social equity and justice (McQueen et al., 2021).

The term e-micromobility is a broad concept that has drawn multiple definitions. Consensus definitions seem to gather smaller-scale, lightweight vehicles, electrically powered, operating at speeds up to 25 km/h, that are mainly used for trips up to 10 km (Institute for Transportation and Development Policy, 2021; Milakis et al., 2020). E-MM vehicles can be privately-owned or used through a shared service. Therefore, we find several vehicles that meet the presented definition, mainly e-bicycles (e-cargo bicycles, e-trikes) and e-scooters, but also one-wheeled or two-wheeled alternatives such as hoverboards or segways. Controversy exists on whether to include vehicles that can circulate at speeds over 25 km/h, therefore considering e-mopeds and small e-motorcycles as e-MM. In this line, the definition provided by the International Transport Forum (ITF) is more inclusive and defines e-micromobility as: "vehicles with a mass of no more than 350 kg (771 lb) and a design speed no higher than 45 km/h" (International Transport Forum, 2020). For this literature review, we define e-MM as lightweight vehicles (weighting less than 35kg), which are electrically powered and with a maximum speed of 25km/h, including then e-bikes and e-scooters. We are therefore excluding larger and more powerful vehicles, such as e-speed bikes, e-mopeds, and e-motorcycles. Also, this selected definition let us include other modes such as segways and hoverboards. However, these modes are usually let out of e-MM research as they are not present in many cities, so their usage is minor and limited to some regions and specific contexts (Fang, 2022; Fang et al., 2019).

To date, the e-MM literature has focused on testing some of the claims and potentials of these new forms of mobility. As such, several studies have examined the potential positive and negative impacts resulting from the deployment of a fleet of e-MM

(Bieliński et al., 2020; Chapman & Larsson, 2021; De Geus & Hendriksen, 2015; Fearnley et al., 2020; Johnson & Rose, 2013; Oeschger et al., 2020; Teixeira et al., 2021; Van Cauwenberg et al., 2019; Zagorskas & Burinskiene, 2020). Other studies focused on technical and operational aspects (Gojanovic et al., 2011; Ji et al., 2014; Moran et al., 2020; Shaheen et al., 2019; Shaheen & Cohen, 2019); health benefits and physical activity (Alessio et al., 2021; Bernstein & McNally, 2017; Bini & Bini, 2020; Bourne et al., 2018; Castro et al., 2019; De Geus & Hendriksen, 2015; Glenn et al., 2020; Gojanovic et al., 2011; Hoj et al., 2018; Langford et al., 2017; Peterman et al., 2016; Sperlich et al., 2012); safety, injuries, and security concerns (Beck et al., 2020; Bekhit et al., 2020; Blomberg et al., 2019; Bloom et al., 2021; Brownson et al., 2019; Faraji et al., 2020; Kim et al., 2021; Kobayashi et al., 2019; Lavoie-Gagne et al., 2021; McGuinness et al., 2021; Moftakhar et al., 2021; Oksanen et al., 2020; Panwinkler & Holz-Rau, 2021; Pétursdóttir et al., 2021; Qian et al., 2020; Savitsky et al., 2021; Siebert et al., 2021; Smit et al., 2021; Stoermann et al., 2020; Traynor M.D. et al., 2021; Trivedi et al., 2019; Verstappen et al., 2021; Wang et al., 2018; Watson et al., 2020). There is also a body of research dedicated to economic aspects of e-MM such as rising fuel and congestion costs, wasted time, and resources (Adler et al., 2019; Button et al., 2020; Compostella et al., 2020; Kazmaier et al., 2020; Laurischkat & Jandt, 2018; Pavlenko et al., n.d.; Pietrzak & Pietrzak, 2021; Suchanek & Wolek, 2018) and on environmental impacts such as contributing to climate change, air quality, and congestion (Hollingsworth et al., 2019; Hsieh et al., 2018; Hulkkonen et al., 2020; Moreau et al., 2020; Nematchoua et al., 2020; Sousa-Zomer & Miguel, 2016; Weiss et al., 2020). Additionally, there is an emerging number of literature devoted to the social dimension of these new modes of transport, i.e., literature focused on the factors behind e-MM adoption, understanding why some individuals choose to start using these innovative alternatives, and why others are reluctant to do so, including studies on intentions and deterrents (Alessio et al., 2021; Almannaa et al., 2021; Andersson et al., 2021; Berge & (TOI), 2019; Bielinski & Wazna, 2020; Cao et al., 2021; Chapman & Larsson, 2021; De Geus & Hendriksen, 2015; Dias et al., 2021; Edge et al., 2018; Fearnley et al., 2020; Fyhri et al., 2017; Glavić et al., 2021; Johnson & Rose, 2015; Jones et al., 2016; McQueen et al., 2020; Oeschger et al., 2020; Teixeira et al., 2021; Van Cauwenberg et al., 2019; Zagorskas & Burinskiene, 2020); user characteristics and patterns (Campbell et al., 2016; Campisi et al., 2021; Chavis et al., 2021; Christoforou et al., 2021; Kaplan et al., 2018; Rérat, 2021; Yin et al., 2021); modal shift (Bourne et al., 2020; Dill & Rose, 2012; Fitch et al., 2021; Fyhri & Fearnley, 2015;

Gössling, 2020; Jahre et al., 2019; Jones et al., 2016; McQueen et al., 2021; Smith & Schwieterman, 2018; Wang et al., 2021; Zagorskas & Burinskiene, 2020); the built and natural environment (Bieliński et al., 2020; Chavis et al., 2021; Ding et al., 2019; Hawa et al., 2021; Hosseinzadeh et al., 2021); accessibility and connectivity (Chen et al., 2021; Jones et al., 2016; Milakis et al., 2020; Mooney et al., 2019; Shaheen & Chan, 2016); and socio-demographics (Almannaa et al., 2021; Campbell et al., 2016; Christoforou et al., 2021; Fearnley et al., 2020; Fitch et al., 2020; Glavić et al., 2021; Kaplan et al., 2018; McQueen et al., 2021; Rérat, 2021; Winslott Hiselius & Svensson, 2017; Yin et al., 2021; Zagorskas & Burinskiene, 2020). Nonetheless, a research gap exists on what specifically relates to the sociopsychological determinants of the adoption and usage of e-MM, with the existing contributions being limited and fragmented. Therefore, there is a need to review the existent available evidence to map all sociopsychological factors that have been found to influence e-MM adoption and usage.

Thus, the present paper aims at providing some clarity on how the main social and psychological factors influence the adoption and usage of e-MM. By reviewing the literature that has attempted to understand the social and psychological determinants of e-MM adoption we can advance on our understanding of these new micromobility modes and their contribution to urban transportation schemes.

4.1.2. Theoretical framework

Early transportation literature tried to explain modal choice by using tangible factors such as travel cost and time, as well as the demographic characteristics of the traveller, such as age, gender, income, or household size (Lisco, 1968; Oort, 1969; Quarmby, 1967; Williams, 1978). More recently, new theoretical models and empirical studies have incorporated a more holistic and multi-factorial approach (De Witte et al., 2013; Klöckner & Matthies, 2004; Soria-Lara et al., 2017; van Acker et al., 2010; Verplanken et al., 2008). Among these new modal choice factors, sociopsychological factors such as habits and social status were found to play a key role in comprehending travel-related choices of individuals (De Witte et al., 2013; Soria-Lara et al., 2017; van Acker et al., 2010).

Social and psychological factors can influence people's behaviour when taking decisions and making preferences, and they have been found to be good predictors of actions such as the purchasing or adopting intention of consumers in transport research (Galdames et al., 2011; Hunecke et al., 2010; Levin et al., 1977). Psychosocial factors are often classified into functional and non-functional values (Forsythe et al., 2006; Han et al., 2017; Sheth et al., 1991). This classification originates from analytical literature (Holbrook & Hirschman, 1982; Leroi-Werelds et al., 2014; Woodruff, 1997) exploring factors that affect consumers' purchasing behavior, and how different authors (Babin et al., 1994; Gwinner et al., 1998; Roy, 1994; Schuitema et al., 2013; Whitelock, 1989) identify values and factors that are key to understanding why individuals purchase or use products. Sheth et al. (1983) offered a first five-dimension (functional, social, emotional, epistemic, and conditional) categorisation of values, which a subsequent study resulting in the two-dimension (functional and non-functional) classification presented (Sheth et al., 1991). This classification was also adopted by Forsythe et al. (2006), and more recently by Han et al. (2017) when analysing the intention to adopt electric vehicles. Thus, functional values are defined as the tangible attributes and utilitarian functions such as the variety, price, convenience, and quality of the product; while non-functional values are related to the intangible characteristics of the product regarding social and emotional needs (Han et al., 2017; Ko et al., 2019; Li et al., 2020; Queiroz et al., 2020). Following the trends set by the most recent and advanced mode choice modelling (Kroesen & Chorus, 2020; Nordfjærn & Rundmo, 2018; Shirgaokar, 2019; Simsekoglu & Klöckner, 2019), micromobility studies have also started to incorporate sociopsychological factors in their attempt to achieve a more realistic and complete representation of micromobility decision-making.

Early studies seem to indicate that the adoption of e-MM might be strongly dependent on several sociopsychological factors that often affect decision-making simultaneously (Han et al., 2017). In this regard, functional values are related to the traditional needs perceived by consumers when deciding which transport mode to use, which regarding e-MM adoption and usage will mainly be price, operation cost, performance, driving range, comfortability, convenience and charging time, together with the specific attributes of the service or product. On the other hand, non-functional values will be related to associations that individuals build with regard to these modes and those values associated with certain social, emotional, and epistemic needs such as environmental attitude, innovative personality and social beliefs (Sheth et al., 1991). Functional values can be thought to be one of the main rational causes for consumers to consider adopting any new transportation service, considering time or cost savings resulting from its use. However, consumers can also be influenced by other non-functional values linked with experience, status, and perception.

4.1.3. Materials and Methods

A systematic literature review method was adopted to synthesize the existing studies, thus providing insights into the factors affecting the adoption intention and usage of e-MM. This review follows the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) procedure that includes four steps: identification, screening, eligibility, and inclusion.

4.1.3.1. Search strategy and selection criteria

A systematic literature search was performed across three electronic databases: Web of Science (WoS), Scopus, and Transport Research International Documentation (TRID). Due to the novelty of the transport modes analysed, the search was limited to the period from 2010 until the present time. The search was conducted between December 2021 and January 2022. Papers were required to have been written in the English language.

The primary searches were carried out using a combination of keywords that related to e-MM (vehicles) and the sociopsychological factors or determinants. Before conducting the searches, terms were identified to specifically search for publications including both functional and non-functional factors, and/or social factors, determinants, or motivations to adopt or use e-MM. Then, several terms and spelling variations were used to first relate the light vehicles included in the e-MM concept (e-bicycles, e-scooters, and e-micromobility in general) with the sociopsychological attributes. All searches were constructed similarly, containing the e-MM vehicles AND the sociopsychological keywords (as shown in Table 3). It is important to clarify that vehicles included in this analysis follow the definition of having a speed up to 25 km/h, it is for that reason that e-speed bikes, e-mopeds and e-motorcycles are not considered for this particular review. Moreover, hoverboards and Segway-type are also excluded. Hoverboards are particularly popular with children and teenagers and mostly are used for fun. Segway-related studies are almost inexistent, and they are not even allowed in several cities. Therefore, the modes included in this review are mainly e-bikes and e-scooters.

Table 3 Example of selected keywords for the primary literature search

E-micromobility (vehicles)		Sociopsychological factors (Example: General factors)
("electric bike") OR ("e-bike") OR ("ebike") OR ("electric bicycle") OR ("e-cycling") OR ("pedelec") OR ("pedelec bike") OR ("pedelec mobility")) OR (("electric scooter") OR ("e-scooter")) OR (("electric micromobility") OR ("e-micromobility") OR ("electric two-wheelers")	*AND*	("psychological factors") OR ("motivations") OR ("perceived benefits") OR ("perceived barriers") OR ("social factors")

Source: own production

All types of study designs were included: scoping reviews, systematic reviews, meta-analysis, ecological, longitudinal, cross-sectional, case-control, intervention, and experimental study designs. Searches in all three databases resulted in a total of 10,032 hits, as shown in Table 4.

Table 4 Search strategy database results

Database	Focus	Publication date	Hits
Web of Science (WoS)	Multidisciplinary	2010-2022	968
Scopus	Multidisciplinary	2010-2022	8,497
Transport Research International Documentation (TRID)	Transportation science	2010-2022	567
		Total hits	**10,032**

Source: own production

During the process of selection of the papers, we followed the four phases of the PRISMA statement: identification, screening, eligibility, and inclusion (see Figure 13). In this case, the inclusion criteria were:

- Papers providing insights into electric micromobility and including micromobility or light means of transport (i.e., scooters, bicycles, or mopeds).
- Papers reporting objective measurements of social factors, the roles of users, and/or user decision-making for electric micromobility.

- Papers providing quantitative results from surveys.
- Papers providing qualitative results from interviews.

Out of the total 10,032 papers, 6,271 resulted once the duplicated were eliminated. After the title screening of these resulting non-duplicated publications, 974 qualified for abstract screening. Based on the abstract screening, 246 remained as for the full-text screening. After full-text screening, 63 articles qualified for review inclusion. Reference screening added another 4 articles. Finally, 67 articles were included in this review, as detailed in Table 5 and Figure 13.

The majority of papers were excluded based on their titles as some of them followed a completely different approach (environmental, economic, industrial) and were not related to the social dimension of e-MM adoption or usage. Others clearly presented an analysis of other types of factors such as spatial, temporal, or data privacy. Of the resulting 246 papers for abstract screening, some articles were excluded for not being written in English. Also, a big part of the articles was excluded because they were not referring to e-MM vehicles, but to other kinds of electric vehicles such as cars or motorcycles, and some others did not specify if the micromobility mode studied was electrically powered or not. The rest of the excluded articles analysed other factors or topics of no interest for this review (built environment, trip purpose, spatial coverage, modal shift, etc.).

4.1.3.2. Data extraction

In the analysis of the sociopsychological factors affecting the adoption intention and usage of e-MM, the factors identified were those that could either be perceived as functional or non-functional, from a private or individual point of view. Private or individual means that the beneficiary of the factor is the user of the service.

The selection of the factors was based on the factors that were objectively measured in the analysed studies. Only the factors that were clearly described in the results of more than one publication were selected. Most of the included studies used surveys or interviews, and some complemented the research with statistics to show the results. This process resulted in a total of 17 factors: 10 within the functional category and 7 within the non-functional category.

4.1.4. Results

4.1.4.1. Study characteristics

After reviewing the 67 papers that met the selection criteria, a series of key characteristics were extracted. As shown in Table 3, the studies presented differences in terms of geography, target population, and methodology. Regarding the time of publication, most papers were published between 2018 and today. This is directly related to the recent surge of e-MM around the world and the growing interest in their impacts on society. In fact, 24 articles were published in 2021 (Abouelela et al., 2021; Andersson et al., 2021; Bateman et al., 2021; Biegańska et al., 2021; Bielinski et al., 2021; Buehler et al., 2021; De Ceunynck et al., 2021; Eccarius et al., 2021; Edel et al., 2021; Esztergár-Kiss & Lopez Lizarraga, 2021; Flores & Jansson, 2021; Glavić et al., 2021; Huang, 2021; Kazemzadeh & Koglin, 2021; Kopplin et al., 2021; Kwiatkowski et al., 2021; Lee et al., 2021; Melia & Bartle, 2021; Mitra & Hess, 2021; Patil & Majumdar, 2021; Rejali et al., 2021; Teixeira et al., 2021; Thomas, 2021; Will et al., 2021), showing the attention academia is paying to these new modes.

Table 5 Summary of the reviewed studies

Author(s)	**Title**	**Year**	**Publication**	**Type**	**Vehicle**	**Modality**	**Geography**	**Method**	**Sample**	**Target population**
6t-bureau de recherche	Uses and Users of Free-floating Electric Scooters in France	2019	-	Report	E-scooter	Shared	Paris, Lyon and Marseille (France)	Survey	4382	Users
Abouelela, et al.	Are young users willing to shift from carsharing to scooter-sharing?	2021	Transportation Research Part D- Transport and Environment	Journal Article	E-scooter	Shared	Munich (Germany)	Survey	503	Young individuals from 18 to 34 years old
Alamelu, et al.	Preference of E-bike by women in India -a niche market for auto manufacturers	2015	Business: Theory and Practice	Journal Article	E-bike	Private	Madurai City (India)	Survey	1100	Women
An, et al.	Travel Characteristics of E-bike Users: Survey and Analysis in Shanghai	2013	Procedia - Social and Behavioral Sciences	Journal Article	E-bike	Private	Shanghai (China)	Survey	470	Users
Andersson, et al.	What is the substitution effect of e-bikes? A randomised controlled trial	2021	Transportation Research Part D- Transport and Environment	Journal Article	E-bike	Private	Skövde (Sweden)	Survey	65	Company employees
Arsenio, et al.	Assessing the market potential of electric bicycles and ICT for low carbon school	2018	European Transport Research Review	Journal Article	E-bike	Private/Shared	Águeda (Portugal)	Survey	248	Students (secondary school)

	travel: a case study in the Smart City of ÁGUEDA									
Bateman, et al.	Barriers and facilitators to bikeshare programs: A qualitative study in an urban environment	2021	Journal of Transport & Health	Journal Article	E-bike	Shared	Birmingham, Alabama (US)	Focus Group	27	Users
Behrendt, F	Why cycling matters for electric mobility: towards diverse, active and sustainable e-mobilities	2018	Mobilities	Journal Article	E-bike	Private	Brighton and Hove (UK)	Interview, Focus Group, Survey	80	Trial commuters
Biegańska, et al.	A typology of attitudes towards the e-bike against the background of the traditional bicycle and the car	2021	Energies	Journal Article	E-bike	Private/Shared	Poland	Survey	456	Users and non-users
Bieliński, et al.	Electric bike-sharing services mode substitution for driving, public transit, and cycling	2021	Transportation Research Part D: Transport and Environment	Journal Article	E-bike	Shared	Gdansk, Gdynia, and Sopot (Poland)	Survey	488	Users and non-users
Bieliński, et al.	Electric scooter sharing and bike sharing user behaviour and characteristics	2020	Sustainability	Journal Article	E-bike/E-scooter	Shared	Gdansk, Gdynia, and Sopot (Poland)	Survey	633	Users and non-users

Buehler, et al.	Changes in Travel Behavior, Attitudes, and Preferences among E-Scooter Riders and Nonriders: First Look at Results from Pre and Post E-Scooter System Launch Surveys at Virginia Tech	2021	Transportation Research Record	Journal Article	E-scooter	Shared	Virginia Tech Campus, Virginia (US)	Survey	129	Members university community
De Ceunynck, et al.	Assessing the Willingness to Use Personal e-Transporters (PeTs): Results from a Cross-National Survey in Nine European Cities	2021	Sustainability	Journal Article	PeTs	Private/Shared	Ghent and Liège (Belgium), Tilburg and Groningen (The Netherlands), Trondheim and Bergen (Norway) and Düsseldorf, Dortmund and Berlin (Germany)	Survey	2159	General population > 18 years
Dill & Rose	Electric Bikes and Transportation Policy: Insights from Early Adopters	2012	Transportation Research Record: Journal of the	Journal Article	E-bike	Private	Portlant, Oregon (US)	Interview	28	E-bike owners

			Transportation Research Board						
Dowling, et al.	Use of personal mobility devices for first-and-last mile travel: the Macquarie-Ryde trial	2015		Conference Proceeding	E-scooter	Private	Macquarie University, New South Wales (Australia)	Survey	17	University employees
Eccarius, et al.	Prospects for shared electric velomobility: Profiling potential adopters at a multi-campus university	2021	Journal of Transport Geography	Journal Article	E-bike	Shared	Multi-campus university in the South East Queensland (SEQ), (Australia)	Survey	368	Students and staff university
Eccarius & Lu	Exploring consumer reasoning in usage intention for electric scooter sharing	2018	Transportation Planning Journal	Journal Article	E-scooter	Shared	Taiwan (China)	Survey	98	Local students
Edel & Kern	Potential analysis of E-Scooters for commuting paths	2021	World Electric Vehicle Journal	Journal Article	E-scooter	Private	Hannover (Germany)	Survey	152	Users and not-users
Edge, et al.	Exploring e-bikes as a mode of sustainable transport: A temporal qualitative study of the perspectives of a sample of novice riders in a Canadian city	2018	Canadian Geographer	Journal Article	E-bike	Private	Kitchener-Waterloo (Canada)	Focus Group	10	Staff and students at the University of Waterloo (novice users)

Elias & Gitelman	Youngsters' opinions and attitudes toward the use of electric bicycles in Israel	2018	Sustainability	Journal Article	E-bike	Private	Israel (central region)	Survey	326	Young riders (students from junior high-schools and high-schools)
Esztergár-Kiss, et al.	Exploring user requirements and service features of e-micromobility in five European cities	2021	CASE STUDIES ON TRANSPORT POLICY	Journal Article	E-micromobility	Private/Shared	Munich, Barcelona, Copenhagen, Tel Aviv, and Stockholm	Survey	790	General population > 18 years
Fitt & Curl	The early days of shared micromobility: A social practices approach	2020	Journal of Transport Geography	Journal Article	E-scooter	Shared	New Zealand	Survey	491	General population > 18 years
Fitt & Curl	E-scooter use in New Zealand: Insights around some frequently asked questions	2019	-	Report	E-scooter	Private/Shared	New Zealand	Survey	563	Users and non-users
Flores & Jansson	The role of consumer innovativeness and green perceptions on green innovation use: The case of shared e-bikes and e-scooters	2021	Journal of Consumer Behaviour	Journal Article	E-bike/E-scooter	Shared	Copenhagen and Stockholm	Survey	1501	General population btw 16-65 years

Fyhri, et al.	A push to cycling: exploring the e-bike's role in overcoming barriers to bicycle use with a survey and an intervention study	2017	International Journal of Sustainable Transportation	Journal Article	E-bike	Private	Oslo and the Akershus County (Norway)	Survey, Intervention Study	5460/240	Members of the Norwegian Automobile Federation (NAF)
Glavić, et al.	The e-scooter potential to change urban mobility—Belgrade case study	2021	Sustainability	Journal Article	E-scooter	Private/Shared	Belgrade (Serbia)	Survey	1143	Users
Gorenflo, et al.	Usage Patterns of Electric Bicycles: An Analysis of the WeBike Project	2017	Journal of Advanced Transportation	Journal Article	E-bike	Private	University of Waterloo (Canada)	Survey	172/24/24	Staff/faculty members and graduate students
Hardt & Bogenberger	Usage of e-Scooters in Urban Environments	2019	21st Euro Working Group on Transportation Meeting (Ewgt 2018)	Conference Proceeding	E-scooter	Shared	Munich (Germany)	Survey	38	General population > 18 years
Haustein & Møller	Age and attitude: Changes in cycling patterns of different e-bike user segments	2016	International Journal of Sustainable Transportation	Journal Article	E-bike	Private	Denmark	Survey	427	E-bike users
Hiselius & Svenssona	Could the increased use of e-bikes (pedelecs) in Sweden	2014	9th International Conference on	Conference Proceeding	E-bike	Private	Sweden	Survey	321	E-bike purchasers

	contribute to a more sustainable transport system?		Environmental Engineering, ICEE 2014							
Huang, F.-H.	User behavioral intentions toward a scooter-sharing service: an empirical study	2021	Sustainability	Journal Article	E-scooter	Shared	Campus of Asia Eastern University of Science and Technology in New Taipei City, Taiwan (China)	Survey	99	Individuals with no previous experience of a shared two-wheeler service, possession of a driver's license, and being over 20 years
Hyvönen, et al.	Light electric vehicles: substitution and future uses	2016	Transforming Urban Mobility (Tum 2016)	Conference Proceeding	Light electric vehicles	Private/Shared	Finland	Survey	1030	Individuals aged 15–79
Johnson & Rose	Electric bikes - cycling in the New World City: An investigation of Australian electric bicycle owners and the decision-making process for purchase	2013	Australasian Transport Research Forum, ATRF 2013 - Proceedings	Conference Proceeding	E-bike	Private	Australia	Survey	529	E-bike owners
Jones, et al.	Motives, perceptions and experiences of electric bicycle owners and implications for	2016	Journal of Transport Geography	Journal Article	E-bike	Private	Amsterdam, Utrecht and Groningen (Netherlands); Oxford (UK)	Interview	22	Adult e-bike owners

	health, wellbeing and mobility									
Kaplan, et al.	Intentions to use bike-sharing for holiday cycling: An application of the Theory of Planned Behavior	2015	Tourism Management	Journal Article	E-bike	Shared	Copenhagen (from 35 countries, mostly European)	Survey	655	Potential tourists
Kaplan, et al.	The role of human needs in the intention to use conventional and electric bicycle sharing in a driving-oriented country	2018	Transport Policy	Journal Article	E-bike	Shared	Three Polish cities (Poznan, Szczecin, Gorzow Wielkopolski)	Survey	717	General population
Kazemzadeh & Koglin	Electric bike (non)users' health and comfort concerns pre and peri a world pandemic (COVID-19): A qualitative study	2021	Journal of Transport & Health	Journal Article	E-bike	Private	Sweden	Interview	23	E-bike rider or with experience
Kopplin, et al.	Consumer acceptance of shared e-scooters for urban and short-distance mobility	2021	Transportation Research Part D-Transport and Environment	Journal Article	E-scooter	Shared	Germany	Survey	749	General population
Krauss, et al.	What drives the utility of shared transport services for urban travellers? A stated	2022	Travel Behaviour and Society	Journal Article	E-scooter	Shared	Germany	Survey	1779	General population with driver's license

	preference survey in German cities									
Kwiatkowski, et al.	Could it be a bike for everyone? The electric bicycle in Poland	2021	Energies	Journal Article	E-bike	Private	Poland	Survey	456	General population
Lee, et al.	Public intentions to purchase electric vehicles in Pakistan	2021	Sustainability	Journal Article	E-bike	Private	Lahore City (Pakistan)	Survey	359	General population
Leger, et al.	"If I had a regular bicycle, I wouldn't be out riding anymore": Perspectives on the potential of e-bikes to support active living and independent mobility among older adults in Waterloo, Canada	2019	Transportation Research Part A: Policy and Practice	Journal Article	E-bike	Private	Region of Waterloo (Canada)	Interview, Focus Group	17/37	Older adults (>55 years)
Lin, et al.	The death of a transport regime? The future of electric bicycles and transportation pathways for sustainable mobility in China	2018	Technological Forecasting and Social Change	Journal Article	E-bike	Private	Nanjing City (China)	Survey	1003	General population

Ling, et al.	Differences of cycling experiences and perceptions between e-bike and bicycle users in the United States?	2017	Sustainability	Journal Article	E-bike	Private	US	Survey	806	Bike owners (electric and conventional)
Macarthur, John	Evaluation of an Electric Bike Pilot Project at Three Employment Campuses in Portland, Oregon	2017	National Institute for Transportation and Communities (NITC)	Report	E-bike	Private	Three Campuses Portland, Oregon (US)	Survey	129	Campus employees
Mayer, A	Motivations and barriers to electric bike use in the U.S.: views from online forum participants	2020	International Journal of Urban Sustainable Development	Journal Article	E-bike	Private	US	Interview	47	E-bike riders
Melia & Bartle	Who uses e-bikes in the UK and why?	2021	International Journal of Sustainable Transportation	Journal Article	E-bike	Private	UK	Survey, Interview	2092	People living in the UK who had ever used or considered using an e-bike
Mitra & Hess	Who are the potential users of shared e-scooters? An examination of socio-demographic,	2021	Travel Behaviour and Society	Journal Article	E-scooter	Shared	Greater Golden Horseshoe (GGH) region (Canada)	Survey	1640	Residents 18 years or above

	attitudinal and environmental factors									
Munkácsy & Monzón	Impacts of smart configuration in pedelec-sharing: Evidence from a panel survey in Madrid	2017	Journal of Advanced Transportation	Journal Article	E-bike	Shared	Madrid (Spain)	Survey, Interview	205	Users and non-users
Nematchoua, et al.	Evaluation of the potential of classic and electric bicycle commuting as an impetus for the transition towards environmentally sustainable cities: A case study of the university campuses in Liege, Belgium	2020	Renewable and Sustainable Energy Reviews	Journal Article	E-bike	Private	University of Liège (Belgium)	Survey	1206	Campus users (students, PhD students, staff members)
Patil & Majumdar	Prioritizing key attributes influencing electric two-wheeler usage: A multi criteria decision making (MCDM) approach – A case study of Hyderabad, India	2021	Case Studies on Transport Policy	Journal Article	Electric-two-wheelers	Private	Hyderabad (India)	Survey	1070	Motorised-two-wheelers users

Pimentel & Lowry	If You Provide, Will They Ride? Motivators and Deterrents to Shared Micromobility	2020		Report	E-bike/E-scooter	Shared	Washington, Oregon, and Idaho (US)	Survey	1502	Users and non-users
Plazier, et al.	The potential for e-biking among the younger population: A study of Dutch students	2017	Travel Behaviour and Society	Journal Article	E-bike	Private	University of Groningen (Netherlands)	Survey, Interview	37/8	University students
Popovich, et al.	Experiences of Electric Bicycle Users in the Davis/Sacramento, California Area	2014	Travel Behaviour and Society	Journal Article	E-bike	Private	Sacramento, California (US)	Interview	27	E-bike owners
Rayaprolu & Venigalla	Motivations and Mode-choice Behavior of Micromobility Users in Washington, DC	2020	Journal of Modern Mobility Systems	Journal Article	E-bike/E-scooter	Shared	Washington DC (US)	Survey	440	Users and non-users
Rejali, et al.	Assessing a priori acceptance of shared dockless e-scooters in Iran	2021	Transportation Research Part D: Transport and Environment	Journal Article	E-scooter	Shared	Iran	Survey	1078	General population
Sanders, et al.	To scoot or not to scoot: Findings from a recent survey about the benefits and barriers of using E-scooters for riders and non-riders	2020	Transportation Research Part A: Policy and Practice	Journal Article	E-scooter	Private	Arizona State University, Tempe, Arizona (US)	Survey	1256	University staff

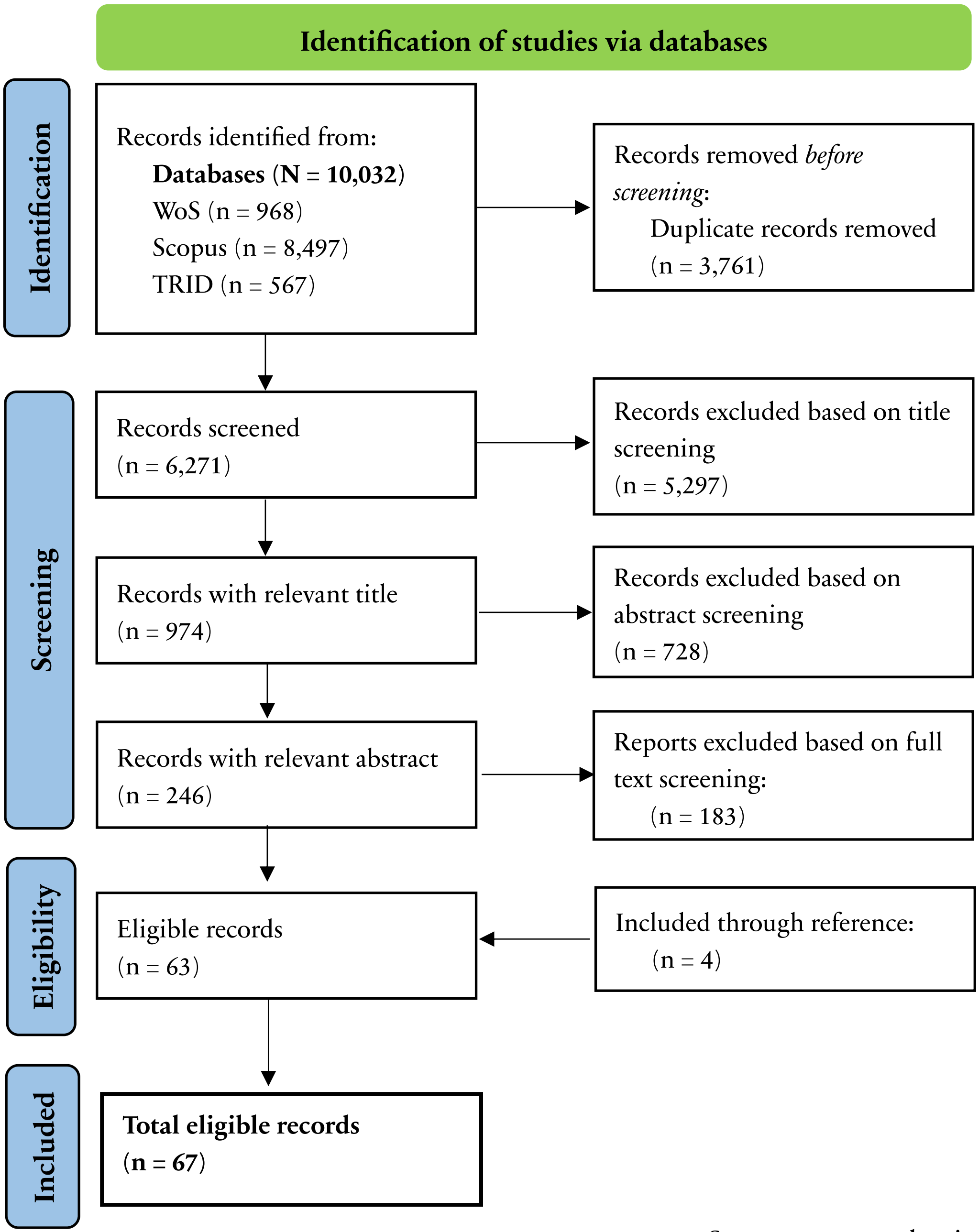
Sellaouti, et al.	Analysis of the use or non-use of e-scooters, their integration in the city of Munich (Germany) and their potential as an additional mobility system	2020	2020 IEEE 23rd International Conference on Intelligent Transportation Systems, ITSC 2020	Conference Proceeding	E-scooter	Shared	Munich (Germany)	Survey	277	General population
Simsekoglu & Klöckner	The role of psychological and socio-demographical factors for electric bike use in Norway	2019	International Journal of Sustainable Transportation	Journal Article	E-bike	Private	Norway	Survey	910	Users and non-users
Simsekoglu & Klöckner	Factors related to the intention to buy an e-bike: A survey study from Norway	2019	Transportation Research Part F: Traffic Psychology and Behaviour	Journal Article	E-bike	Private	Norway	Survey	910	Users and non-users
Teixeira, et al.	The motivations for using bike sharing during the COVID-19 pandemic: Insights from Lisbon	2021	Transportation Research Part F: Traffic Psychology and Behaviour	Journal Article	E-bike	Shared	Lisbon (Portugal)	Survey	294	Users or past users
Thomas, A	Electric bicycles and cargo bikes—Tools for parents to keep on biking in auto-centric	2021	International Journal of Sustainable Transportation	Journal Article	E-bike/E-cargo bike	Private	San Francisco Bay Area (US)	Interview	20	E-bike users with children

	communities? Findings from a US metropolitan area									
Van Cauwenberg, et al.	E-bikes among older adults: benefits, disadvantages, usage and crash characteristics	2019	Transportation	Journal Article	E-bike	Private	Flanders (Belgium)	Survey	357	E-bike users > 65 years
Washington, et al.	Would you consider using an electric bicycle (e-bike) to make work-related or personal trips? Report on Survey and Focus Groups with TMR employees	2018		Report	E-bike	Private	Brisbane (Australia)	Survey, Focus Group, Interview	392/31	Employees
Will, et al.	Towards the future of sustainable mobility: Results from a European survey on (electric) powered-two wheelers	2021	Sustainability	Journal Article	Electric-two-wheelers	Private/Shared	Several European countries	Survey	283	General population > 16 years
Ye, et al.	Characteristics of the electric bicycle: A comparative analysis with bicycles and public transit	2014	Proceedings of the 14th COTA International Conference of	Conference Proceeding	E-bike	Private	Shanghai (China)	Survey	650	Users

			Transportation Professionals							
Zuev, D	Urban mobility in modern China: The growth of the E-bike	2018		Book	E-bike	Private	China	Interview, Focus Group	40/30	Users

Source: own production

Figure 13 PRISMA flow diagram



Source: own production

In terms of geographical distribution, the majority of studies (35 articles) were from Europe (Abouelela et al., 2021; Arsenio et al., 2018; Behrendt, 2018; Biegańska et al., 2021; Bieliński et al., 2021; Bielinski & Wazna, 2020; bureau de recherche, 2019; De Ceunynck et al., 2021; Edel et al., 2021; Esztergár-Kiss & Lopez Lizarraga, 2021; f.k.a. Andersson et al., 2021; Flores & Jansson, 2021; Fyhri et al., 2017; Glavić et al., 2021; Hardt & Bogenberger, 2019; Haustein & Møller, 2016; Hiselius & Svenssona, 2014; Hyvönen et al., 2016; Jones et al., 2016; Kaplan et al., 2015, 2018; Kazemzadeh & Koglin, 2021; Kopplin et al., 2021; Krauss et al., 2022; Kwiatkowski et al., 2021; Melia & Bartle, 2021; Munkacsy & Monzon, 2017; Nematchoua et al., 2020; Plazier et al., 2017; Sellaouti et al., 2020; Simsekoglu & Klöckner, 2019a, 2019b; Teixeira et al., 2021; Van Cauwenberg et al., 2019; Will et al., 2021), where Germany (6) (Abouelela et al., 2021; Edel et al., 2021; Hardt & Bogenberger, 2019; Kopplin et al., 2021; Krauss et al., 2022; Sellaouti et al., 2020), Poland (5) (Biegańska et al., 2021; Bieliński et al., 2021; Bielinski & Wazna, 2020; Kaplan et al., 2018; Kwiatkowski et al., 2021), Norway (3) (Fyhri et al., 2017; Simsekoglu & Klöckner, 2019a, 2019b), Sweden (3) (f.k.a. Andersson et al., 2021; Hiselius & Svenssona, 2014; Kazemzadeh & Koglin, 2021) and the United Kingdom (3) (Behrendt, 2018; Jones et al., 2016; Melia & Bartle, 2021) present most of the contributions. The rest of studies were distributed as follow: 15 publications in America (Bateman et al., 2021; Buehler et al., 2021; Dill & Rose, 2012; Edge et al., 2018; Gorenflo et al., 2017; Leger et al., 2019; Ling et al., 2017; Macarthur, 2017; Mayer, 2020; Mitra & Hess, 2021; Pimentel & Lowry, 2020; Popovich et al., 2014; Rayaprolu & Venigalla, 2020; Sanders et al., 2020; Thomas, 2021), mostly in the United States (11) (Bateman et al., 2021; Buehler et al., 2021; Dill & Rose, 2012; Ling et al., 2017; Macarthur, 2017; Mayer, 2020; Pimentel & Lowry, 2020; Popovich et al., 2014; Rayaprolu & Venigalla, 2020; Sanders et al., 2020; Thomas, 2021); 11 in Asia (Alamelu et al., 2015; An et al., 2013; Eccarius & Lu, 2018; Elias & Gitelman, 2018; Huang, 2021; Lee et al., 2021; Lin et al., 2018; Patil & Majumdar, 2021; Rejali et al., 2021; Ye et al., 2014; Zuev, 2018), mainly from China (6) (An et al., 2013; Eccarius & Lu, 2018; Huang, 2021; Lin et al., 2018; Ye et al., 2014; Zuev, 2018); and 6 in Oceania (Dowling et al., 2015; Eccarius et al., 2021; Fitt & Curl, 2019, 2020; Johnson & Rose, 2013; Washington et al., 2018), being 4 set in Australia (Dowling et al., 2015; Eccarius et al., 2021; Johnson & Rose, 2013; Washington et al., 2018).

In terms of which transport mode they focused their analysis on, 41 studies focused on e-bikes (mainly in its private form) (Alamelu et al., 2015; An et al., 2013; Andersson et al., 2021; Arsenio et al., 2018; Bateman et al., 2021; Behrendt, 2018; Biegańska et al., 2021; Bielinski et al., 2021; Dill & Rose, 2012; Eccarius et al., 2021; Edge et al., 2018; Elias & Gitelman, 2018; Fyhri et al., 2017; Gorenflo et al., 2017; Haustein & Møller, 2016; Hiselius & Svenssona, 2014; Johnson & Rose, 2013; Jones et al., 2016; Kaplan et al., 2015, 2018; Kazemzadeh & Koglin, 2021; Kwiatkowski et al., 2021; Lee et al., 2021; Leger et al., 2019; Lin et al., 2018; Ling et al., 2017; Macarthur, 2017; Mayer, 2020; Melia & Bartle, 2021; Munkácsy & Monzón, 2017; Nematchoua et al., 2020; Plazier et al., 2017; Popovich et al., 2014; Simsekoglu & Klöckner, 2019a, 2019b; Teixeira et al., 2021; Thomas, 2021; Van Cauwenberg et al., 2019; Washington et al., 2018; Ye et al., 2014; Zuev, 2018), 17 focused on the e-scooter (mainly in its shared form) (Abouelela et al., 2021; Buehler et al., 2021; bureau de recherche, 2019; Dowling et al., 2015; Eccarius & Lu, 2018; Edel et al., 2021; Fitt & Curl, 2019, 2020; Glavić et al., 2021; Hardt & Bogenberger, 2019; Huang, 2021; Kopplin et al., 2021; Krauss et al., 2022; Mitra & Hess, 2021; Rejali et al., 2021; Sanders et al., 2020; Sellaouti et al., 2020), 4 used both e-bikes and e-scooters (Bieliński & Ważna, 2020; Flores & Jansson, 2021; Pimentel & Lowry, 2020; Rayaprolu & Venigalla, 2020), and the rest were not specifically using one of these vehicles, but e-MM, PETs and light electric two-wheelers (De Ceunynck et al., 2021; Esztergár-Kiss & Lopez Lizarraga, 2021; Hyvönen et al., 2016; Patil & Majumdar, 2021; Will et al., 2021).

Finally, regarding the methodology, a total of 51 studies collected data using surveys (Abouelela et al., 2021; Alamelu et al., 2015; An et al., 2013; Andersson et al., 2021; Arsenio et al., 2018; Biegańska et al., 2021; Bielinski et al., 2021; Bieliński & Ważna, 2020; Buehler et al., 2021; bureau de recherche, 2019; De Ceunynck et al., 2021; Dowling et al., 2015; Eccarius et al., 2021; Eccarius & Lu, 2018; Edel et al., 2021; Elias & Gitelman, 2018; Esztergár-Kiss & Lopez Lizarraga, 2021; Fitt & Curl, 2019, 2020; Flores & Jansson, 2021; Glavić et al., 2021; Gorenflo et al., 2017; Hardt & Bogenberger, 2019; Haustein & Møller, 2016; Hiselius & Svenssona, 2014; Huang, 2021; Hyvönen et al., 2016; Johnson & Rose, 2013; Kaplan et al., 2015, 2018; Kopplin et al., 2021; Krauss et al., 2022; Kwiatkowski et al., 2021; Lee et al., 2021; Lin et al., 2018; Ling et al., 2017; Macarthur, 2017; Mitra & Hess, 2021; Nematchoua et al., 2020; Patil & Majumdar, 2021; Pimentel & Lowry, 2020; Rayaprolu & Venigalla, 2020; Rejali et al., 2021; Sanders et al., 2020; Sellaouti et al., 2020; Simsekoglu & Klöckner, 2019a, 2019b; Teixeira et al., 2021; Van Cauwenberg et al., 2019; Will et al., 2021; Ye et al., 2014), with sample sizes varying between 17 and 4382 participants. In fact, more than half of these articles (26) present sample sizes surpassing the 500 participants (Abouelela et al., 2021; Alamelu et al., 2015; Bieliński & Ważna, 2020; bureau de recherche, 2019; De Ceunynck et al., 2021; Esztergár-Kiss & Lopez Lizarraga, 2021; Fitt & Curl, 2019; Flores & Jansson, 2021; Glavić et al., 2021; Hyvönen et al., 2016; Johnson & Rose, 2013; Kaplan et al., 2015, 2018; Kopplin et al., 2021; Krauss et al., 2022; Lin et al., 2018; Ling et al., 2017; Mitra & Hess, 2021; Nematchoua et al., 2020; Patil & Majumdar, 2021; Pimentel & Lowry, 2020; Rejali et al., 2021; Sanders et al., 2020; Simsekoglu & Klöckner, 2019a, 2019b; Ye et al., 2014). Qualitative interviews were used in 6 articles as their main methodology (Dill & Rose, 2012; Jones et al., 2016; Kazemzadeh & Koglin, 2021; Mayer, 2020; Popovich et al., 2014; Thomas, 2021), with sample sizes between 20 and 47 interviewees while 2 other studies chose to use focus groups (Bateman et al., 2021; Edge et al., 2018) with sample sizes of 10 and 27 participants. The remaining 8 studies used multimethod designs, combining surveys, interviews, and focus groups (Behrendt, 2018; Fyhri et al., 2017; Leger et al., 2019; Melia & Bartle, 2021; Munkácsy & Monzón, 2017; Plazier et al., 2017; Washington et al., 2018; Zuev, 2018). The majority of the analysed studies included both male and female subjects and included different age ranges, with some exceptions: 1 study analysed only students from high schools (Elias & Gitelman, 2018), 2 studies focused only on older adults (Leger et al., 2019; Van Cauwenberg et al., 2019), 1 study used only younger adults between 18 and 34 years (Abouelela et al., 2021), 1 study used potential tourists (Kaplan et al., 2015), 1 study analysed only women (Alamelu et al., 2015), and 1 study examined users with children (Thomas, 2021). Moreover, in 11 studies the sample comprised only users from university campuses, i.e., students and staff (Arsenio et al., 2018; Buehler et al., 2021; Dowling et al., 2015; Eccarius et al., 2021; Eccarius & Lu, 2018; Edge et al., 2018; Gorenflo et al., 2017; Macarthur, 2017; Nematchoua et al., 2020; Plazier et al., 2017; Sanders et al., 2020).

4.1.4.2. Social analysis: factors influencing the adoption of electric micromobility

In this section, the results of the social analysis are presented, listing the functional and non-functional factors most mentioned throughout the articles reviewed, and so, considered to potentially be the most relevant when determining the adoption and usage of e-MM. Table 6 includes all the factors found to be significant in the analysed studies, categorizing them as functional or non-functional while indicating the type of association found (positive, negative, or mixed).

Table 6 Functional and non-functional factors

Factors	**Positive association**	**Mixed association**	**Negative association**
Functional			
Monetary cost	3, 4, 10, 17, 18, 26, 29, 33, 36, 38, 45, 46, 48, 55, 56, 63, 66, 67	1, 2, 6, 7, 12, 16, 25, 27, 32, 35, 39, 43, 47, 51, 62	8, 9, 11, 13, 20, 21, 23, 34, 37, 40, 44, 50, 54, 58, 65
Practicality/ Convenience	1, 4, 9, 13, 14, 19, 20, 21, 22, 23, 28, 32, 36,	5, 7, 12, 16, 17, 39, 52, 56, 57, 63	

	40, 42, 45, 46, 48, 53, 59, 64, 66, 67		
Ease of use/Comfort	3, 5, 12, 15, 25, 27, 28, 32, 35, 36, 38, 45, 53, 54, 55, 59, 60, 61, 65, 66	37, 49	
Accessibility/ Flexibility	1, 14, 17, 21, 40, 43, 46, 47, 54, 56, 61, 62, 67	39	
Time savings	1, 4, 7, 10, 18, 25, 26, 30, 35, 36, 37, 39, 43, 53, 54, 55, 59, 61, 66, 67	2, 5	
Safety	8, 12, 40	2, 14, 53	1, 4, 7, 10, 11, 13, 16, 17, 19, 20, 21, 22, 23, 26, 27, 28, 34, 35, 37, 38, 40, 42, 43, 44, 45, 48, 49, 50, 51, 52, 54, 55, 56, 57, 58, 60, 62, 64, 65, 67
Reliability/Security	37, 38	6, 41	5, 14, 16, 17, 19, 20, 25, 27, 34, 39, 47, 50, 51, 52, 54, 60, 62, 63, 64, 65, 67
Non-functional			
Environmental awareness	3, 4, 5, 10, 14, 16, 17, 18, 19, 24, 25, 26, 27, 29, 30, 31, 32, 33, 35, 38, 40, 41, 44, 45, 46, 47, 48, 49, 51, 54, 56, 59, 60, 61, 63, 67		58
Health/Well-being	3, 5, 7, 8, 10, 19, 22, 25, 27, 29, 33, 34, 35, 36, 40, 42, 44, 45, 47, 48, 49, 51, 53, 54, 55, 59, 60, 61, 62, 63, 64, 67		
Social perception	17, 22, 27, 38, 40, 52, 56, 60, 61	31, 41, 48	7, 33, 42, 46, 47, 53, 54, 62

Riding experience	1, 5, 7, 9, 11, 13, 15, 16, 19, 20, 23, 27, 28, 32, 35, 38, 42, 44, 45, 47, 52, 53, 54, 55, 56, 57, 58, 61, 63, 65, 67		
Interest in innovation/technology	3, 24, 30, 35, 36, 46, 59, 65		

1. 6t-bureau de recherche (2019)
2. Abouelela, et al. (2021)
3. Alamelu, et al. (2015)
4. An, et al. (2013)
5. Andersson, et al. (2021)
6. Arsenio, et al. (2018)
7. Bateman, et al. (2021)
8. Behrendt, F. (2018)
9. Biegańska, et al. (2021)
10. Bieliński, et al. (2021)
11. Bieliński, et al. (2020)
12. Buehler, et al. (2021)
13. De Ceunynck, et al. (2021)
14. Dill & Rose (2012)
15. Dowling, et al. (2015)
16. Eccarius, et al. (2021)
17. Eccarius & Lu (2018)
18. Edel & Kern (2021)
19. Edge, et al. (2018)
20. Elias & Gitelman (2018)
21. Esztergár-Kiss, et al. (2021)
22. Fitt & Curl (2020)
23. Fitt & Curl (2019)
24. Flores & Jansson (2021)
25. Fyhri, et al. (2017)
26. Glavić, et al. (2021)
27. Gorenflo, et al. (2017)
28. Hardt & Bogenberger (2019)
29. Haustein & Møller (2016)
30. Hiselius & Svenssona (2014)
31. Huang, F. H. (2021)
32. Hyvönen, et al. (2016)
33. Johnson & Rose (2013)
34. Jones, et al. (2016)
35. Kaplan, et al. (2015)
36. Kaplan, et al. (2018)
37. Kazemzadeh & Koglin (2021)
38. Kopplin, et al. (2021)
39. Krauss, et al. (2022)
40. Kwiatkowski, et al. (2021)
41. Lee, et al. (2021)
42. Leger, et al. (2019)
43. Lin, et al. (2018)
44. Ling, et al. (2017)
45. Macarthur, J. (2017)
46. Mayer, A. (2020)
47. Melia & Bartle (2021)
48. Mitra & Hess (2021)
49. Munkácsy & Monzón (2017)
50. Nematchoua, et al. (2020)
51. Patil & Majumdar (2021)
52. Pimentel & Lowry (2020)
53. Plazier, et al. (2017)
54. Popovich, et al. (2014)
55. Rayaprolu & Venigalla (2020)
56. Rejali, et al. (2021)
57. Sanders, et al. (2020)
58. Sellaouti, et al. (2020)
59. Simsekoglu & Klöckner (2019a)
60. Simsekoglu & Klöckner (2019b)
61. Teixeira, et al. (2021)
62. Thomas, A. (2021)
63. Van Cauwenberg, et al. (2019)
64. Washington, et al. (2018)
65. Will, et al. (2021)
66. Ye, et al. (2014)
67. Zuev, D. (2018)

Source: own production

4.1.4.2.1. Functional factors

In general, most functional factors were found to be positively related to e-MM use, meaning that e-MM serve a practical function that makes them more competitive against other traditional modes. Among the most frequently studied functional factors we can summarize the following as the ones having the larger positive associations with e-MM use.

Monetary cost

Among the functional factors, the *monetary cost* was the most frequently mentioned factor. Some individuals seem to perceive e-MM as being economically viable, cheaper than other modes, and thus with the potential to save money in the long run (Alamelu et al., 2015; An et al., 2013; Bielinski et al., 2021; Eccarius & Lu, 2018; Edel et al., 2021; Glavić et al., 2021; Haustein & Møller, 2016; Johnson & Rose, 2013; Kaplan et al., 2018; Kopplin et al., 2021; Macarthur, 2017; Mayer, 2020; Mitra & Hess, 2021; Rayaprolu & Venigalla, 2020; Van Cauwenberg et al., 2019; Ye et al., 2014; Zuev, 2018). In terms of sharing systems, the pricing mechanisms of the e-MM services provided by operators are considered to be convenient and economical (Buehler et al., 2021). Also, the fact that there are no ownership and maintenance costs nor are there parking expenses contributes to this generalized perception (Eccarius & Lu, 2018). E-MM users state to perceive money savings, mainly when compared to owning a car, in terms of fuel, insurance, vehicle maintenance and parking fees (Edel et al., 2021; Mayer, 2020; Popovich et al., 2014; Will et al., 2021). However, Mayer A. (2020) shows how among those that own an e-micromobility vehicle still some concern exists regarding future potential policy changes that may force them to license and insure these vehicles, which would lead to losing this economic benefits (Mayer, 2020).

However, not all studies reach the same positive conclusions. Some studies have found how purchasing price and operating cost (use fees) are considered the most or one of the most important attributes when choosing e-MM, but individuals seem to be uncertain regarding whether these modes are a cheaper solution than other forms of transport (Arsenio et al., 2018; bureau de recherche, 2019; Krauss et al., 2022; Munkácsy & Monzón, 2017; Patil & Majumdar, 2021; Thomas, 2021). The study from Bateman et al. (2021) in Birmingham presents this dichotomy between the perception of cost as one of the main deterrents to using e-bikes, and the potential they offer to save money (Bateman et al., 2021). Similar results can be found in other studies where both expensive (high purchase price or cost of use) and inexpensive (affordable or saving money) terms are mentioned (Eccarius et al., 2021; Fyhri et al., 2017; Hyvönen et al., 2016). Also, Lin et al. (2018) state that even when individuals may perceive e-bikes as expensive, they are often willing to take on the initial investment as they expect to use them for a long time (Lin et al., 2018).

On the other end of the spectrum, several studies have found present cost and price as negatively influencing the use of e-MM (Behrendt, 2018; Biegańska et al., 2021; Bielinski & Wazna, 2020; De Ceunynck et al., 2021; Elias & Gitelman, 2018; Esztergár-Kiss & Lopez Lizarraga, 2021; Fitt & Curl, 2019; Jones et al., 2016; Kazemzadeh & Koglin, 2021; Kwiatkowski et al., 2021; Ling et al., 2017; Nematchoua et al., 2020; Popovich et al., 2014; Sellaouti et al., 2020; Will et al., 2021), both in terms of costs associated with private ownership of the vehicles (acquisition price and maintenance cost) as well as costs required to access shared vehicles (usage or monthly fees).

Practicality and Convenience

Another highly rated attribute of e-MM is *practicality* and *convenience*. In the majority of the reviewed studies, e-MM usage is perceived as practical for everyday use as a commuter vehicle, as these vehicles improve travel independence and mobility, offer better schedule predictability, and require minimal physical exertion (Biegańska et al., 2021; Edge et al., 2018; Elias & Gitelman, 2018; Hyvönen et al., 2016; Kaplan et al., 2018; Leger et al., 2019; Mitra & Hess, 2021; Plazier et al., 2017; Simsekoglu & Klöckner, 2019; Washington et al., 2018; Zuev, 2018). Buehler et al. (2021) demonstrate how the usefulness perception of e-scooters increases once individuals try them for the first time. In this line, convenience can be conceptualized as the perception of time and effort that users invest into using a service (Buehler et al., 2021). This means that the less time and effort users have to invest in the service, the higher the level of convenience perceived by individuals (An et al., 2013; Bateman et al., 2021; De Ceunynck et al., 2021; Eccarius et al., 2021; f.k.a. Andersson et al., 2021; Hardt & Bogenberger, 2019; Leger et al., 2019; Plazier et al., 2017; Rejali et al., 2021; Sanders et al., 2020; Ye et al., 2014; Zuev, 2018). In this context, convenience includes aspects such as distance to the service (coverage), availability of vehicles (fleet size), accident/damage handling, avoiding traffic congestions, or lack of problems with parking spaces.

Despite most of the examined studies finding positive associations between e-MM use and practicality and convenience, some studies have also found convenience issues mainly related to the access to shared vehicles. As such, e-scooter users in a university campus in Arizona reported how difficulties in finding vehicles when needed or sometimes finding them broken, made e-scooters impractical for everyday commuting (Sanders et al., 2020). Similar results were found in Eccarius and Lu

(2018). An additional source of burden found also in other studies was the low carrying or baggage capacity and the heaviness of the vehicles which were mentioned as deterrents in terms of practicality (Andersson et al., 2021; Bateman et al., 2021; Pimentel & Lowry, 2020; Rejali et al., 2021).

Ease of use and Comfort

One of the main selling points of e-MM is the promise of easy circulation in contrast with the inconvenience, slowness, or crowdedness of other traditional modes of transport. Thus, e-MM are seen as really *easy to drive and manage* (Andersson et al., 2021; Dowling et al., 2015; Hardt & Bogenberger, 2019; Hyvönen et al., 2016; Kaplan et al., 2015, 2018; Kopplin et al., 2021; Macarthur, 2017; Plazier et al., 2017; Simsekoglu & Klöckner, 2019; Teixeira et al., 2021; Will et al., 2021), with no training or license required, which makes them available to almost everybody. In studies such as that of Eccarius and Lu (2018), and regarding shared services, participants seem to universally praise how easy it is to operate the App or Platform that supports the service (Eccarius & Lu, 2018). Together with ease of use, *comfort while driving* is often mentioned as a positive attribute of e-MM (Alamelu et al., 2015; Dowling et al., 2015; Kopplin et al., 2021; Macarthur, 2017; Plazier et al., 2017; Popovich et al., 2014; Ye et al., 2014).

Accessibility and Flexibility

Additionally, surveyed users from various studies commented that e-MM can ease *access* to mobility and widen transport options (Lin et al., 2018; Melia & Bartle, 2021; Rejali et al., 2021; Zuev, 2018). In one of the oldest studies included in the sample, Dill and Rose found how e-bikes made cycling accessible among some populations such as women, elderly people, or individuals that would not normally ride (i.e., with physical limitations) (Dill & Rose, 2012). This usefulness for the elderly is also mentioned by Kwiatkowski et al. (2021), as well as the potential usage when having an injury or disability (Mayer, 2020; Popovich et al., 2014). The study conducted by Thomas, A. (2021) shows the potential e-bikes have to overcome the limitations that parents with children face, being these limitations the physical environment, the weight of the children, and their own physical limitations. Moreover, e-MM can be seen as a tool to mitigate the first- and last-mile problems as well as the connectivity with other modes of transport, such as public transportation (Bielinski & Wazna, 2020; Dowling et al., 2015; Edel et al., 2021). Likewise, e-MM seems to score high on *flexibility*, by offering high route and scheduling resilience in most of the studied urban areas (bureau de recherche, 2019; Eccarius & Lu, 2018; Esztergár-Kiss & Lopez Lizarraga, 2021; Lin et al., 2018; Popovich et al., 2014; Teixeira et al., 2021).

Time savings

Another recurrent topic for most e-MM users is savings in travel time. The majority of studies find users reporting their total commute *time to be reduced* thanks to using e-MM (An et al., 2013; Bateman et al., 2021; Bielinski et al., 2021; bureau de recherche, 2019; Glavić et al., 2021; Hiselius & Svenssona, 2014; Kaplan et al., 2015, 2018; Kazemzadeh & Koglin, 2021; Plazier et al., 2017; Popovich et al., 2014; Rayaprolu & Venigalla, 2020; Simsekoglu & Klöckner, 2019; Ye et al., 2014). In fact, Ling et al. (2017) found that for both Millennials and Generation X individuals saving of travel times was among the most important factors explaining e-cycling adoption (Ling et al., 2017). Also, interviews carried out by Plazier et al. (2017) demonstrated that starting using e-bikes for commuting meant shorter travel times for almost all participants (Plazier et al., 2017). An et al. described the way e-bikes guarantee punctuality during peak times compared to the use of public transport modes such as buses (An et al., 2013). Indeed, time savings and the potential to combine several modes of transportation seem to feed into the perception of the convenience of these new modes. Users of e-MM shared services tend to appreciate time gains for intra-city trips as well as the time required to find a parking place, as indicated by the results in the work of Krauss et al. (2022).

Not all functional factors, however, were associated with positive connotations. *Safety and reliability* for instance were the two most mentioned factors with a negative association, and thus they offer two clear barriers to the adoption of e-MM.

Safety

Safety is repeatedly found as the most negatively perceived factor by both users and non-users of e-MM (Bateman et al., 2021; Bielinski et al., 2021; Bieliński et al., 2020; De Ceunynck et al., 2021; Eccarius et al., 2021; Elias & Gitelman, 2018; Esztergár-Kiss & Lopez Lizarraga, 2021; Fitt & Curl, 2019; Hardt & Bogenberger, 2019; Jones et al., 2016; Ling et al., 2017; Munkacsy & Monzon, 2017; Rayaprolu & Venigalla, 2020; Sellaouti et al., 2020; Simsekoglu & Klöckner, 2019; Will et al., 2021; Zuev, 2018). This unsafe perception is aggravated by most participants recognizing that in most cases infrastructure is not yet ready to support e-MM (i.e., not enough lanes or parking) (Bateman et al., 2021; Eccarius & Lu, 2018; Glavić et al., 2021; Leger et al., 2019; Nematchoua et al., 2020; Popovich et al., 2014; Washington et al., 2018). The vast majority of e-MM users feel safer when dedicated and exclusive lanes are available, which are separated from motor traffic (Bateman et al., 2021; Edge et al., 2018; Leger et al., 2019; Rayaprolu & Venigalla, 2020; Sanders et al., 2020). Most participants of the reviewed studies report that the absence of infrastructure in combination with unfriendly drivers is unsettling (Bateman et al., 2021). Also, participants suggest promoting protective gear, clear and more advanced safety regulations, and training on road norms and rules of conduct, to increase overall safety perception (De Ceunynck et al., 2021; Esztergár-Kiss & Lopez Lizarraga, 2021).

Moreover, in terms of speed and according to Popovich et al. (2014) study, e-bike users expressed feeling unsafe interacting with other road users despite the higher speed of e-bikes. In the same line, Patil and Majumdar (2021) state that in heterogeneous conditions, the lower speed associated with e-MM compared to motorized vehicles such as cars and motorcycles is posing a serious safety threat, as the other vehicles travel faster. These interaction issues with other road users such as cars and pedestrians are also mentioned by Rejali et al. (2021). Indeed, another significant safety concern related to velocity is the difficulty of distinguishing e-bikes from regular bikes, making car drivers underestimate the speed at which they approach (Popovich et al., 2014).

Further, it is important to distinguish the safety-perception differences between users and non-users of e-MM. According to some of the reviewed studies, most potential users reported concerns with e-MM in terms of incorrect parking, speeding, and unsafe riding, including riding in sidewalks (Buehler et al., 2021; Rejali et al., 2021). Also, some studies defend that rider's familiarity with the e-MM increases perceived safety (Buehler et al., 2021; Kopplin et al., 2021; Simsekoglu & Klöckner, 2019).

On the other hand, the current pandemic context has created a new dimension regarding transport and safety (in terms of safety from contagion through social distancing), which positively impacted e-MM acceptance. Actually, with the impact of COVID-19, personal mobility has gained more attractiveness compared to public transport (Huang, 2021). Kazemzadeh and Koglin (2021) for example, found interviewees to be highly concerned about contagion risk when using public transport, a factor that was mitigated by increased commuting with e-bikes (Kazemzadeh & Koglin, 2021). Similarly, Eccarius et al. (2021) mention the surge of new personal mobility vehicles to avoid the use of public transport due to perceived infection risks (Eccarius et al., 2021). In the same line, the use of e-bike sharing in Lisbon skyrocketed after COVID-19 as individuals wanted to maintain social distance during trips (Teixeira et al., 2021). It is precisely this resilience of e-MM at offering a solution to specific transportation disruptions during times of crisis that Glavić et al. (2021) highlight as a potentially positive factor for the future of this transportation options (Glavić et al., 2021).

Reliability

Together with safety, *reliability* is also often mentioned as a barrier to the adoption of e-MM. The risk of theft is often stated by individuals as a big concern, especially when parking in public spaces (Andersson et al., 2021; Dill & Rose, 2012; Elias & Gitelman, 2018; Fyhri et al., 2017; Melia & Bartle, 2021; Nematchoua et al., 2020; Popovich et al., 2014; Thomas, 2021; Van Cauwenberg et al., 2019; Washington et al., 2018; Zuev, 2018). While all e-MM vehicles seem to be affected by the risk of theft, some of them such as e-bikes are even more in danger as they look more expensive than a conventional bike (Edge et al., 2018). Another common finding regarding the reliability of these vehicles is what has been labeled as 'range anxiety'. That is the concern about battery performance in terms of range and the fear of becoming stranded right in the middle of a trip (Edge et al., 2018; Jones et al., 2016; Krauss et al., 2022; Patil & Majumdar, 2021; Popovich et al., 2014; Van Cauwenberg et al., 2019; Will et al., 2021).

Likewise, users express concerns about maintenance and cleanliness, that is to say, they worry about the state of the vehicle they are sharing (Eccarius et al., 2021; Eccarius & Lu, 2018). This cleanliness issue has become more important after the COVID-19 pandemic due to the rise in public health awareness.

4.1.4.2.2. Non-functional factors

After all functional factors presented in the previous sections, it is time to go through the most mentioned and significant non-functional factors found in the reviewed papers.

Environmental awareness

The most frequent non-functional factor affecting e-MM use is *environmental awareness*. In more than half of the papers analyzed some of the individuals interviewed or surveyed noted that they are environmentally conscious concerning their lives, hence they try to use transport modes that do not negatively affect the environment. In that case, e-MM is considered as more environmentally friendly (Alamelu et al., 2015; An et al., 2013; Andersson et al., 2021; Bielinski et al., 2021; Eccarius et al., 2021; Edel et al., 2021; Edge et al., 2018; Glavić et al., 2021; Haustein & Møller, 2016; Hiselius & Svenssona, 2014; Huang, 2021; Hyvönen et al., 2016; Johnson & Rose, 2013; Kaplan et al., 2015; Lee et al., 2021; Ling et al., 2017; Macarthur, 2017; Melia & Bartle, 2021; Mitra & Hess, 2021; Popovich et al., 2014; Rejali et al., 2021; Simsekoglu & Klöckner, 2019; Teixeira et al., 2021). Pimentel and Lowry (2020) also found the dimension of doing 'social good' as determining the adoption and usage of e-MM (Pimentel & Lowry, 2020). However, those who frequently use active modes such as walking and cycling are more reluctant to adopt these innovative modes, as they perceive them as less environmentally friendly than their current mode of transport. Notwithstanding, prior experience with e-MM seems to awaken a perception of them as environmentally friendly and thus might reduce skepticism toward their adoption (Eccarius & Lu, 2018; Flores & Jansson, 2021).

On the other hand, some users correlate environmental friendliness with an enhanced social image. Eccarius and Lu (2018) introduce the concept of green hypocrisy, as some people tend to state environmental reasons when justifying their use of e-MM, when in fact they just care about their own projected image when doing so (Eccarius & Lu, 2018).

Health and Well-being benefits

E-MM (mainly e-bikes) are repeatedly considered in the articles analysed as providing other added values such as increased well-being and health (e.g., by increasing physical activity levels), which make them more attractive for adoption (Andersson et al., 2021; Bielinski et al., 2021; Johnson & Rose, 2013; Jones et al., 2016; Kaplan et al., 2018; Kwiatkowski et al., 2021; Ling et al., 2017; Melia & Bartle, 2021; Plazier et al., 2017; Popovich et al., 2014; Simsekoglu & Klöckner, 2019; Thomas, 2021; Washington et al., 2018). Additionally, e-MM is seen as a health tool, as it can address concerns about health problems related to inactivity and pollution, mainly in comparison to motorized vehicles (Alamelu et al., 2015; Behrendt, 2018; Edge et al., 2018; Macarthur, 2017; Patil & Majumdar, 2021; Teixeira et al., 2021). In fact, most of the times the perception of the health benefits depends on the mode of transportation being replaced. For instance, at Edge et al. (2018) study, e-bikes were perceived as having greater impact on physical activity when replacing sedentary modes for commuting such as car or bus (Edge et al., 2018). It is also important to mention that, for older people, to start using an e-MM vehicle may potentially allow them to continue exercising when they otherwise would not be able to (Haustein & Møller, 2016; Popovich et al., 2014). Bateman et al. (2021) conclude that one of the motivations of e-bike share users is to improve their health and reduce stress while riding (Bateman et al., 2021), while the study by Bieliński et al. (2021) found the positive effect on health as the top reason reported to encourage e-biking (Bieliński et al., 2021). Similarly, female participants interviewed in Washington et al. (2018) study reported to have already achieved tangible health benefits such as weight loss and strength as a result of riding an e-bike to work, (Washington et al., 2018).

Riding experience

Apart from increased health and well-being, several articles include individual perceptions of a positive and pleasant riding experience, as a motivation to adopt and use e-MM for daily commuting. Andersson et al. (2021) show how participants mention having fresh air in the morning and being fun as two factors that make them use e-bike (Andersson et al., 2021). Indeed, fun and enjoyment is emphasized in several of the reviewed articles (Bateman et al., 2021; Biegańska et al., 2021; Bielinski & Wazna, 2020; Dowling et al., 2015; Eccarius et al., 2021; Fitt & Curl, 2019; Hyvönen et al., 2016; Kopplin et al., 2021; Leger et al., 2019; Ling et al., 2017; Macarthur, 2017; Pimentel & Lowry, 2020; Plazier et al., 2017; Popovich et al., 2014; Rayaprolu & Venigalla, 2020; Rejali et al., 2021; Sanders et al., 2020; Sellaouti et al., 2020; Teixeira et al., 2021; Van Cauwenberg et al., 2019). Will et al. (2021) study highlights how important is to experience fun and freedom as part of the riding experience when using an e-two-wheeler (Will et al., 2021). Apart from being fun to ride, interviewees from the Melia and Bartle study also seemed to value the opportunities their e-bikes offer for exploration of new places and routes (Melia & Bartle, 2021).

Social perception

Social influence can affect modal choice in different forms and at different stages of adoption. For once, it is well known that individuals want to be part of a group as this makes them feel socially accepted. These dynamics are also found in e-MM adoption. Kaplan et al. for instance found that the users of shared e-cycling in Poland tended to associate this mode with the feeling of being part of a community as well as with self-fulfillment (Kaplan et al., 2018). This argument supports the presence of what is called "social pull", meaning that individuals feel a personal identification with the group of e-MM users, together with a sense of belongingness (Behrendt, 2018; Kaplan et al., 2015, 2018; Leger et al., 2019; Zuev, 2018). The study by Simsekoglu and Klöckner (2019) demonstrates that e-bike users believe that by using these vehicles they can distinguish themselves from the rest and that this usage says something positive about them (Simsekoglu & Klöckner, 2019). The same idea of positive image and enhanced status is also found by Eccarius and Lu (2018) and Huang, F. (2021). Moreover, the use of e-MM is sometimes considered a social activity and a way to keep up with family and friends (Kopplin et al., 2021).

On the negative side, some studies have also found a *social stigma* attached to e-MM vehicles, mainly e-bikes and especially when compared with traditional bikes (Jones et al., 2016; Leger et al., 2019; Mayer, 2020; Melia & Bartle, 2021; Plazier et al., 2017; Popovich et al., 2014; Thomas, 2021). Jones et al. (2016) for instance found that e-bike users felt they were in some way 'cheating' vis-à-vis conventional cycling (Jones et al., 2016). Similarly, Mayer, A. (2020) study shows that individuals indicated that they had experienced negative comments about their electric bikes and received what they named 'the cheating shaming' (Mayer, 2020).

<u>Interest in innovation and technology</u>

Finally, another non-functional factor found in most studies is the *interest in innovation and technology*. Some individuals find the adoption of these services attractive because of the specific technical aspects and generally, because of the promises concerning these new technologies (Alamelu et al., 2015; Flores & Jansson, 2021; Kaplan et al., 2015, 2018; Mayer, 2020; Will et al., 2021). The individuals are interested in using these innovations because they value gadgetry and technological progress. As the study by Hiselius and Svenssona (2014) found, these technology enthusiasts are more likely to acquire or use these new modes of transport, especially in the earlier stages of development (Hiselius & Svenssona, 2014). In the same line, Simsekoglu and Klöckner's (2019) study concluded that interest in innovation was the second most important predictor of e-bike usage and that the less interested in innovations and technology a person was, the less likely this person was to own an e-bike (Simsekoglu & Klöckner, 2019).

4.1.5. Discussion

Our review found 67 studies that had included functional or non-functional sociopsychological factors in their aim to understand the adoption intention and usage of electric micro mobility (e-MM). While the examined studies used a wide range of methods and definitions, the consensus was that users will act and make travel decision based not only on a rational evaluation of the tangible attributes of the service provided, but rather on a combination of functional and non-functional factors. Our results demonstrate that non-functional factors such as environmental concerns, social perception, interest for new technologies, and the perception of increased well-being can be even more influential at determining e-MM modal choice than traditional functional factors like speed, cost, and time savings. This provides further evidence of the need to include sociopsychological factors in all travel behaviour analysis (De Vos et al., 2021; De Witte et al., 2013).

Regarding the functional factors, users seem to value the low cost-high convenience combination that most of these e-MM have to offer. Modes like electric shared bikes or electric scooters are generally perceived as practical, easy to use, accessible, and flexible. This also indicates that e-MM use is more than a fad or something just fashionable and that there are true functional benefits derived from their everyday use that are helping draw new users as well as keep current users engaged. While some debate exists on whether they are truly cost-efficient along with the real potential to offer true time-savings, a common general sense of convenience -understood as the effort and time that users may have to invest in using a particular mode- make e-MM a very attractive option. The reviewed studies suggest that one should not diminish the role of potential time savings in modal choice decision-making. On the other hand, two functional factors that were constantly mentioned as negatively affecting e-MM usage were safety and lack of reliability. These two adoption barriers are based on early reports that find a clear relationship between some of these new modes (e-scooters in particular) and a higher rate of reported accidents and injuries (Badeau et al., 2019; James et al., 2019; Puzio et al., 2020; Sikka et al., 2019). Also, noteworthy is how the COVID-19 pandemic has altered this negative view of e-MM in terms of safety, as some users now may perceive e-micromobility options as safer than other options such as public transport.

The most influential non-functional factor appears to be the belief that e-MM is environmentally friendly. More than half of the reviewed studies reported that environmental benefits were important motivations for users. In general, users tend to perceive e-MM as a step towards a greener lifestyle. Studies approaching e-MM from the environmental sustainability discipline, however, reveal two main drawbacks. On the one hand, the value-action gap (that is the gap between the attitude and actual behaviour of individuals) makes it challenging to identify whether users are adopting these modes because they care about the environment or rather because they want to improve their social image (Eccarius & Lu, 2018). On the other hand, while e-MM may bring more efficient transport, their overall environmental sustainability is under debate once the whole lifecycle of the vehicles is examined (de Bortoli, 2021; Felipe-Falgas et al., 2022; Hollingsworth et al., 2019; McQueen et al., 2020; Severengiz et al., 2020; Zheng et al., 2019). Recent Life Cycle Analysis studies on e-MM vehicles (de Bortoli, 2021; Felipe-Falgas et al., 2022; Hollingsworth et al., 2019; Moreau et al., 2020) demonstrate that for e-MM to be environmentally sustainable, vehicle life span needs to be significantly extended, collection and distribution distances must be reduced, and better strategies for battery charging must be implemented (Moreau et al., 2020).

The idea that e-MM may also be positive in terms of individual health has also been found to be a catalyst for e-MM use. Individuals state adopting e-MM to enhance or maintain current physical activity levels, while due to lower physical intensities and possibly shorter trip durations, e-MM need to cover longer distances or be used more frequently, to achieve the same health benefits than conventional active modes (i.e., walking and cycling). Indeed, if individuals switch from the most sedentary modes (i.e., cars and motorbikes), there will be an increase in the level of transport-related physical activity and therefore health gains (Berntsen et al., 2017; Castro et al., 2019; Glenn et al., 2020; Sanders et al., 2022). Some other studies report a desire by users to improve their well-being and enjoy the riding experience. In this sense, existing evidence suggest that e-MM can be fun and thrilling and thereby have a positive impact on mood and mental health (Milakis et al., 2020). A few studies also have found e-bike users as having lower perceived stress, better mental health and improved cognition (Avila-Palencia et al., 2018; Leyland et al., 2019).

Another non-functional value, such as the sense of belonging, was found to be of high significance, to the point that some studies report it can even override conflicting functional factors. Users may routinely choose a suboptimal mode of transport just for the gained status or the sense of belonging associated with using that particular mode of transport. These dynamics have been found to affect modal choice as they can express social and self-identities (Kaplan et al., 2018). Our findings suggest that adoption is also driven by the symbolism users projected towards innovation, as well as individual interests in gadgets and cutting-edge technology. On the other side, some studies have found some non-functional factors, that are discouraging e-MM adoption. Social stigma for example was found to be associated with e-bike use in some studies, as some populations felt e-bikes constituted a form of cheating when compared with traditional bikes.

In all, the present review demonstrates the complex mix of functional and non-functional factors behind the adoption and usage of e-MM. Moreover, there would be other factors, such as cultural differences and levels of support depending on the geographical location, that could be playing a role in the adoption of e-MM, and that should also be considered. For instance, in terms of e-bike, a country's "cycling culture" appears to shape e-bike use in a similar way than conventional cycling (Melia & Bartle, 2021). Therefore, perceptions might diverge, and results cannot be generalized as they would differ between cities with a strong cycling tradition and emerging cycling cities or car-dependent locations.

4.1.5.1. Implications for policy and practice

Our findings contribute to a better understanding of e-MM as a rapidly growing urban phenomenon and suggest that planners and policymakers should integrate sociopsychological factors in their attempts to manage e-MM. If city officials want to encourage e-MM use as a cleaner alternative they should emphasize the positive benefits that individuals associate with e-MM which, according to our results, are speed, convenience, easy driving, flexibility, accessibility, health, enjoyment, social status, and innovation while at the same time lowering concerns regarding safety, security, reliability, and social stigma. Given the importance of being familiar with the new technology for attracting users and the difficulty in breaking already-established travel habits, it would help to provide some type of incentive or trial period that can encourage new users to try e-MM for the first time. For instance, cities such as Christchurch (in New Zealand) and Dallas (TX) implemented trial periods before introducing e-scooters permanently (Gössling, 2020).A study in the Netherlands that included e-bike monetary incentive programs, showed how these programs can be very effective tools when targeting specific groups such as car commuters (de Kruijf et al., 2018). The same results were found by a study in Switzerland, offering free e-bike trials for two weeks (Moser et al., 2018). Further, as monetary cost has been identified by this review to be a critical factor, policy level interventions such as tax rebates or subsidies should be considered to encourage e-MM purchase, and to highlight the affordability of these modes of transport. Economic incentives for e-bike purchase and use have been offered in numerous European countries (Austria, Belgium, France, Germany, Italy, the Netherlands, Spain), for several years (Newson & Sloman, 2019). A study in Oslo demonstrated how basic financial incentives can contribute to boost e-bike adoption even when they are not targeting any specific population group (Sundfør & Fyhri, 2022). In New Zealand, e-bike purchase incentives were launched in 2019, performing strongly and showing how individuals perceived these schemes as relevant and promising (Waka Kotahi Transport Agency, 2021).

However, cities and public officials should first have a clear discussion on the benefits and threats that incorporating e-MM into a large transport system might entail. As stated by Latinopoulos (2021), as a result of a study carried in Paris, there is a clear need for collaboration between local authorities and operators when deploying e-scooters and integrating them with public transport and other active modes (Latinopoulos et al., 2021), which can be applied to the whole e-MM system. In particular, safety concerns remain in regards to e-MM along with the potential negative impacts on health and the environment when e-MM is used to replace active commuting (De Ceunynck et al., 2021). Also, e-MM usage is supported by proper dedicated infrastructure, therefore, improvements are required including more dedicated lanes, racks, marked parking areas, and charging stations before introducing tailored e-MM-friendly policies. A report from the Institute of Transportation Studies in Berkeley summarizes some of the existent measures to support safe and correct parking of e-MM, especially e-scooters, including corrals or designated parking spaces, restricted sidewalk parking, and geofencing (virtual geographic boundary around an area) (Reinhardt et al., 2020). There is also the need for policies to establish a clear legal framework for e-MM use that prevent conflicts with other road users. Transparent and clear enforcement of established rules is also necessary to avoid conflicts and ensure a safe co-existence and appropriate public space allocation and usage.

On the manufacturers side, they should consider the relevance given by users to environmental concerns and product performance. Improving battery capacities and generally improving the life cycle of e-MM vehicles, and reducing the environmental footprint related to the manufacturing and disposal of vehicles and batteries should be a priority, as findings from recent studies suggest that in general e-scooters have a more negative life cycle impact on the environment that the modes they most often replace (Hollingsworth et al., 2019). In China, government supported clustering of e-bike manufacturing, which accelerated the R&D of the innovation, which exemplifies how collaboration could result on these needed improvements (Ruan et al., 2014). From the companies' side, some are developing better software to make e-scooters last longer and to prevent safety issues such as problems with batteries (Reinhardt et al., 2020). At the institutional level, schemes for battery recycling, treatment, and disposal should also be considered. We found there exist a variety of measures with the aim to reduce this negative environmental impact that e-scooters present. In Germany, government pushes towards a system of swappable batteries for operators, with the goal to reduce pollution generated by vehicles dedicated to charging the e-scooters (Reinhardt et al., 2020).

4.1.6. Limitations and Future Research

This review provided valuable results for interventions aiming to encourage e-MM adoption and usage but is not without limitations. Firstly, the review does not include communication and social media publications which may have contributed some valuable information had they been consulted, especially regarding the latest information on e-micromobility. Second, the majority of the reviewed studies were conducted in European countries, followed by the United States, Canada, and the United Kingdom, which can bias some of the observed trends. Third, the extraction data process that was followed may result in some biases, as some of the studies used more than one analysis, but only the comprehensive results aligned with the research focus were selected and summarized.

In terms of future research, it would be necessary to focus on the factors determining the adoption and usage of specific types of e-MM modes, as opposed to study them as a group, as they can present distinct characteristics that may affect these decisions.

Also, these vehicles are sometimes used in combination with other modes, therefore this line of research could also provide new insights on the main social and psychological determinants affecting this mode of usage. In the same line of reasoning, other e-MM modes not included in this review such as hoverboards, segways and e-skateboards could be explored, as even today their usage is limited to some population segments and geographical contexts, they have potential to gain importance in the near future. On the other hand, cultural differences can be incorporated in future studies, as well as considering the characteristics that determine the different geographical regions where e-MM are used, and how local transport cultures affect the adoption (e.g., between driving- and cycling- oriented countries). Finally, the perceived positive and negative factors can also be affected by the destination or type of trip (e.g., commuting, leisure, care).

4.1.7. Conclusions

This review has focused on the sociopsychological determinants of e-MM use and adoption by analysing the role of functional and non-functional factors in explaining modal shift towards e-MM options. We conducted a literature search in four different databases, following the PRISMA guidelines and found a total of 67 studies. Our review demonstrates that users are motivated by a number of factors beyond just monetary costs, or other functional aspects. Rather, most of the reviewed studies highlight the importance of more symbolic factors in association with personal perceptions, self-identity, sense of belongingness, and pro-environmental attitudes. Our findings demonstrate that individuals perceive these services as being socially positive, contributing to improved liveability, equity of access, and diversity of choice. Out of all the analysed factors, safety and the lack of reliability were the two only issues discouraging the adoption of e-MM.

5. Exploring the relationship between electric micromobility use and physical activity

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

Journal of Transport & Health 29 (2023) 101588

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

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

Alexandra Bretones [a,*], Oriol Marquet [a,b]

[a] Geography Department, Autonomous University of Barcelona, Spain
[b] Institute of Environmental Science and Technology (ICTA-UAB), Spain

ARTICLE INFO

Keywords:
Physical activity
Accelerometer
Micromobility
Travel modes

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.

Bretones, A., & Marquet, O. (2023). Riding to health: Investigating the relationship between micromobility use and objective physical activity in Barcelona adults. *Journal of Transport & Health*, *29*, 101588. https://doi.org/10.1016/j.jth.2023.101588

JCR (2022): Impact Factor = 3.6 / Journal Citation Indicator (JCI) = 0.85 / Journal Ranking by JCI = Q2 (Transportation) and Q2 (Public, Environmental and Occupational Health)

5.1.1. 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 minutes of moderate-intensity or 75-150 minutes 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., 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 & 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 & 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 & 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 & 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 & McNally, 2017; De Geus & 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; van 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.

5.1.2. Materials and Methods

5.1.2.1. 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 minutes. 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 & 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 & Lopez Lizarraga, 2021).

5.1.2.2. 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 hours each day.

Non-wearing time was defined as intervals of 90 minutes 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).

5.1.2.3. 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 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 & 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.

5.1.3. Results

5.1.3.1. 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 7. 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 8. 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.

5.1.3.2. 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 9). With this approach, we were able to compare the PA time of participants with different numbers of participated and valid days.

Table 7 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

Source: own production

Table 8 Valid days (wearing time of at least 8 hours/day) by transport mode used

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%) [a]	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 (%)

Source: own production

Table 9 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%.

Source: own production

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

5.1.3.3. *Adherence to physical activity guidelines*

With regards to the PA guidelines compliance, and according to Table 10, 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%).

Table 10 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 (%)

Source: own production

5.1.3.4. Multivariate results

In Table 11, 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 (Figure 14).

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.

Table 11 Fit Linear Mix Effects Models: Linear associations of Mode Used with PA (all kinds)

	Model 1				***Model 2***				***Model 3***			
	Moderate-to-vigorous PA				**Light PA**				**Sedentary PA**			
	Coeff.	Std. Err.	tvalue	P > | z |	Coeff.	Std. Err.	tvalue	P > | z |	Coeff.	Std. Err.	tvalue	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

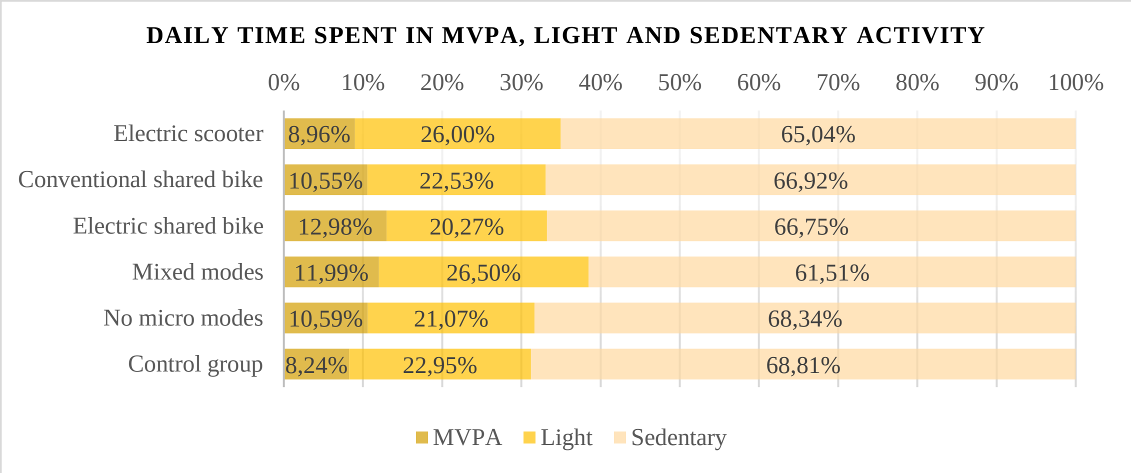
***: $p<0.001$; **: $p<0.01$; *: $p<0.05$

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)

Source: own production

Figure 14 Model estimates of daily time spent in PA (all kinds) by mode used



Source: own production

5.1.4. 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 sociodemographic 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 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 & 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 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.

5.1.4.1. 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.

5.2. Real-World and Traffic-Adjusted Physical Activity Levels of Micromobility Modes in Barcelona

Journal of Transport & Health 34 (2024) 101732

ELSEVIER

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: www.elsevier.com/locate/jth

Real-world and traffic-adjusted physical activity levels of micromobility modes in Barcelona

Alexandra Bretones [a,*], Carme Miralles-Guasch [a,b], Oriol Marquet [a,b]

[a] Grup d'Estudis en Mobilitat, Transport i Territori (GEMOTT), Geography Department, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, CP 08193, Barcelona, Spain
[b] Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, CP 08193, Barcelona, Spain

ARTICLE INFO

Keywords:
Micromobility
Physical activity
E-Bike
E-scooter
Accelerometer
GPS

ABSTRACT

Introduction: The goal of this study is to assess the level of physical activity associated with the use of different micromobility modes in the context of the city of Barcelona, considering both real-world and traffic-adjusted conditions.
Methods: The study used GPS and accelerometer devices to obtain objective measurements from 502 trips taken, including 128 trips by electric scooter users, 308 trips by conventional shared bike users, and 66 trips taken by electric shared bicycle users.
Results: The analysis confirmed that a notable disparity exists between the various modes of micromobility used in the city and the physical activity levels their usage entails.
Conclusions: Our findings highlight the importance of recognizing conventional and electric bikes as active modes of transport that may provide greater health benefits than e-scooters.

Bretones, A., Miralles-Guasch, C., & Marquet, O. (2024). Real-world and traffic-adjusted physical activity levels of micromobility modes in Barcelona. *Journal of Transport & Health*, *34*, 101732. https://doi.org/10.1016/j.jth.2023.101732

JCR (2022): Impact Factor = 3.6 / Journal Citation Indicator (JCI) = 0.85 / Journal Ranking by JCI = Q2 (Transportation) and Q2 (Public, Environmental and Occupational Health)

5.2.1. Introduction and literature review

Micromobility modes of transport have seen a significant increase in popularity in recent years. This trend has been driven by a variety of functional and non-functional factors (Bretones & Marquet, 2022), including concerns about the environment and traffic congestion (de Bortoli, 2021; McQueen et al., 2021), as well as the emergence of new technologies that make these modes of transportation more accessible and convenient (Milakis et al., 2020). One area of particular interest is the relationship between micromobility and physical activity (PA), as in the context of expanding urbanization and the associated increase in sedentary lifestyles, micromobility modes have emerged as potential solutions to these challenges. Understanding how these modes influence PA levels is crucial as PA entails direct benefits for health, reducing the risk of developing cardiovascular and respiratory diseases, type 2 diabetes, and some types of cancer, and diminishing the risk of all-cause mortality (Berntsen et al., 2017; Castro et al., 2019; Gojanovic et al., 2011; Sanders et al., 2022; Woodcock et al., 2011, 2014). Moreover, while there is a consensus that traditional active mobility involves physical effort to initiate movement, exemplified by activities like walking and cycling, our study endeavours to scrutinize these conventional classifications within the context of micromobility. This inquiry arises from the ongoing debate surrounding whether micromobility modes, including e-cycling and e-scootering, align with the traditional definitions of active transportation and what implications this classification might carry for overall PA levels.

Micromobility encompasses a range of small, lightweight vehicles powered by humans or electricity, including bicycles, e-bikes, e-scooters, and similar electrically powered modes of transportation, for both shared and private use. Research suggests that using micromobility modes for transportation can lead to increased PA, especially when cycling (Gojanovic et al., 2011; Otero et al., 2018; Peterman et al., 2016; Raustorp & Koglin, 2019). Additionally, research has shown that e-bikes can also promote PA (Castro et al., 2019; Chabanas et al., 2019; Fyhri & Fearnley, 2015; Gojanovic et al., 2011; Sundfør & Fyhri, 2017; Wild & Woodward, 2019). However, the current body of literature on e-scooters, while growing, is still relatively limited compared to bicycles and e-bikes. As e-scooters fall within the category of micromobility and share characteristics with e-bikes, including electric propulsion, it is plausible that they may provide some form of PA engagement, although the extent and nature of this engagement remain to be fully understood._ Hence, the current debate is centred on accurately quantifying the PA generated by various micromobility modes, particularly e-scooter use, and comparing these activity levels with those achieved through previous modes of transportation (Glenn et al., 2020; Sanders et al., 2022).

Previous research on the relationship between micromobility and PA has primarily relied on self-reported measures, such as questionnaires and surveys. While these methods provide valuable information on the socioeconomic context of micromobility users and their self-reported PA levels (Troiano et al., 2014), they also have limitations, including potential reporting biases, variability in perception, and issues with reliability and validity (Matthews et al., 2012; Shephard, 2003; Sylvia et al., 2014). Self-reporting often requires individuals to reflect on past experiences, which can be influenced by inherent memory limitations or the tendency for selective recall. This means that respondents may bring diverse and potentially nuanced personal perceptions to their responses, contributing to variability in reported data. To overcome some of these limitations, recent studies have begun to use accelerometers and GPS as more objective and precise measures, as these devices have helped enhance human movement monitoring, particularly in everyday life (Batista Ferrer et al., 2018; Chaix et al., 2019; Duncan et al., 2016; Marquet et al., 2020; Plasqui et al., 2013; Rowlands, 2018; White et al., 2019). Accelerometers can provide simple ratios of time spent in active or sedentary modes, while also being able to categorize the data according to the intensity of the activity (such as light or moderate exercise) or estimate distance travelled (such as steps), On the other hand, GPS devices can pinpoint a location within a few meters at any given time, as well as generate mobility indicators that describe an individual's daily mobility patterns. However, when it comes to distinguishing transportation-related activities like walking or cycling, the combination of GPS and accelerometer is more useful than using each sensor separately. Indeed, when distinguishing between active and passive modes of transportation, the performance of transport mode detection is improved when GPS data, such as speed, is added to accelerometer data (Brondeel et al., 2015; Ellis et al., 2014; Lee & Kwan, 2018). Therefore, these wearable devices accurately measure daily PA, energy expenditure and are valid and reliable predictors of total PA.

In the context of transportation, energy expenditure is often reported as the number of Metabolic Equivalents of Tasks (METs) per minute or MET-minutes per day (Castro et al., 2019; Gojanovic et al., 2011; Tao et al., 2020; Wilson et al., 2020). This allows for a direct comparison of the energy expenditure of different modes of transportation and can provide insight into the potential health benefits of different modes. The Compendium of Physical Activities provides data on the energy expenditure of various activities and transportation modes, including cycling and scootering (Ainsworth et al., 2011). However, it is important to note that the values provided in the Compendium are based on laboratory settings and may not accurately reflect the energy expenditure of these activities in real-life conditions (Ainsworth et al., 2011; Allahbakhshi et al., 2019). Factors such as terrain, weather, and personal characteristics can all affect energy expenditure (Cusack, 2021; Langford et al., 2017; McGinn et al., 2007), and therefore, it is important to assess PA levels under real-life conditions to obtain a more accurate understanding of the impact of these modes on energy expenditure and overall PA levels (Allahbakhshi et al., 2019, 2020; Awais et al., 2015). Similarly, while most previous studies have sought to generate objective PA gained per minute of a trip in a micromobility mode, we also need to consider that travel behaviours in each mode of transport are significantly different from each other (Arias-Molinares et al., 2023; Cubells et al., 2023; Rayaprolu & Venigalla, 2020; Roig-Costa et al., 2021; Şengül & Mostofi, 2021). Thus, resulting PA levels will likely differ when analysing PA data standardized by a minute of use, or analysing total PA gained from typical micromobility use.

Therefore, the primary aim of this research is to assess the PA (in METs) associated with the use of different micromobility modes in the context of the city of Barcelona both in real-world and traffic-adjusted conditions. Indeed, this study offers a deeper understanding of the potential differences between biking and scootering. By using objective measures from both accelerometer and GPS devices, this study aims to provide a more accurate understanding of the matter, providing valuable insights into the latent health benefits in terms of PA of using micromobility modes for transportation, which can help inform policies and interventions aimed at promoting active transportation.

The paper is organized as follows. Section 2 introduces the study case, data and methods used, while Section 3 presents the results obtained. Section 4 is dedicated to the discussion of the results and the limitations of the study. Finally, conclusions and further implications are drawn in Section 5.

5.2.2. Methods and data

5.2.2.1. Study setting

The study took place in the municipality of Barcelona, a densely populated urban area with mixed land use and a continuous, compact layout (Marquet & Miralles-Guasch, 2018). The urban environment of Barcelona makes it a popular location for micromobility usage and is representative of traditional European cities with dense, compact urban areas where these new modes of transportation compete for public space with pedestrians, cyclists, and cars (Esztergár-Kiss & Lopez Lizarraga, 2021). In fact, in 2021 bicycle trips accounted for a total of 144,950, and e-scooter trips for 37,621 (representing a 3.3 and 0.9% of total trips, respectively) (IERMB, 2021). Our analysis focused on conventional and electric bicycles from the public bike-sharing system along with privately owned e-scooters. The dock-based bicycle sharing system, Bicing, has over 100,000 registered users and a fleet of 7,000 bikes (Soriguera & Jiménez-Meroño, 2020). Unlike Bicing, the municipality does not offer an e-scooter sharing platform and does not allow private e-scooter companies to operate within city limits, meaning all e-scooter users in Barcelona use their privately owned vehicles (Figure 15).

Figure 15 Barcelona dock-based bicycle sharing system and private e-scooter

5.2.2.2. Overview of the data collection methodology

The NEWMOB study conducted in 2020 surveyed 902 micromobility users in Barcelona, Spain. The study aimed to understand the travel behaviour and impact of COVID-19 on micromobility adoption. The survey was conducted between September 15th to October 1st using 8 pollsters that 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 modalities) users were randomly intercepted and asked to answer a questionnaire that took 10-15 minutes. Eligible participants had to be living or working in Barcelona and were over 16 years old due to the minimum age requirement for driving an electric scooter and using the public bike sharing system. The sample consisted of 326 electric scooter users, 251 moped scooter users, 217 traditional bike users, and 108 electric bike users. The questionnaire covered socio-demographic characteristics, transport usage, multimodality, and use of public space and mobility (further information is available at (Roig-Costa et al., 2021)).

From this initial sample, a subsample of participants 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 ending up with 65 e-scooters, 74 conventional bikers, and 37 e-bike users. Participants in the study first signed an informed consent and then completed a baseline questionnaire covering their demographics, self-reported health, and PA habits. They were then provided with an accelerometer device (GT3X-BT; ActiGraph LLC, Pensacola, FL, USA) and a GPS device (BT-Q1000X; QStarz, Taiwan, R.O.C.). The devices were to be worn all day, except during activities like showering, swimming, contact sports, and night-time sleeping. Participants were also asked to fill out a daily travel diary, sent via smartphone messages at the end of each day, to help with cross-checking their trips and interpreting accelerometer-recorded PA levels. To analyse daily mobility patterns, we excluded participants who did not wear the devices for a minimum of 8 hours in one of the seven days it was given to them. This resulted in a sample of 39 eligible users, and 502 trips. The study aimed to collect a sufficiently large number of trips for each micromobility mode, prioritizing data accuracy over sample size. Ensuring that the trips were accurately associated with their respective modes was crucial to the study's reliability and validity.

5.2.2.3. Accelerometer and GPS data processing

Accelerometer data were analysed using Actilife software. The data were summarized into fifteen-second intervals and any periods of 60 minutes or more with zero values were considered as "non-wear" and were excluded from analysis. For analysing mode and PA during commuting, participants had to provide at least one day (8 hours) of valid accelerometer and GPS data from a working day. Likewise, the GPS devices were set to record the participants' location every 15 seconds. The GPS data were processed using the Human Activity Behaviour Identification Tool and Data Unification System (HABITUS) software. HABITUS applies a heuristic algorithm to identify trips from GPS trajectories and determine their mode of transportation by calculating the distance and speed between sequential GPS points (Berjisian & Bigazzi, 2022). This software classifies trips with a 90th percentile speed ranging from ≥10 km/h to <25 km/h as "micromobility trips." For this research, only micromobility trips were considered in the analysis. Because the HABITUS software is unable to differentiate between e-scooter and bicycle trips, travel diaries were used to help identify the specific mode of transportation for each micromobility trip. These travel diaries were designed to have information regarding the number of trips and the micromobility mode used for each of the participants, daily. They were sent to the participants every day through WhatsApp or Email (in accordance with their preferences) to be filled (see Annex 1). They gave self-reported information about trips that complemented the objective data coming from accelerometers.

Accelerometer and GPS data were combined for every fifteen-second epoch. The merged data were imported into ArcGis Pro software (Esri, Redlands, California, USA) where trips that had taken place outside the limits of Barcelona municipality were visually identified and removed. We also filtered out trips that were either too short (less than 2 minutes) or too long (more than 2 hours, n = 176) or had an average speed above 60 km/h (n = 32). After the data cleaning process, 502 routes remained.

Once valid trips were identified, we first decided to express the intensity of PA as Metabolic Equivalents of Task (METs) to enhance comparability between different studies. MET is a unit that measures the energy consumption rate during PA (Mendes et al., 2018). One MET is equal to the amount of energy expended while sitting at rest, calculated as oxygen uptake per kilogram of body mass per minute (3.5 ml/O2/kg/min) (Hills et al., 2014). The total amount of METs per route was calculated by using the Freedson equation (METS/min = 1.439008 + 0.000795 × count/min (vertical axis)) (Freedson et al., 1998). The average MET/minute corresponding to each trip was obtained by dividing the overall estimated number of METs by the total minutes of the trip. Additionally, the PA data were summarized into minutes spent for each trip identified, and in terms of total minutes of sedentary, light, moderate, vigorous, and very vigorous activity levels. We applied Troiano et al. (2008) set of cut points commonly used to define PA intensities (Sedentary: < 100 cpm; Light: 100 – 1951 cpm; Moderate: 1952 – 5724 cpm; Vigorous: 5725 – 9498; Very vigorous: > 9488).

5.2.2.4. Data analysis

The sample characteristics were assessed based on age, gender, occupation, education, and Body Mass Index (BMI) category (Table 12). Participants were asked to self-report which mode of micromobility they primarily used. This information was then used to categorize the participants into bike, e-bike, or e-scooter habitual users. Apart from employing descriptive statistics, bivariate analysis was applied to characterize the attributes of trips (average time, distance, speed), the average gained METs, and the average time spent in each PA intensity (Table 13). In addition, we assessed differences in total METs and MET/minute in relation to transport mode, gender, and age (Table 14).

To evaluate energy expenditure (METs) across various micromobility modes and uses, we differentiated between two distinct measurements: (1) capturing all PA from the start to the end of the trip, inclusive of sedentary time (e.g., at intersections, traffic lights, etc.), and (2) focusing solely on trip segments during which the user was actively engaged, thereby excluding sedentary time. We designated the first metric as 'Real-World Energy Expenditure' (RWE) and the second as 'Traffic-Adjusted Energy Expenditure' (TAE).

Real-World Energy Expenditure (RWE) offers a comprehensive assessment of the PA experienced by micromobility users in Barcelona. However, this metric is heavily influenced by factors such as local street layout, driving conditions, and available infrastructure, which may not accurately reflect the typical PA associated with micromobility use. Consequently, we introduce the 'Traffic-Adjusted Energy Expenditure' (TAE) measurement to account for stops and driving conditions imposed by the local context. This alternative measure more precisely estimates the PA generated by micromobility while in motion, making it a more suitable metric for inter-city comparisons. We further categorize both measurements into Total METs and METs per minute. This differentiation is crucial because energy expenditure depends not only on the type of micromobility employed but also on the specific trip characteristics, such as distance. Given that previous studies have established distinct trip features for various micromobility modes, it is essential to evaluate energy expenditure by examining both the entire trip and by stratifying PA on a per-minute basis.

In summary, the combination of measurement types - Real-World Energy Expenditure (RWE) and Traffic-Adjusted Energy Expenditure (TAE) - along with measurement characteristics - Total METs and METs per minute - generates a comprehensive set of four distinct metrics for assessing the PA generated by micromobility usage. The definitions, advantages, and practical applications of each measure are concisely presented in Figure 16.

To examine the relationship between micromobility modes used in a trip and the total METs and METs per minute generated, while controlling for key sociodemographic characteristics, we utilized multilevel linear mixed-effects models built with the R package "lme4" (Bates et al., 2015). These models incorporated user-specific and trip-specific random effects to account for any unobserved heterogeneity (refer to Tables 4 and 5), as MLME modelling allows us to incorporate the hierarchical structure of our data, where PA measurements are nested within specific routes and individual user profiles.

Also, to facilitate the interpretation of the models, we calculated and graphed the marginal effects using the R package "ggeffects" (Lüdecke, 2018). This approach allowed us to predict the total MET and MET/minute per trip for each transport category, with all other variables held at their average values (refer to Figure 3). Additionally, we assessed these values in terms of gender to investigate significant differences between male and female users, and to determine which modes may accentuate these differences (Figures 4 and 5). The decision to include gender-specific figures in the analysis was based on a preliminary descriptive examination of the data presented in Table 3, indicating potential differences in physical activity levels. Given these findings, we deemed it relevant to present gender-specific results aligning with existing research in the field of transport and micromobility, which emphasizes the importance of considering gender differences when conducting analyses (Beecham & Wood, 2014; Campisi et al., 2021; Cubells et al., 2023; Frings et al., 2012; Haynes et al., 2019).

Figure 16 Definition, benefits, and utility of using Total METs and MET/minute under the two scenarios proposed

	Total METs	**MET/minute**
Real World Energy Expenditure (RWE)	Total energy expenditure accumulated in a single trip and real world driving conditions for a specific micromobility mode.	Energy expenditure per minute accumulated in a single trip and real world driving conditions for a specific micromobility mode.
	Pros •Comprehensive measure of overall PA intensity during the entire trip. ***Useful for*** •Providing a more detailed understanding of patterns of physical activity throughout the trip, such as how much time is spent in different activity intensities.	***Pros*** •Provides a more precise measure of the intensity of physical activity by accounting for the duration of the trip. •Less prone to measurement errors associated with averaging the intensity of all activities throughout the trip. ***Useful for*** •Comparing the relative intensity of trips when using different modes.
	Useful measure to compare WITHIN cities.	
Traffic Adjusted Energy Expenditure (TAE)	Total energy expenditure accumulated in a single trip when accounting only for active phases of the trip, excluding traffic light stops or other sedentary phases of the trip, for a specific micromobility mode.	Energy expenditure per minute accumulated in a single trip when accounting only for active phases of the trip, excluding traffic light stops or other sedentary phases of the trip, for a specific micromobility mode.
	Pros •Provides a more precise estimate of the actual physical activity that occurs during the active part of the trip.	***Pros*** •Provides a precise measure of the active part and intensity of the physical activity, on a per-minute basis.

	Useful for •Comparing the overall physical activity intensity of different trips or modes of transportation.	•Help standardize the measurement of physical activity across different studies and populations, allowing for more meaningful comparisons. ***Useful for*** •Quantifying the health benefits of physical activity during a trip.
	Useful measure to compare BETWEEN cities/urban environments.	

Source: own production

5.2.3. Results

5.2.3.1. Descriptive characteristics

The final data set consisted of 502 trips that belonged to 39 individuals distributed between 11 electric scooter users (128 trips), 20 conventional shared bike users (308 trips), and 8 electric shared bike users (66 trips). The characteristics of the study population are outlined in Table 12. The participants, on average, were 31 years old and of regular weight (mean BMI of 23.68 kg/m2), with 23% considered overweight. Over half of the participants were men (64%) and had completed high school (44%) or college/university education (49%), being almost 85% of the participants employed. Both conventional and electric shared bike users were more likely to be men (70 and 63% respectively) and highly educated (55 and 50% respectively). On the other hand, electric scooter users were more likely to have a lower education level, i.e., high school (55%), and to present overweight or even obesity levels (45%). In terms of age, the e-scooter and the conventional shared bike are more used for younger population groups (under 35 years old), while the shared e-bike is mainly for individuals between 25 and 45 years old. Regarding professional status, almost all our sample was working at the time of the analysis.

5.2.3.2. Physical activity analysis

For the aims of the statistical analyses, a summary of objectively measured energy expenditure, distance, time, and speed of overall sample trips and per mode of transport is presented in Table 13.

Table 12 Sociodemographic characteristics of the sample

Sample characteristics (n = 39)	**Overall**	**Electric scooter**	**Conventional shared bike**	**Electric shared bike**
N	*39*	*11*	*20*	*8*
Demographics				
Male	25 (64.10%)*	6 (54.55%)	14 (70.00%)	5 (62.50%)
Age, years (mean (SD))	31.03 (11.12)	30.36 (8.96)	29.80 (12.17)	35.00 (11.46)
Age, years				
16-24	13 (33.33%)	3 (27.27%)	9 (45.00%)	1 (12.50%)
25-34	14 (35.90%)	5 (45.45%)	6 (30.00%)	3 (37.50%)
35-44	7 (17.95%)	2 (18.18%)	2 (10.00%)	3 (37.50%)

45+	5 (12.82%)	1 (9.09%)	3 (15.00%)	1 (12.50%)
Education level				
< High school	3 (7.69%)	1 (9.09%)	2 (10.00%)	-
High school	17 (43.59%)	6 (54.55%)	7 (35.00%)	4 (50.00%)
College	19 (48.72%)	4 (36.36%)	11 (55.00%)	4 (50.00%)
Professional status				
Student	5 (12.82%)	-	5 (25.00%)	-
Active	33 (84.62%)	10 (90.91%)	15 (75.00%)	8 (100.00%)
Retired	1 (2.56%)	1 (9.09%)	-	-
BMI index (kg·m^2)				
Mean (SD)	23.68 (3.18)	25.36 (4.11)	22.88 (2.42)	23.36 (2.90)
Regular weight	29 (74.36%)	6 (54.55%)	17 (85.00%)	6 (75.00%)
(18.5 – 25)	9 (23.08%)	4 (36.36%)	3 (15.00%)	2 (25.00%)
Overweight (25 –	1 (2.56%)	1 (9.09%)	-	-
30)				
Obesity (≥30)				

*Results are presented as n (%)

Source: own production

On average, a single trip taken in a micromobility mode generates 2.47 METs in Real World Energy (RWE) conditions, while generating 2.65 in Traffic-Adjusted conditions (TAE). Under the RWE scenario, the conventional bike is the micromobility mode presenting the highest RWE MET values (2.66) as opposed to the e-scooter which presents the lowest ones (1.98). Also, the electric bike presents an average MET value that is close to the conventional one (2.55). Similar results are found under the TAE scenario but with overall higher values. It is also important to note that the differences in averaged MET values between modes is found as statistically significant (<0.001).

Table 13 Objectively measured physical activity by micromobility mode of transport

	All N = 502	Conventional shared bike N = 308	Electric shared bike N = 66	Electric scooter N= 128	
	Mean (SD)	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**p-value***
RWE - Average METs	2.47 (1.06)	2.66 (1.15)	2.55 (1.08)	1.98 (0.53)	< 0.001
TAE - Average METs	2.65 (1.06)	2.81 (1.16)	2.75 (1.09)	2.20 (0.56)	< 0.001

Average distance (kilometres)	2.28 (2.13)	2.37 (2.21)	2.46 (2.52)	1.96 (1.64)	0.138
Average time (minutes)	11.87 (9.29)	12.38 (9.98)	12.12 (8.39)	10.51 (7.84)	0.157
Average speed (km/h)	11.46 (6.81)	11.42 (6.88)	12.17 (8.72)	11.17 (5.41)	0.618
Average active time (minutes)	9.30 (8.27)	10.43 (9.16)	9.52 (7.13)	6.47 (5.44)	< 0.001
Average time in sedentary activity (minutes)	2.57 (2.93)	1.95 (2.25)	2.61 (2.69)	4.05 (3.85)	< 0.001
Average time in light activity (minutes)	6.44 (6.30)	6.97 (7.18)	6.23 (5.37)	5.26 (3.90)	0.034
Average time in MVPA activity (minutes)	2.86 (4.92)	3.45 (5.36)	3.28 (5.31)	1.21 (2.79)	< 0.001

SD: Standard Deviation; MVPA: Moderate to Vigorous Physical Activity.

* Derived from Analysis of Variance (Anova) statistics.

Source: own production

Regarding other basic characteristics, in terms of distance, micromobility trips are on average of 2.28 kilometres long, not presenting a substantial difference between modes, yet e-scooter trips are the shortest ones. Regarding total time, we can see that the average time per trip is of 12 minutes, with again no significant variations between modes. Indeed, as distance and time define speed, results show that the average speed is around 11.5km/h. These three factors present high standard deviations, suggesting that there is a wide range of variation in these variables across the sample.

Additionally, it is interesting to see how the total time of trips is distributed between sedentary and active time, and more specifically, between sedentary, light, and moderate-to-vigorous (MVPA) physical intensity. Remarkably, only in the case of e-scooter trips do we find sedentary time to be almost as high (4.05 minutes) as light active time (5.26 minutes), while for both bike and e-bike trips a major part of the time is associated with light activity (6.97 and 6.23 minutes, respectively). Also, the difference between MVPA minutes is significant when comparing bike and e-bike (3.45 and 3.28 minutes, respectively) with e-scooter (1.21 minutes), with bike trips entailing at least on average 3 minutes of this intense PA.

Table 14 Total METs and MET/minute

	RWE Total METs*	TAE Total METs	RWE MET/minute	TAE MET/minute
Transport Mode				
Conventional bike	34.23 (15.07) *	31.23 (15.30)	2.66 (0.35)	2.83 (0.37)
Electric bike	32.95 (14.28)	29.37 (14.14)	2.59 (0.39)	2.78 (0.39)
Electric scooter	19.44 (9.04)	14.10 (7.92)	2.02 (0.30)	2.24 (0.33)
Gender				
Male	31.23 (16.66)	27.84 (16.91)	2.53 (0.43)	2.73 (0.44)
Female	27.23 (10.42)	22.75 (11.01)	2.34 (0.44)	2.52 (0.43)
Age				
16-24	25.76 (7.80)	21.70 (8.05)	2.46 (0.40)	2.67 (0.43)
25-34	25.57 (11.95)	22.08 (12.23)	2.40 (0.46)	2.59 (0.46)
35-44	37.34 (21.40)	33.74 (21.90)	2.54 (0.57)	2.70 (0.57)
45+	41.55 (18.24)	37.44 (19.64)	2.54 (0.35)	2.72 (0.32)

* Results are presented as Mean (Standard Deviation)

Source: own production

Table 14 shows the average total METs and METs per minute of trips now incorporating not just the mode of transport but other sociodemographic characteristics of interest such as gender and age. In terms of mode of transport, trips done by conventional bike present the higher PA expenditure both per trip and per minute, followed by the e-bike and the e-scooter. Regarding gender, men present slightly higher METs in all cases. In terms of age, results are somewhat different between total METs and METs per minute. Total METs (both including and excluding sedentary activity) are higher for individuals older than 35 years old, whilst METs per minute are similar in all age groups.

5.2.3.3. Multivariate analysis

Table 15 explores the relationship between the different micromobility modes used and average total METs per trip, for the two scenarios previously mentioned, RWE and TAE. Because Model 1 and Model 2 do not adjust by the length of the trip, observed differences might be caused by a combination of different physical energy expenditures inherent to each mode of transport in combination with travel behaviour patterns regarding types and lengths of routes chosen in each mode of transport. For instance, a lengthy e-bike journey may result in a comparable PA outcome as a shorter conventional bicycle trip, even though the energy expenditure per kilometre on a conventional bicycle is likely to be greater.

The models in this table also account for the influence of age and gender. Model 1 finds the Total METs of trips made by conventional bikes to be significantly higher than those trips that were made using an e-scooter (coefficient = 18.293, $p = 0.005$). While the association was not found significant, the direction and magnitude of coefficients also suggest that e-bikes were generating higher Total METs than e-scooters although, predictably, those differences were smaller than those observed for conventional bike trips. In Model 2, which excludes sedentary activity, the Total METs were in this case positively associated with the use of both conventional (coefficient = 21.785, $p < 0.001$) and electric bikes (coefficient = 16.615, $p = 0.050$) indicating similar directions and magnitudes of coefficients that situate conventional bike as the most active micromobility mode, being followed by electric bike and e-scooter respectively.

Table 15 Fit Linear Mix Effects Models: Linear associations of Mode Used with Total METs

	Model 1 **RWE - Total MET**				***Model 2*** **TAE - Total MET**			
	Coeff.	Std. Err.	t value	P > | z |	Coeff.	Std. Err.	t value	P > | z |
Transport Mode								
Electric scooter (REF)								
Conventional bike	18.293	5.845	3.129	0.005**	21.785	5.968	3.650	0.000***
Electric bike	12.825	7.179	1.786	0.108	16.615	7.302	2.275	0.050*
Age								
16-24 (REF)								
25-34	3.574	6.186	0.578	0.697	2.728	6.336	0.431	0.634
35 - 44	16.395	7.484	2.191	0.054	13.782	7.668	1.797	0.042*
45 +	11.517	7.876	1.462	0.247	11.453	8.099	1.414	0.253
Gender								

Female (REF)								
Male	1.22	5.238	0.233	0.786	0.678	5.359	0.126	0.682

***: p<0.001

**: p<0.01

*: p<0.05

Source: own production

In the below table (Table 16), models are presented to show the associations between the micromobility mode used and METs per minute, accounting for the above-mentioned sociodemographic characteristics. For this second case, in both scenarios (with and without sedentary activity) METs/minute are positively associated with the use of the conventional bike (coefficient = 0.831, $p < 0.001$ for Model 3; coefficient = 0.626, $p < 0.001$ for Model 4) and electric bike (coefficient = 0.776, $p = 0.001$ for Model 3; coefficient = 0.578, $p < 0.001$ for Model 4), as compared to the e-scooter that acts as the reference group.

Table 16 Fit Linear Mix Effects Models: Linear associations of Mode Used with METs per minute

	Model 3 **RWE – MET/minute**				***Model 4*** **TAE – MET/minute**			
	Coeff.	Std. Err.	t value	P > | z |	Coeff.	Std. Err.	t value	P > | z |
Transport Mode								
Electric scooter (REF)								
Conventional bike	0.831	0.161	5.154	**0.000***	0.626	0.139	4.514	**0.000***
Electric bike	0.776	0.199	3.902	**0.001***	0.578	0.170	3.401	**0.000***
Age								
16-24 (REF)								
25-34	0.005	0.170	0.029	0.365	0.127	0.147	0.865	0.387
35 - 44	0.143	0.206	0.693	0.173	0.186	0.178	1.044	0.297
45 +	-0.011	0.216	-0.051	0.604	0.031	0.188	0.163	0.871
Gender								
Female (REF)								

Male	0.075	0.144	0.520	0.370	0.081	0.124	0.648	0.517

***: $p<0.001$

**: $p<0.01$

*: $p<0.05$

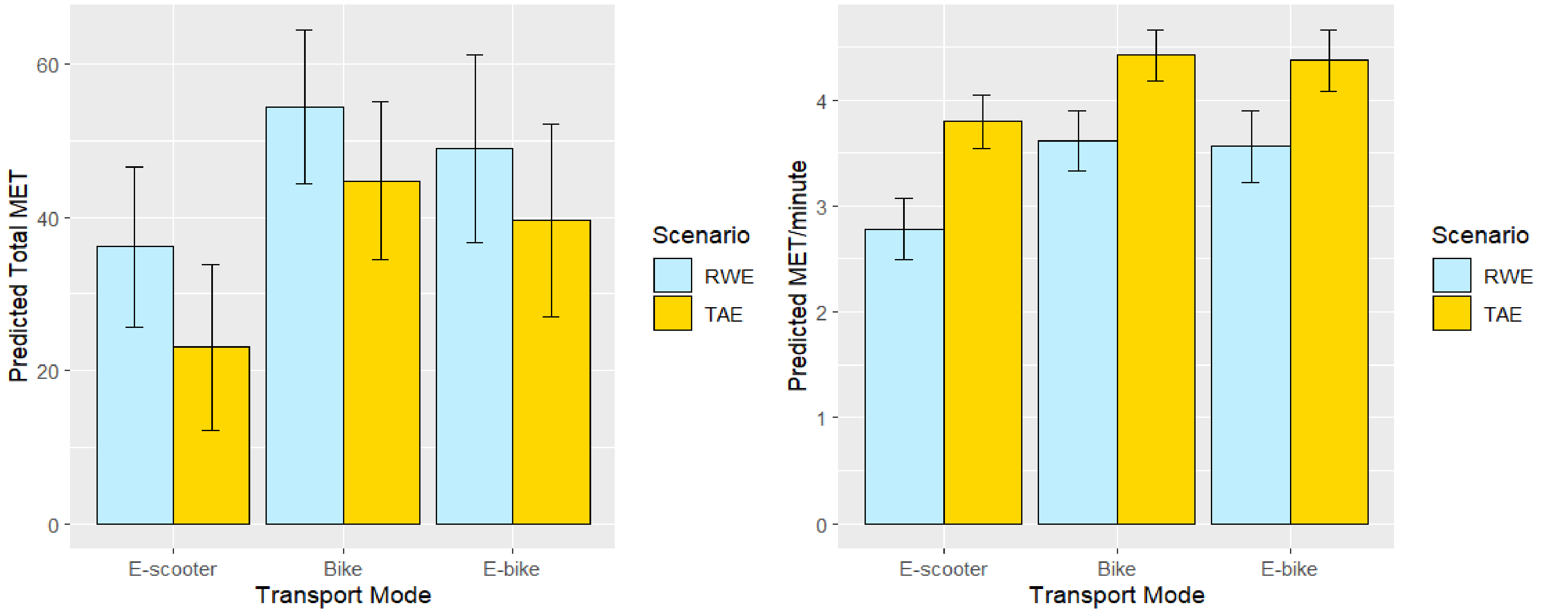
Source: own production

Additionally, to understand the impact of the mode of transport chosen on the outcome variable (METs/minute), we estimated the margin effects to calculate predicted values, allowing us to assess the effect of a unit change in each predictor on the outcome, holding all other variables constant. In Figure 17 we see the predicted values in terms of Total METs for both scenarios analysed on the left bar plot. In this case, an expected increment of 50.66% is expected for using the bike rather than the e-scooter, and 11.17% if using the e-bike under the RWE scenario. These expected increases are even higher when just considering the active time (TAE scenario), being an increment of 94.70% for the e-scooter, and 13.05% for the e-bike. Also in Figure 3, we have the predicted values now in terms of MET per minute (right graph). In this case, a minute on a conventional bike causes 28.06% more PA than a minute on an e-scooter. For the e-bike, the difference is smaller, being 1.40% less PA per minute.

When estimating Total METs for both RWE and TAE scenarios, in terms of gender (Figure 18), men present higher estimated values than women, with similar increases for the three modes, being 12.80% for e-scooters, 10.50% for bikes and 8.90% for e-bikes under the RWE scenario; and 20.58% for e-scooters, 15.26% for bikes, and 12.12% for e-bikes, under the TAE scenario. Therefore, e-scooter male users are the ones presenting a higher increment in expected Total METs per trip, as compared to women.

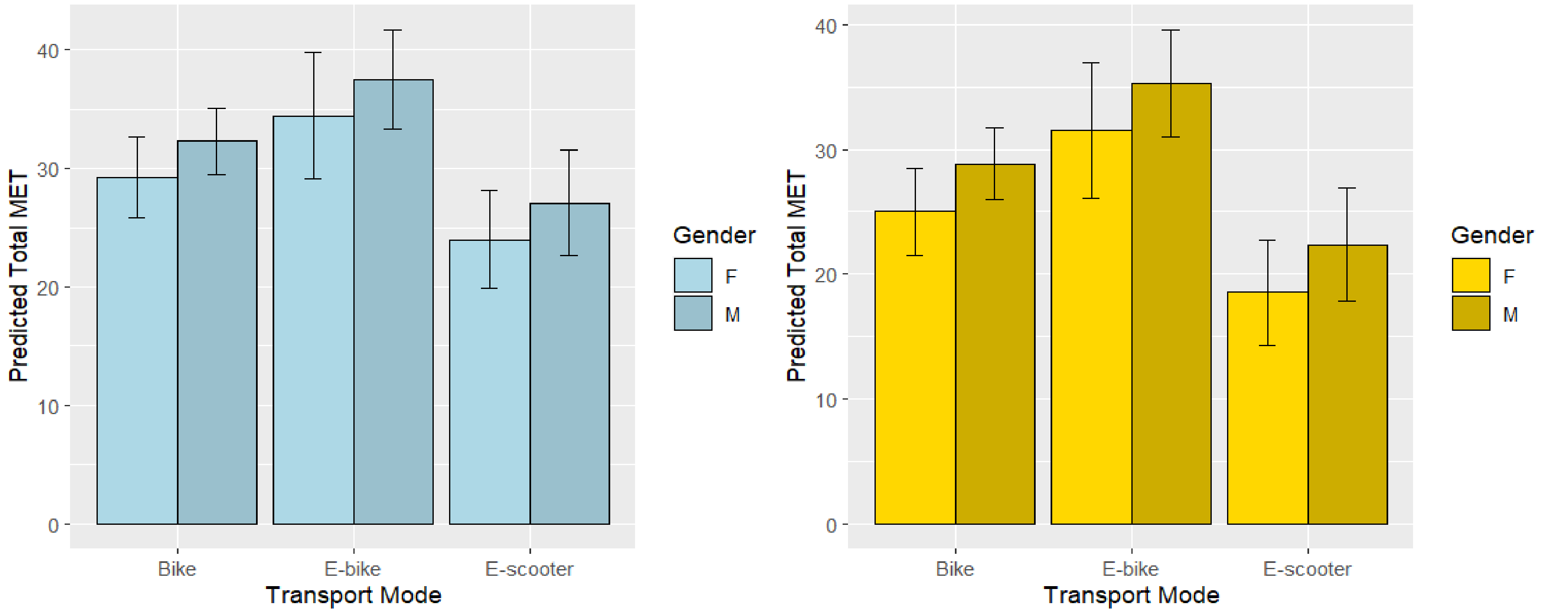
In Figure 19, the same outcomes are found, now regarding estimated MET/minute. Under the first scenario (RWE), males can expect higher MET/minute than women by all modes, concretely, an increment of 8.65% for e-scooters, 7.56% for bikes, and 7.12% for e-bikes. The same happens under the second scenario presented (TAE), where the percentual increases are as follows: 8.81% for e-scooters, 7.84% for bikes, and 7.07% for e-bikes.

Figure 17 Predicted Total METs and MET/minute for both scenarios, RWE and TAE



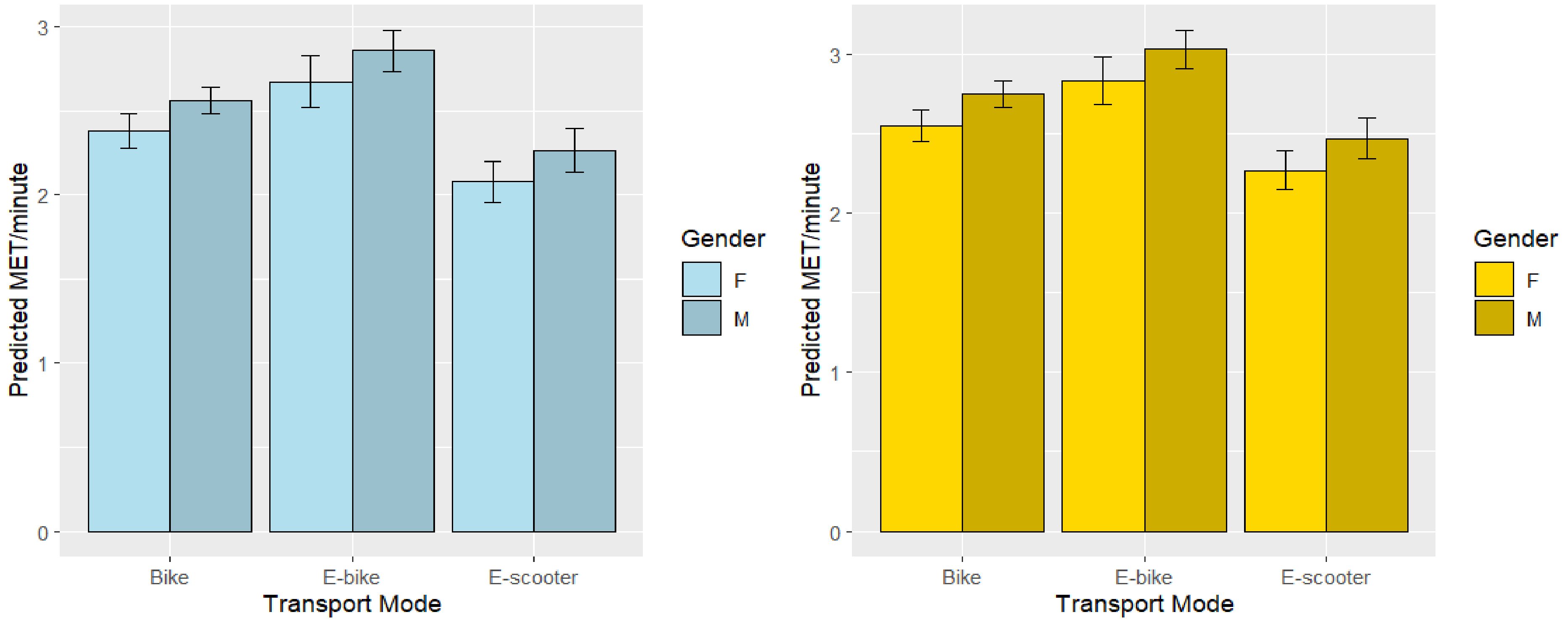
Source: own production

Figure 18 Predicted Total METs by gender, for both scenarios, RWE (left) and TAE (right)



Source: own production

Figure 19 Predicted MET/minute by gender, for both scenarios, RWE (left) and TAE (right)



Source: own production

5.2.4. Discussion

The goal of this study was to assess the level of PA related to different modes of micromobility in Barcelona, considering both real-world scenarios and traffic-adjusted conditions. To achieve this, we used GPS and accelerometer devices to obtain objective measurements. The final data set included 502 trips taken by 39 people, including 128 trips taken by electric scooter users, 308 trips taken by conventional shared bike users, and 66 trips taken by electric shared bike users. Under Real World Energy (RWE) conditions, a micromobility trip generated an average of 2.47 METs, while in Traffic-Adjusted Energy (TAE) conditions, it generated 2.65 METs. As expected, conventional bikes presented the highest MET values, while e-scooters had the lowest. E-scooter trips resulted in 2.20 METs (in the TAE scenario), which is below the value that is assigned to automobile driving by the 2011 Compendium (Ainsworth et al., 2011). This is consistent with Sanders et al. (2022) most recent research, which found that e-scooter trips were approximately as active as auto trips.

When trying to understand micromobility PA, however, it is important to acknowledge the distinct travel patterns associated with different micromobility modes in terms of distance and frequency of use. Our findings reveal that, on average, e-scooter trips are shorter (1.96 km) compared to the mean distance covered by other micromobility modes (2.28 km), as other studies suggest (Liao & Correia, 2022; Reck et al., 2021). The observed relationship between e-scooters and shorter trips can be attributed to two primary factors: (1) the characteristics of the built environment in Barcelona, which facilitates a high prevalence of short-distance trips (Marquet & Miralles-Guasch, 2015), and (2) the interconnectivity between e-scooter usage and walking, as both modes cater to similar travel distances, Reck et al. (2022) study showing how e-scooters tend to replace a significantly higher number of walking trips when compared to e-bikes, for instance.

In the multivariate analyses, the Total METs of trips taken by conventional bicycles were significantly higher than those made using e-scooters. Results suggested that e-bikes also generated higher Total METs than e-scooters although the association was not found significant. When focusing on the active phase of the trip, both conventional and electric bikes were also found to generate more Total METs. This indicates that conventional bikes are the most active micromobility mode, followed by electric bikes and e-scooters, respectively. Similar results were found when we stratified the analysis in terms of METs per minute to account for possible trip-structure differences between modes. Our findings reinforce the idea that both conventional and electric bikes need to be considered active modes of transport that may provide greater health benefits than e-scooters.

In terms of how PA levels are generated during the trip itself, our analysis reveals a clear difference between e-scooter trips and bike and e-bike trips, with e-scooter showing intermittent PA peaks interspersed with extended sedentary periods, while bikes and e-bikes both exhibited a more uniform distribution of PA throughout the journey without pronounced fluctuations in intensity. While both travel modes may generate equivalent overall PA per trip, the more spread-out distribution of PA observed in cycling trips is likely to offer superior cardiovascular and metabolic benefits, as it promotes sustained aerobic exercise, facilitates beneficial metabolic adaptations and might reduce the risk of overexertion and injury (Garber et al., 2011; Holtermann et al., 2018).

On the aggregate, our results position both conventional and electric bikes as active modes of transport that can provide significant public health benefits. At the same time, we provide further evidence for e-scooters not to be considered active travel modes, as they not only generate lower overall PA (Glenn et al., 2020; Sanders et al., 2022) but also exhibit a highly inconstant in-trip distribution of PA, reliant on sporadic exertion peaks, which may be less beneficial for cardiovascular and metabolic health.

When trying to precisely quantify these PA differences by using margin effects our analysis revealed an expected increment of almost 51% Total METs when using a bike as opposed to an e-scooter under the RWE scenario. When we controlled for sedentary trip sections and accounted only for the active stages of the trip (TAE scenario), the expected increments were even greater, with Total METs gained from a bike trip being almost double than those generated by e-scooter use. Our analysis also indicated that a minute of riding a conventional bike is associated with 28% more PA than a minute of riding an e-scooter. Conversely, the difference between a minute of riding an e-bike versus an e-scooter was smaller, with 1.4% less PA per minute.

When stratifying by gender, PA gained by male participants was higher in all cases, and measurement types. This is likely because, as previous literature has found, men are more inclined towards adopting risky and fast riding practices and tend to exhibit less compliance with rules (Cubells et al., 2023; Gioldasis et al., 2021; Lind et al., 2021), while women have traditionally been found to develop risk-averse attitudes when riding micromobility modes (Graystone et al., 2022; Prati et al., 2019).

These findings have significant implications for policymakers and transport policy experts, particularly regarding initiatives that aim to plan for health and PA. Our study is among the first to use device-based measures of PA and tracking to estimate accurate PA levels for three different micromobility modes. Previous research had used self-reported measures to underscore the importance of the choice of transport mode on PA levels, emphasizing the critical role of active micromobility modes such as conventional and electric bicycles (Castro et al., 2019; Dons et al., 2018; Hajna et al., 2019; Miller et al., 2015; Raza et al., 2020; Vich et al., 2019; Wild & Woodward, 2019).

Our findings underscore the importance of recognizing conventional and electric bicycles as the primary active micromobility modes, despite the growing popularity of e-scooters worldwide. The relatively low PA associated with e-scooter use is even more worrisome given the fact that in cities such as Barcelona the majority of new e-scooter users replace walking (Felipe-Falgas et al., 2022), effectively substituting an active mode of transportation for a more sedentary one. Considering these findings, we recommend that transport planners prioritize promoting modal shifts toward cycling and electric cycling since any shift from walking or biking to e-scootering would result in a net loss of PA.

The analysis of e-scooters and other micromobility modes' specific impacts is heavily influenced by their intended use and the types of transportation they replace. While e-scooters may provide a net benefit in situations where they replace more sedentary modes, such as private vehicles, this is not necessarily true in dense and compact cities like Barcelona. In these environments, short trips well-suited for e-scooters are often already served by active transport modes like walking and biking, making it less likely that e-scooters will offer significant advantages over existing options. This aligns with the findings of several studies that have consistently demonstrated e-scooters' tendency to replace walking trips (Christoforou et al., 2021; de Bortoli & Christoforou, 2020; Fearnley et al., 2020; James et al., 2019; Laa & Leth, 2020; Mitropoulos et al., 2023; Nikiforiadis et al., 2021; Reck et al., 2022).

Therefore, only by considering the modal replacement can we accurately assess the impact of these modes on public health. With active travel being a crucial source of

PA and having a substantial influence on health outcomes, such as cardiovascular health, weight management, mental health, cognitive function, and chronic diseases, policymakers should differentiate between active micromobility modes - bikes and e-bikes - and those that tend to be more sedentary than their most common alternatives - e-scooters. To maximize the public health benefits of promoting micromobility modes, it is crucial that a significant proportion of new micromobility users effectively replace car usage with e-scooter or bike sharing. Thus, policymakers can incentivize the adoption of these micromobility modes by investing in infrastructure, such as bike lanes and parking, and creating a regulatory framework that supports bike and e-bike sharing programs. Education and outreach campaigns can also encourage the public to replace car usage with micromobility modes. By taking these policy actions, cities and municipalities can create a supportive environment that makes it easier for individuals to adopt micromobility modes, leading to improved public health outcomes and reduced risk of chronic diseases.

5.2.4.1. Limitations

This study is subject to certain limitations that must be acknowledged. Firstly, the sample size utilized in the analysis is limited and may be subject to bias, as those who agreed to participate may not represent the average adult population in terms of their general health conditions and PA levels. Second, the classification of trips according to the mode(s) of transport employed was based on self-reported data from travel diaries, which may be less reliable than objective identification. Similarly, BMI scores were calculated using self-reported height and weight data. Thirdly, it is important to exercise caution when interpreting the results of the multivariate models presented, as they have been standardized on a per-minute basis, and thus, the theoretical differences may not align with the actual daily usage patterns of these modes of transportation. Nonetheless, accurately assessing the total energy expenditure per minute of each mode is still valuable as it provides the capability to construct hypothetical scenarios based on possible alterations to current mobility practices. Fourthly, several factors differentiate private and shared micromobility modes, potentially affecting their usage patterns and, consequently, their associated PA levels. In the context of Barcelona, there may be potential variations in trip characteristics, particularly distance, influenced by factors such as the distribution of Bicing stations in the case of the public bicycle system. Unlike privately-owned e-scooter trips, which are often door-to-door and may encompass the entire trip, trips made using Bicing are conditioned by the availability and location of Bicing stations. Likewise, we acknowledge that trips involving Bicing may inherently provide users with additional PA due to walking to and from the stations. To account for these variations, control variables were incorporated into the analysis. However, it is important to recognise that these differences between private and shared modes introduce complexity into the analysis, and the study's findings should be interpreted within this specific urban context. And, finally, it is worth noting that hip-worn accelerometers may not be as accurate as other methods when assessing PA specifically related to cycling or electric scooter use, as these activities involve complex body movements that may not be captured as effectively by a device worn on the hip. For assessing PA associated with cycling, thigh-worn accelerometers may provide a more accurate measurement of PA. However, these devices may be less effective at measuring other types of PA, such as e-scootering. Although hip-worn accelerometers have wide-ranging applicability, easy data processing, cost-effectiveness, and accessibility, as indicated by other transport and health studies (Brondeel et al., 2015; Kerr et al., 2016; Voss et al., 2016), their limitations in assessing PA related to micromobility use must be acknowledged and considered as an opportunity for further research advancement in this field.

To enhance comprehension of the subject matter, future investigations should employ larger participant cohorts to bolster the veracity of the results. Moreover, it is vital to acknowledge that innovative research endeavours in these domains can broaden the horizons of knowledge and contribute to the formulation of more precise and effective measurement instruments in the future. Lastly, further studies ought to be conducted in other urban and semi-urban regions where micromobility is gaining prominence in modal share, to validate the conclusions suggested in this investigation.

5.2.5. Conclusions

The goal of the present study was to assess the level of PA related to different modes of micromobility in Barcelona, considering both real-world scenarios and traffic-adjusted conditions. The study used GPS and accelerometer devices to obtain objective measurements from 502 trips taken, including 128 trips taken by electric scooter users, 308 trips taken by conventional shared bike users, and 66 trips taken by electric shared bike users.

The analysis suggests the presence of potential differences among various modes of micromobility used in the city of Barcelona and the associated PA levels. Shared bicycles and electric bicycles are associated with higher MET values, while the use of electric scooters cannot be regarded as an active mode of transportation, as e-scooter users accumulate fewer METs per trip. By stratifying results using different measurements including real-world conditions and active-only portions of the trips we are also able to understand how these PA values will translate in other geographic contexts or under different driving conditions. The study highlights the significant impact that the mode of transportation can have on PA levels, with biking offering the greatest potential for increasing trip METs. Overall, results reinforce the idea that not all micromobility modes should be treated equally when addressing public health expected outcomes, as our models clearly define conventional bikes and electric bikes as net generators of PA. Micromobility management policies should thus differentiate between modes to avoid unexpected negative outcomes. However, it is important to acknowledge that our findings should be interpreted with caution due to the limitations imposed by our sample size. While our results provide preliminary insights into potential disparities there is need for further research with larger and more representative samples to draw more definitive conclusions regarding PA levels across different micromobility modes.

PART III. DISCUSSION AND CONCLUSION

6. Discussion

6.1. Discussion of the main findings

The primary findings derived from the analysis included in this dissertation (a literature review and two empirical studies) are synthesized in this section. Its purpose is to provide a comprehensive overview of the outcomes in relation to the research questions and associated hypotheses described in Section 1.

H0: The use of EMM significantly influences the level of daily PA of Barcelona adults, across the different EMM modes, which can have direct effects on individual's health.

The main objective of this thesis was to examine and comprehend the impact of EMM usage on PA and its varying effects depending on the chosen mode of micromobility, ultimately affecting individuals' health. This overarching proposition finds support in the diverse array of studies conducted within this dissertation. While the systematic literature review does not directly confirm the main hypothesis (H0) through empirical findings, it underscores the crucial role of PA (and its consequent impacts on health and well-being) in individuals' decisions to adopt or utilize EMM. Furthermore, the two empirical studies illustrated the potential influence of EMM usage on individuals' daily PA and revealed significant disparities among micromobility modes.

In order to support these general findings, the following paragraphs aim to delve into each specific hypothesis, culminating in a collective conclusion regarding the interplay of EMM and PA.

H1: The potential for PA is perceived by individuals as a positive sociopsychological factor when deciding to adopt and use EMM. Therefore, this provision of exercise is an important determinant of travel behaviour.

Findings from the systematic literature review showed that the notion that EMM could have positive implications for individual health emerged as a driving factor behind its adoption. In the articles reviewed, EMM (mainly e-bikes) are perceived by individuals as providers of PA, expressing their desire to maintain or enhance their current levels of PA through their usage, making these mobilities an appealing modal choice (Andersson et al., 2021; Bieliński et al., 2021; Johnson & Rose, 2013; Jones et al., 2016; Kaplan et al., 2018; Kwiatkowski et al., 2021; Ling et al., 2017; Melia & Bartle, 2021; Plazier et al., 2017; Popovich et al., 2014; Simsekoglu & Klöckner, 2019; Thomas, 2021; Washington et al., 2018). Moreover, the studies found that EMM was considered a valuable tool for promoting health and mitigating concerns related to physical inactivity. One collective that showed especial interest on using EMM (mainly the e-bike) was older people, as adopting an EMM vehicle may enable them to maintain an active lifestyle when they might otherwise struggle (Haustein & Møller, 2016; Popovich et al., 2014). However, this perception of the health benefits offered by EMM often hinges on the mode of transportation being replaced; for example, e-bikes are perceived to have a more significant impact on PA when replacing sedentary modes of commuting such as cars or buses (Edge et al., 2018). Therefore, only switching from the most sedentary modes to EMM can result in heightened levels of PA related to transportation, thereby potentially improving overall health (Berntsen et al., 2017; Castro et al., 2019; Glenn et al., 2020; Sanders et al., 2022). In fact, in comparison to the traditional active modes (i.e., walking and cycling), EMM users may need to travel longer distances or use them more frequently to attain comparable health benefits in terms of PA. Another important aspect repeatedly mentioned in the literature review related to PA and health is the perception of EMM as enjoyable. A fun and thrilling trip can encourage individuals to engage in PA as part of their daily travel routines, while having a positive impact on their mood, level of stress and mental health (Avila-Palencia et al., 2018; Leyland et al., 2019; Milakis et al., 2020).

From a different perspective, as suggested by my own scoping review (Bretones et al., 2023), EMM is not only perceived as a potential provider of daily PA, but it also offers the advantage of engaging in PA without causing excessive fatigue, particularly beneficial during uphill rides. In the same line, EMM potentially diminishes sweating and the need for post-ride showers, e-bike users for instance valuing being able to cover longer distances and ride faster while avoiding this particular drawback of conventional cycling (Cairns et al., 2017; Fyhri et al., 2017; Kroesen, 2017). In fact, for many individuals, especially those living in urban areas with limited parking and congested traffic, biking to work offers a practical alternative to driving or taking public transportation. However, concerns about arriving at work sweaty and needing to freshen up can be a significant deterrent to choosing biking as a commuting option, EMM, therefore, addressing this concern directly (Jahre et al., 2019). Moreover, not only older adults are attracted to e-bikes, but e-bikes are also particularly appealing to groups with lower levels of PA or no interest in conventional biking. The appeal of e-bikes to individuals with lower levels of PA highlights their potential to promote exercise among those less inclined towards traditional forms of physical exertion. E-bikes offer a low-impact, accessible option for increasing activity levels, particularly beneficial for individuals facing barriers such as age, fitness, or health concerns (Langford et al., 2017; Mildestvedt et al., 2020). Then, EMM, in general, can motivate a shift towards more inclusive and flexible transportation options, accommodating diverse preferences and lifestyles.

Regarding individuals facing health concerns, EMM provides mobility options for users with physical limitations (Popovich et al., 2014). EMM offers a range of features and adaptations that cater to users with various physical limitations, such as mobility impairments or chronic health conditions. For example, e-bikes can provide electric assistance to users who may have difficulty pedalling due to muscle weakness or joint pain, allowing them to travel longer distances or navigate hilly terrain with greater ease. Similarly, e-scooters offer a convenient and efficient mode of transportation for individuals who may struggle with walking long distances or standing for extended periods. Moreover, the availability of shared EMM services in urban areas ensures that individuals with physical limitations have access to affordable and flexible transportation options, regardless of their ability to own or operate a personal vehicle. This can significantly enhance their mobility and independence, enabling them to participate more fully in daily activities, such as commuting to work, running errands, or socializing with friends and family. However, without modifications, these transportation options typically demand active user involvement, including using legs to embark and disembark from the vehicle and maintaining balance, while necessitating perceptual alertness and responsiveness to traffic conditions, along with leg engagement for stability or propulsion. Then, those with physical, visual, or multiple disabilities may encounter barriers due to disparities between vehicle design and user requirements (Dill & McNeil, 2021; Goralzik et al., 2022).

Finally, and compared to traditional active transport modes, EMM is perceived as more suitable for daily use, especially when individuals are physically tired, dressed formally, or carrying personal belongings. EMM provides a convenient and flexible transportation option for individuals who may be physically tired after a long day at work or school. Unlike walking or traditional biking, which can require significant physical exertion, EMM devices such as e-scooters or e-bikes offer electric assistance that reduces the effort needed for travel. Also, EMM is well-suited for individuals who need to maintain a formal appearance throughout the day. EMM devices can be used while wearing formal attire without the risk of getting sweaty or dishevelled. This makes EMM an attractive option for professionals commuting to work or attending meetings, as well as for individuals traveling to social events or gatherings where appearances matter. Furthermore, EMM is ideal for individuals carrying personal belongings or shopping items. Some EMM devices are equipped with storage compartments or accessories such as baskets or racks, making it easy to transport bags, backpacks, or other items while traveling, enhancing convenience and practicality for users.

In conclusion, the exploration of EMM's impact on health and PA underscores its potential as a positive contributor to individual well-being. The literature reveals that individuals perceive EMM, particularly e-bikes, as a means to maintain or enhance PA levels, thereby making it an attractive mode of transport. However, the realization of health benefits hinges on the mode of transportation being replaced, highlighting the importance of transitioning from sedentary modes to EMM to achieve heightened levels of PA. Additionally, the enjoyable and stress-reducing aspects of EMM contribute to its appeal, positively impacting mood and mental health. From a practical standpoint, EMM offers advantages such as reduced fatigue and sweating, making it accessible to various user groups, including those with physical limitations. Overall, these findings underscore the multifaceted benefits of EMM in promoting health and PA across diverse populations.

While the systematic literature review did not provide direct support for H1 through its findings, the evidence presented aligns with H1 by demonstrating that the perceived potential for PA plays a significant role in individuals' decision-making regarding the adoption and use of EMM.

H2: The different micromobility modes (shared bike, shared e-bike, private es-cooter) are associated to different levels of daily and trip-related PA. Specifically, the levels

of PA, associated with biking and e-biking are anticipated to be higher than those linked to e-scooter usage.

In the realm of PA, existing research predominantly focused on e-bike utilization, revealing MET values typically ranging from 4 to 7 METs (Alessio et al., 2021; Bini & Bini, 2020; Bourne et al., 2018), aligning with moderate-to-vigorous intensity PA standards outlined by the WHO, implying that regular e-cycling could meet PA guidelines and contribute to overall health enhancement (Bernstein & McNally, 2017; De Geus & Hendriksen, 2015; Hoj et al., 2018; Langford et al., 2017; World Health Organization, 2020). Contrarily, there remains a shortage of research on the PA levels linked to e-scooter use, the debate surrounding around both the specific PA derived from e-scooter usage and how this PA might replace the activity gained from the mode of transportation used prior to switching to an e-scooter (Sanders et al., 2022). Some e-scooter operators argue that e-scooters offer a low-intensity workout that can enhance core strength and engage leg muscles and a study utilizing objective PA data found a potential increase in PA resulting from standing compared to sitting while using a car or public transport (Glenn et al., 2020). However, research on travel behaviour and mode shifts indicates that e-scooters are rarely replacing car usage and are actually supplanting active travel modes. Therefore, the first empirical study (see Section 5.1.) sought to investigate the relationships between the transportation modes utilized by micromobility users for their daily trips and the duration of various PA intensities in Barcelona. It employed accelerometer assessments to measure MVPA, light, and sedentary PA, in conjunction with self-reported data on daily mode of EMM.

The findings revealed disparities in the daily levels of PA among users of shared bikes, shared e-bikes, and e-scooters. While shared bikes and e-bikes allocate approximately 10% of their daily time to MVPA, e-scooters only account for an average of 7%. Besides, the PA obtained on days when e-scooters were used was notably lower than that of users employing other micromobility devices, and only marginally higher (in terms of light PA) than that of the control group comprising non-micromobility users. E-scooter usage correlated with diminished levels of higher intensity PA but also reduced sedentary behaviour. This result strongly indicates that e-scooter users spend more time engaging in PA, albeit in less vigorous activity compared to other modes. In contrast, shared bikes and shared e-bikes exhibited more vigorous PA patterns but fewer total daily minutes of activity (MVPA + light), resulting in more sedentary time. One possible explanation for these findings is that individuals using e-scooters inherently tend to be more active. E-scooters require users to actively balance and propel themselves, which may contribute to increased physical exertion compared to passive modes of transportation, such as riding in a car or using public transit. As a result, even though the intensity of PA may be lower, the cumulative time spent engaging in physical activity may be higher for e-scooter users. On the other hand, users of bikes may exhibit more vigorous PA patterns during their rides, possibly due to the higher physical demands associated with pedalling or navigating urban terrain on traditional bicycles. However, the total duration of their PA may be limited by factors such as trip distance, route conditions, or user preferences, leading to more sedentary time outside of their active commuting or recreational biking sessions. Additionally, differences in user demographics, trip purposes, or environmental factors between micromobility users may also influence PA patterns and sedentary behaviour. Further research is needed to explore these factors and better understand the complex relationship between transportation mode choice, PA levels, and sedentary behaviour in urban environments.

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. For instance, using more advanced accelerometers or positioning them in closer proximity to the lower limbs may enhance the sensitivity and specificity of PA measurements during e-biking. This could provide a more accurate representation of the physical exertion exerted by individuals. However, such approaches may also entail greater invasiveness and discomfort for users, as they may require wearing additional sensors or placing them in locations that are more intrusive or restrictive. Increasing the complexity or invasiveness of measurement methods may compromise participant compliance and acceptance, leading to higher rates of dropout or non-adherence in research studies. Therefore, while it is important to explore alternative measurement approaches and to test the sensitivity capacity of accelerometers with respect to accurately detecting PA while e-biking, researchers must carefully consider the balance between precision and practicality.

In terms of trip-related PA, the findings from the second empirical study provide valuable insights into the PA levels associated with micromobility trips under real-world and traffic-adjusted conditions. The comparison of MET values across the different modes highlights the varying levels of PA required during these trips. Notably, conventional bikes exhibited the highest MET values, indicating that biking typically involves the highest levels of physical exertion among micromobility options. This aligns with the well-established notion that biking is a highly active mode of transportation, requiring significant effort from the rider. In contrast, e-scooters demonstrated the lowest MET values, suggesting that they involve less PA compared to biking. This aligns with the findings of Sanders et al. (2022), which indicated that e-scooter trips were comparable in activity level to auto trips. These findings are particularly interesting in light of the growing popularity of e-scooters as a convenient and accessible mode of urban transportation. While e-scooters offer advantages such as ease of use and flexibility, their lower PA levels may have implications for public health, especially in promoting active lifestyles and reducing sedentary behaviour.

Furthermore, the observed increase of nearly 51% in Total METs when using a conventional bike compared to an e-scooter under real-world conditions underscores the substantial differences in PA between these modes. This suggests that individuals who choose biking over e-scooters may experience significantly higher levels of physical exertion, potentially leading to greater health benefits. When considering only the active phases of the trip, the disparity between biking and e-scooter usage becomes even more pronounced, with total METs from a bike trip nearly doubling those generated by e-scooter usage. This highlights the importance of accounting for the entire trip duration and differentiating between active and sedentary phases when evaluating PA levels associated with different transportation modes. Additionally, the analysis reveals that a minute of riding a conventional bike is associated with 28% more PA than a minute of riding an e-scooter. This emphasizes the significant differences in PA intensity between these modes, with biking requiring substantially more physical effort compared to e-scooters. Conversely, the difference in PA per minute between e-bikes and e-scooters is smaller, with only a slight decrease of 1.4%.

This suggests that while e-bikes offer some level of electric assistance, they still provide a comparable level of PA to e-scooters, albeit with slightly reduced intensity.

Finally, regarding the generation of PA levels during trips, the analysis underscores a distinct contrast between journeys. E-scooter trips exhibit intermittent peaks of PA interspersed with prolonged sedentary periods, whereas cycling trips display a more consistent distribution of PA throughout the journey, lacking significant fluctuations in intensity. While both modes may result in comparable overall PA levels per trip, the evenly distributed PA observed in cycling trips is likely to offer superior cardiovascular and metabolic benefits (Garber et al., 2011; Holtermann et al., 2018).

Apart from the purely objective measures of PA studied, in exploring micromobility PA, it is also crucial to recognize the diverse travel patterns associated with the different micromobility modes regarding distance and frequency of use. The findings indicate that, on average, e-scooter trips cover shorter distances (1.96 km) compared to other micromobility modes (2.28 km), as supported by prior research (Liao & Correia, 2022; Reck et al., 2021). This association between e-scooters and shorter trips can be attributed to two main factors: (1) the characteristics of Barcelona's built environment, which favour short-distance travel (Marquet & Miralles-Guasch, 2015), and (2) the synergy between e-scooter usage and walking, as both modes serve similar travel distances, with Reck et al. (2022) illustrating how e-scooters tend to substitute a notably higher number of walking trips compared to e-bikes, for instance.

Overall, the findings presented trough both empirical studies provide robust evidence to support hypothesis H2, demonstrating that different micromobility modes indeed have varying associations with daily and trip-related PA levels. Biking and e-biking modes emerge as more active forms of transportation compared to e-scooter usage, highlighting the importance of promoting cycling modes to encourage higher levels of PA and contribute to overall health enhancement. Actually, the concerning aspect of the low PA levels linked to e-scooter usage is intensified by the trend observed in cities like Barcelona, where a significant portion of new e-scooter users transition from walking, effectively exchanging an active mode of transportation for a more sedentary alternative (Christoforou et al., 2021; de Bortoli & Christoforou, 2020; Fearnley et al., 2020; Felipe-Falgas et al., 2022; James et al., 2019; Laa & Leth, 2020; Mitropoulos et al., 2023; Nikiforiadis et al., 2021; Reck et al., 2022; Roig-Costa et al., 2021), potentially leading to detrimental impacts on public health and well-being. By prioritizing cycling modes over e-scooter usage, urban planners and policymakers can play a pivotal role in promoting active lifestyles and reducing sedentary behaviour. Strategies to incentivize cycling can help create environments that support and encourage active transportation choices. Furthermore, raising awareness about the health benefits of cycling and the potential risks associated with prolonged sedentary behaviour linked to e-scooter usage is crucial. Therefore, there is a need for comprehensive approaches to urban mobility planning that prioritize active transportation modes and promote environments conducive to PA. By fostering a culture of active mobility, cities can not only improve public health outcomes but also enhance the liveability, sustainability, and resilience of urban communities.

H3: Micromobility users present higher levels of daily PA than non-users. The hypothesis is grounded in the assumption that individuals engaging in micromobility are more likely to incorporate regular PA into their daily routines, mainly resulting from the active involvement required by these modes. This would be particularly true in the case of using the bike or e-bike, but with less impact when using the e-scooter.

Building upon the findings discussed earlier, which highlight the varying levels of PA associated with different EMM vehicles, it becomes imperative to contextualize these results by comparing them with individuals who do not use these devices. This comparison allows for a comprehensive understanding of the impact of EMM on PA levels within the broader context of urban mobility. By contrasting the PA levels of EMM users with those of non-users, researchers and policymakers can discern whether EMM adoption leads to notable differences in daily activity patterns.

Consequently, in the first empirical study, to provide this basis for comparison, a control group comprising 43 individuals who did not utilize any micromobility mode was established and analysed together with the rest of individuals defining themselves as regular micromobility users. These individuals forming the control group relied on alternative modes of transportation for their daily travel needs, including active modes, public transport, and private transport. From this perspective, the findings indicate that, overall, micromobility users exhibit higher activity levels compared to the control group, even after accounting for individual sociodemographic characteristics. The low average levels of MVPA observed in the control group mirrored those recorded on days when e-scooters were used (both accounting for 7% of the time). However, in the case of the control group, a greater proportion of time was dedicated to sedentary activities (69% versus a 65% for e-scooters). The differences were even higher when compared to the most active micromobility modes (bikes and e-bikes).

Indeed, when conducting the model estimates, these results were confirmed, as the control group exhibits the lowest daily percentage of time spent on MVPA (an 8% as compared to the highest 13% by shared e-bikes), and the highest amount of time spent on sedentary behaviour (almost 69% as compared to other EMM modes ranging between 65-67%). Moreover, emphasize that in terms of PA, the control group showed more similarities with the e-scooter users, proving part of the third hypothesis.

Briefly, the comparison between micromobility users and a control group comprising individuals who did not utilize any micromobility mode revealed notable differences in activity levels. Despite controlling for individual sociodemographic characteristics, micromobility users consistently exhibited higher levels of PA compared to the control group. The low levels of MVPA observed in the control group closely resembled those recorded on days when e-scooters were used, although the control group spent a greater proportion of time in sedentary activities. These results support the notion that micromobility modes, particularly bikes and e-bikes, contribute to higher levels of PA compared to traditional modes of transportation, such as private vehicles or public transport. Additionally, the similarities observed between the control group and e-scooter users underscore the importance of considering the impact of different transportation modes on overall PA levels. Hence, the empirical evidence supports the confirmation of hypothesis H3, indicating that micromobility users indeed present higher levels of daily PA than non-users.

H4: The utilization of shared bikes and e-bikes demonstrates a higher adherence to the physical activity recommendations outlined by the WHO compared to other modes.

The WHO recommends a minimum of 150–300 minutes per week of moderate-intensity PA or 75–150 minutes of vigorous-intensity activity for significant health benefits (World Health Organization, 2020). However, research indicates that globally, 23% of adults fail to meet these recommendations (World Health Organization, 2013), leading primarily sedentary lifestyles during their waking hours.

Daily PA in its various forms offers numerous health benefits, with some attributed to activity during travel. According to global guidelines and to the evidence provided by previous research and in this dissertation, cycling and e-cycling can be classified as MVPA activities, suggesting that regular participation in this activity could lead to compliance with PA recommendations and contribute to maintaining and enhancing overall health (Bernstein & McNally, 2017; De Geus & Hendriksen, 2015; Hoj et al., 2018; Langford et al., 2017). In contrast, e-scooters present lower levels of MVPA, more similar than those of automobile usage, therefore potentially not being a source of sufficient PA to comply with the WHO guidelines.

Thus, through the first empirical study, significant insights into the actual impact of both micromobility and non-micromobility users on population PA were provided, alongside an assessment of the probability of each user group meeting PA health guidelines and recommendations. The findings revealed a correlation between utilizing a micromobility mode during the day and meeting the WHO PA health guidelines. Setting the reference at the minimum requirement of 30 minutes of MVPA daily, over 90% of days when conventional bikes and electric bikes were utilized met this activity target. Additionally, when users combined different micromobility modes throughout the day, particularly between conventional and electric bikes, they also achieved compliance with these guidelines in over 90% of the days. However, the utilization of electric scooters yielded notably lower compliance rates, with fewer than 60% of days meeting the MVPA target. This stark difference underscores the varying effectiveness of micromobility modes in promoting adherence to WHO PA guidelines, with shared bikes and e-bikes demonstrating superior performance compared to electric scooters.

Indeed, bike usage demonstrated the highest compliance rates not only when compared to users of other modes (non-micromobility) but also when regular micromobility users did not utilize a micromobility mode on a specific day. The compliance rates were 65% and 76%, respectively.

In summary, these results shed light on the crucial role of micromobility modes, particularly shared bikes, and e-bikes, in promoting adherence to WHO physical activity guidelines. While cycling and e-cycling activities align well with MVPA activity recommendations, e-scooters fall short in providing sufficient activity levels to meet these guidelines. These findings underscore the significance of integrating active modes of transportation into daily routines to attain optimal health benefits.

Notably, shared bikes and e-bikes exhibit superior performance in promoting adherence to WHO PA guidelines compared to other modes, thus corroborating the validity of hypothesis H4.

6.2. General conclusion

The findings presented in this dissertation provide comprehensive insights into the impact of micromobility modes on PA levels and their implications for individual health. Through a combination of literature review and empirical studies, several key conclusions can be drawn.

EMM, particularly electric bikes, emerge as significant contributors to increased PA levels among Barcelona adults, with the adoption and usage of micromobility modes perceived as positive contributors to individual well-being, with individuals expressing a desire to maintain or enhance PA levels through their utilization. Notably, older adults and those seeking alternatives to sedentary commuting modes show particular interest in micromobility, highlighting its potential to promote active lifestyles across diverse populations.

Comparative studies reveal that shared bikes and e-bikes consistently lead to higher daily and trip-related PA levels than e-scooters, positioning them as more effective in adhering to WHO PA guidelines. These findings bear significant implications for policymakers and transport planners, especially concerning initiatives integrating health and PA criteria. It is evident that the choice of transportation mode strongly influences PA levels, with conventional and electric bikes emerging as the only clearly identified active micromobility modes. Therefore, despite the growing popularity of e-scooter use globally, these findings suggest that cities should prioritize promoting modal shifts toward biking and e-biking. Transport planners must recognize that shifts towards increased e-scooter use will only yield a net health benefit when they replace the most sedentary modes of transport, such as cars. Any transition from walking or biking to e-scootering will result in a net loss in terms of PA.

Furthermore, micromobility users, especially those utilizing bikes and e-bikes, exhibit higher levels of daily PA compared to non-users, underscoring the value of promoting these active transport modes. This reinforces the notion that not all micromobility modes should be treated equally in efforts to achieve public health outcomes. Conventional bikes and electric bikes emerge as clear generators of PA. Consequently, micromobility management policies should differentiate between modes to avoid unexpected negative outcomes.

In conclusion, the integration of active modes of transportation, particularly shared bikes, and e-bikes, into daily routines has the potential to promote adherence to PA guidelines and contribute to overall health enhancement. These findings emphasize the importance of promoting cycling modes as a means of encouraging active lifestyles and mitigating the adverse health effects of sedentary behaviour. Certainly, travel behaviour, including modal choice and the resultant PA, profoundly impacts health outcomes such as cardiovascular health, weight management, mental health, cognitive function, and chronic diseases (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 & Wild, 2020). While ample research supports the notion that promoting active travel can effectively enhance public health and reduce the risk of chronic disease, promoting micromobility modes can only be expected to yield similar benefits when a significant portion of new micromobility users effectively replace car use with e-scooters or bike sharing. Therefore, strategic urban mobility planning is essential to harness the potential of micromobility for improving public health outcomes.

7. Final reflections

7.1. Strengths and limitations

The three studies included in this thesis encompass distinct strengths and limitations, which are important to acknowledge for a comprehensive understanding of the findings and their interpretations. This section aims to underscore these aspects before identifying future research directions.

7.1.1. Strengths

This dissertation started with a thorough literature review, which provided a solid theoretical foundation for understanding what is behind the adoption intention and usage of EMM, and to comprehend if the potential of PA provision and health-related benefits are valued by individuals when deciding to incorporate these modes into their daily travel routines. This demonstrates a thorough grasp of the existing research landscape and helps contextualize the empirical findings presented afterwards. The literature review covers a wide range of studies and acknowledges the importance of sociopsychological factors in influencing EMM adoption and usage, a holistic approach providing valuable insights into the multifaceted motivations behind individuals' travel choices. Moreover, by emphasizing the role of this factors, the review goes beyond the traditional functional considerations, such as cost and convenience, to explore the influence of other aspects like personal values and attitudes. This integration enhances the understanding of human behaviour in the context of transportation decisions.

Focusing the research specifically on EMM offers several strengths that contribute to a deeper understanding of this emerging trend in urban transportation. By narrowing the scope to EMM, the research enables a targeted analysis of this specific group's behaviours, characteristics, and impacts, providing valuable insights that may not be fully captured in other studies. This approach is particularly relevant given the growing significance of EMM in urban mobility systems and its potential to reshape travel patterns, environmental sustainability, and public health. Furthermore, the research's policy relevance is enhanced as it can inform the development of tailored policies and infrastructure to support EMM and maximize its benefits. Additionally, by conducting comparative analyses between electric and non-electric micromobility users, the research can elucidate the relative advantages and challenges associated, contributing to a more nuanced understanding of its role within the broader urban transportation landscape. Overall, focusing on EMM not only enriches the understanding of this specific group but also provides insights with broader implications for micromobility trends, behaviour change, and urban mobility planning in diverse contexts.

In order to explore the associations between EMM and daily and trip-related PA, this dissertation employed a combination of methods for data collection, incorporating both objective measures, such as accelerometery-based assessments, and self-reported data, gathered through questionnaires. By combining these methods, the research captured a more complete understanding of this relationship. Moreover, accelerometers offer a reliable and validated method for objectively measuring PA. By using accelerometers, it is possible to obtain accurate and detailed information about individuals' activity levels over time, minimizing potential biases associated with self-reporting PA and then providing robust data for analysing PA patterns. Further, this accelerometer data was combined with GPS measurements, which offers numerous benefits in terms of trip analysis. This approach ensures accuracy by providing precise location information from GPS alongside detailed measurements of movement intensity from accelerometers, facilitating an in-depth understanding of activity patterns during travel. Additionally, GPS data contextualizes accelerometer findings by considering environmental factors like terrain and traffic conditions, enhancing the interpretation of physical activity levels.

Focusing on the specific context of Barcelona in relation to the use of EMM offers a multifaceted lens through which to examine the intersection of urban mobility, PA, and public health. Barcelona stands out as an ideal setting for such research due to its diverse urban landscape, robust transportation infrastructure, and rich cultural fabric, all of which exert significant influences on travel behaviour within the city. Notably, Barcelona boasts a well-established bike-sharing system that encompasses both conventional bicycles and electric bikes, providing a comprehensive framework for exploring the dynamics of micromobility adoption and usage patterns. Additionally, the city is witnessing a notable surge in the use of privately-owned e-scooters, further enriching the micromobility landscape and presenting a unique opportunity to study the interplay between various EMM modalities. The empirical evidence presented in this dissertation, therefore, not only contributes to the academic understanding of urban mobility dynamics but also offers tangible implications for urban planners and policymakers tasked with shaping sustainable transportation strategies. Moreover, studying EMM in the context of Barcelona provides a nuanced understanding of how these modes influence PA levels and public health outcomes within an evolving urban landscape. Overall, the study of EMM in Barcelona serves as a microcosm of broader urban mobility trends, offering valuable lessons and actionable recommendations for cities worldwide seeking to navigate the complex terrain of sustainable transportation and active living initiatives.

At last, an additional strength of this research lies in the efficiency of the data collection process. The dissertation benefited from the fact that a significant portion of the data had already been collected prior to the commencement of the study, as it was part of the NewMob Project. This pre-existing data pool minimized the time and resources required for data acquisition, allowing for a more streamlined and expedited research process. By leveraging existing datasets, the study was able to focus more intently on data analysis, interpretation, and drawing robust conclusions, thereby maximizing the research's productivity and effectiveness.

7.1.2. Limitations

Once the strengths of this dissertation are mentioned, it is even more important to discuss its limitations as a comprehensive understanding of these limitations is crucial for accurately interpreting the findings and pinpointing areas for future research and enhancement.

In terms of the literature review, it is important to acknowledge certain limitations that may impact the interpretation and generalizability of the findings. Firstly, the review's scope was limited to academic publications so it did not extend to grey sources such as communication and social media publications, which could have provided additional relevant information, particularly concerning the latest developments in EMM. Incorporating these sources may have enriched the review's breadth and depth, offering a more comprehensive understanding of current trends and perspectives. Secondly, the search for literature was limited to English language publications, potentially excluding relevant research published in other languages. This may lead to a biased representation of the existing literature, particularly if studies conducted in non-English-speaking countries have different findings or perspectives. Thirdly, a notable proportion of the reviewed studies were conducted in European countries, followed by the United States, Canada, and the United Kingdom. This geographic concentration may introduce bias into the observed trends, potentially overlooking unique dynamics and challenges in other regions where EMM adoption and usage may differ significantly. Lastly, the data extraction process employed in the review may introduce biases, as some studies utilized multiple analyses, but only the overarching results aligned with the research focus were selected and summarized. This selective approach could potentially overlook nuanced findings or variations within individual studies, influencing the overall conclusions drawn from the review.

Regarding the empirical studies, the sample size utilized for each analysis was relatively small, potentially introducing bias as participants who agreed to participate may not represent the broader adult population in terms of their general health conditions and PA levels. Consequently, there is a risk of overestimating adherence to PA recommendations. Additionally, the number of valid accelerometer wear days reported was lower than anticipated, reducing the available data for analysis.

For the aims of the first study, PA levels were assessed over the entire duration of accelerometer wear time, rather than solely during trips. While participants were instructed to wear the device throughout the day except during sleep, contact sports/exercise, or water-related activities, this approach may not accurately capture activity specifically related to travel mode usage. Instead, reported PA levels reflect daily activity patterns influenced by various factors, including the mode of travel on a given day. Besides, self-reported data from travel diaries were used to classify days based on the mode(s) of transportation utilized, which may introduce inaccuracies compared to objective identification methods. Similarly, BMI scores were calculated using self-reported height and weight data, which may be less precise than objective measurements.

As for the second study, it is important to approach the interpretation of the multivariate models with caution, as they have been standardized on a per-minute basis, which may not fully correspond to actual daily usage patterns of transportation modes. However, the assessment of total energy expenditure per minute for each mode remains valuable for constructing hypothetical scenarios and exploring potential changes in current mobility practices. Furthermore, it is essential to acknowledge the disparities between private and shared micromobility modes, as they can significantly influence usage patterns and associated levels of PA. In the specific context of Barcelona, variations in trip characteristics, particularly distance, may be influenced by factors such as the distribution of Bicing stations in the case of the public bicycle system. Unlike privately-owned e-scooter trips, which often involve direct travel from point to point, trips made using Bicing are influenced by station availability and location, potentially impacting PA levels due to walking to and from stations. While efforts were made to address these variations through control variables in the analysis, the distinctions between private and shared modes introduce complexity and should be taken into consideration when interpreting the study's findings within the urban context of Barcelona.

The utilization of accelerometer and GPS tracking data introduces the potential for several biases that should be considered. The awareness of being monitored may induce participants to modify their behaviour, potentially resulting in increased activity levels or altered travel patterns, a phenomenon known as measurement reactivity. Furthermore, hip-worn accelerometers were employed as instructed to participants, potentially limiting their accuracy in assessing PA associated with cycling or electric scooter use. While hip-worn accelerometers offer advantages in terms of applicability, ease of data processing, cost-effectiveness, and accessibility, they may not capture the complex movements associated with cycling as accurately as thigh-worn accelerometers. However, hip-worn accelerometers may still provide a more accurate measurement of PA compared to waist-worn accelerometers, particularly considering their proximity to the body's centre of mass. Overall, while acknowledging the limitations of hip-worn accelerometers in assessing PA associated with micromobility use, they remain a valuable tool for evaluating daily and trip-related PA.

Lastly, another potential limitation of the dissertation lies in the generalizability of its findings beyond the specific context of Barcelona. While the study offers valuable insights into the relationship between micromobility modes and PA levels within this urban environment, it may not fully capture the complexities of micromobility usage and its impact on PA in different cities or regions with varying infrastructural, cultural, and socioeconomic characteristics. Factors such as urban layout, transportation infrastructure, cultural norms, and climate can significantly influence individuals' mode choices and activity levels. Therefore, caution should be exercised when extrapolating the findings to other settings, and further research conducted in diverse geographic contexts is necessary to validate and contextualize the conclusions drawn from the study.

7.2. Future research

After thoroughly examining the strengths and limitations of the current research, it is essential to consider potential avenues for future research that can build upon these findings and address existing gaps in knowledge. By identifying opportunities for further investigation, researchers can contribute to the advancement of understanding in the field of micromobility and its impact on PA. In this section, we outline several promising directions for future research that could enhance our understanding of the complex interplay between micromobility modes and PA levels.

1. Longitudinal studies could be conducted to track individuals' PA patterns and mode choices over time, providing insights into the long-term effects of micromobility adoption on health outcomes. These longitudinal studies could also investigate how changes in infrastructure, policies, or socioeconomic factors influence micromobility usage and its impact on PA across different demographic groups.
2. Comparative studies across multiple cities or regions with diverse urban environments and micromobility infrastructures could elucidate the contextual factors influencing micromobility usage and its impact on PA. By examining variations in micromobility adoption rates, infrastructure accessibility, and cultural norms related to active transportation, researchers can identify best practices and policy recommendations tailored to specific urban contexts.
3. Qualitative research methods such as interviews or focus groups could complement quantitative analyses by capturing individuals' perceptions, motivations, and barriers related to micromobility adoption and PA engagement. Understanding the subjective experiences and preferences of micromobility users can inform the design of more effective interventions and public health campaigns aimed at promoting active transportation modes.
4. Intervention studies could be designed to assess the effectiveness of policy interventions or urban planning initiatives aimed at promoting active modes of transportation and enhancing population-level PA levels. These interventions could include measures such as expanding bike lanes, implementing bike-sharing programs, or providing incentives for micromobility usage. By evaluating the impact of these interventions on PA outcomes and mode choice behaviours, researchers can inform evidence-based policies to create more supportive environments for active living.
5. Future research should prioritize including larger sample sizes to enhance the generalizability and statistical power of findings. Larger sample sizes enable

researchers to detect smaller effect sizes and explore subgroup differences more effectively, providing more robust evidence for informing public health interventions and policies related to micromobility and PA.

6. Advancements in technology, such as wearable sensors or smartphone apps, present opportunities for innovative data collection methods and real-time monitoring of PA and travel behaviour. Integrating these technologies into research protocols allows for more comprehensive and accurate assessments of individuals' activity levels, travel patterns, and environmental exposures. Additionally, data from wearable sensors and smartphone apps can be linked with other sources, such as GPS data or environmental sensors, to examine complex interactions between built environment characteristics, transportation choices, and PA behaviours. By leveraging these technological advancements, researchers can generate novel insights and develop personalized interventions to promote active transportation and improve public health outcomes.

7.3. Policy implications

The findings of this dissertation have significant implications for policymakers and urban planners seeking to promote active transportation and enhance public health. Firstly, the prioritization of infrastructure investments to support micromobility modes, particularly biking and e-biking, could yield substantial benefits in terms of increasing PA levels and reducing reliance on sedentary modes of transport. This includes expanding dedicated bike lanes, improving bike-sharing schemes, and implementing policies to incentivize the use of electric bicycles, which have been identified as effective means of promoting active lifestyles. Secondly, policymakers should consider implementing measures to regulate and manage the use of electric scooters to mitigate potential negative impacts on PA. This may involve setting speed limits, designated parking areas, and safety regulations to ensure the safe integration of e-scooters into urban environments. Additionally, efforts to promote modal shifts away from private motorized modes such as cars and motorbikes towards micromobility modes should be prioritized, as this can lead to significant improvements in population-level PA and public health outcomes. Furthermore, public health campaigns and educational initiatives could raise awareness about the health benefits of active transportation and encourage individuals to incorporate biking and e-biking into their daily routines. By integrating these policy measures and interventions, cities can create more supportive environments for active living and contribute to the prevention of chronic diseases associated with sedentary lifestyles.

PART IV. REFERENCES AND ANNEXES

8. References

Abduljabbar, R. L., Liyanage, S., & Dia, H. (2021a). The role of micromobility in shaping sustainable cities: A systematic literature review. *Transportation Research Part D: Transport and Environment*, *92*, 102734. https://doi.org/10.1016/j.trd.2021.102734

Abouelela, M., Al Haddad, C., & Antoniou, C. (2021). Are young users willing to shift from carsharing to scooter-sharing? *Transportation Research Part D-Transport and Environment*, 95. https://doi.org/10.1016/j.trd.2021.102821

Adler, M. W., Peer, S., & Sinozic, T. (2019). Autonomous, connected, electric shared vehicles (ACES) and public finance: An explorative analysis. *Transportation Research Interdisciplinary Perspectives*, 2, 100038. https://doi.org/10.1016/J.TRIP.2019.100038

Ainsworth, B. E., Haskell, W. L., Herrmann, S. D., Meckes, N., Bassett, D. R. J., Tudor-Locke, C., Greer, J. L., Vezina, J., Whitt-Glover, M. C., & Leon, A. S. (2011). 2011 Compendium of Physical Activities: A Second Update of Codes and MET Values. *Medicine & Science in Sports & Exercise*, 43(8), 1575–1581. https://doi.org/10.1249/MSS.0b013e31821ece12

Ajzen, I. (1991). The theory of planned behavior. *Organizational Behavior and Human Decision Processes*, 50(2), 179–211.https://doi.org/10.1016/0749-5978(91)90020-T

Alamelu, R., Sivasundaram Anushan, C., & Selvabaskar, S. G. (2015). Preference of E-bike by women in India -a niche market for auto manufacturers. *Business: Theory and Practice*, 16(1), 25–30. https://doi.org/10.3846/btp.2015.431

Albalate, D., & Gragera, A. (2020). The impact of curbside parking regulations on car ownership. *Regional Science and Urban Economics*, 81, 103518. https://doi.org/10.1016/j.regsciurbeco.2020.103518

Aldred, R. (2019). Built Environment Interventions to Increase Active Travel: A Critical Review and Discussion. *Current Environmental Health Reports*, 6(4), 309–315. https://doi.org/10.1007/s40572-019-00254-4

Alessio, H. M., Reiman, T., Kemper, B., von Carlowitz, W., Bailer, A. J., & Timmerman, K. L. (2021). Metabolic and Cardiovascular Responses to a Simulated Commute on an E-Bike. *Translational Journal of The American College of Sports Medicine*, 6(2). http://doi.org/10.1249/TJX.0000000000000155

Allahbakhshi, H., Conrow, L., Naimi, B., & Weibel, R. (2020). Using Accelerometer and GPS Data for Real-Life Physical Activity Type Detection. *Sensors*, 20(3), Article 3. https://doi.org/10.3390/s20030588

Allahbakhshi, H., Hinrichs, T., Huang, H., & Weibel, R. (2019). The Key Factors in Physical Activity Type Detection Using Real-Life Data: A Systematic Review. *Frontiers in Physiology*, 10. https://www.frontiersin.org/articles/10.3389/fphys.2019.00075

Almannaa, M. H., Alsahhaf, F. A., Ashqar, H. I., Elhenawy, M., Masoud, M., & Rakotonirainy, A. (2021). Perception Analysis of E-Scooter Riders and Non-Riders in Riyadh, Saudi Arabia: Survey Outputs. *Sustainability,* 13(2), 863. https://doi.org/10.3390/su13020863

Almannaa, M. H., Ashqar, H. I., Elhenawy, M., Masoud, M., Rakotonirainy, A., & Rakha, H. (2021). A comparative analysis of e-scooter and e-bike usage patterns: Findings from the City of Austin, TX. *International Journal of Sustainable Transportation*, 15(7), pp 571-579. https://doi.org/10.1080/15568318.2020.1833117

An, K., Chen, X., Xin, F., Lin, B., & Wei, L. (2013). Travel Characteristics of E-bike Users: Survey and Analysis in Shanghai. *Procedia -Social and Behavioral Sciences*, 96(Cictp), 1828–1838. https://doi.org/10.1016/j.sbspro.2013.08.208

Anderson-Hall, K., Bordenkircher, B., O'Neil, R., Scott, S. C., & Board, T. R. (2019). Governing Micromobility: A Nationwide Assessment of Electric Scooter *Regulations* (p. 18p). https://trid.trb.org/view/1572811

Andersson, A. S. F. K. A., Adell, E., & Hiselius, L. W. (2021). What is the substitution effect of e-bikes? A randomised controlled trial. *Transportation Research Part D-Transport and Environment*, 90. https://doi.org/10.1016/j.trd.2020.102648

Arentze, T., & Timmermans, H. (2008). Social Networks, Social Interactions, and Activity-Travel Behavior: A Framework for Microsimulation. *Environment and Planning B: Planning and Design*, 35(6), 1012–1027. https://doi.org/10.1068/b3319t

Arias-Molinares, D., García-Palomares, J. C., Romanillos, G., & Gutiérrez, J. (2023). Uncovering spatiotemporal micromobility patterns through the lens of space–time cubes and GIS tools. *Journal of Geographical Systems*, 25(3), 403–427. https://doi.org/10.1007/s10109-023-00418-9

Arroyo, R., Ruiz, T., Mars, L., Rasouli, S., & Timmermans, H. (2020). Influence of values, attitudes towards transport modes and companions on travel behavior.

Transportation Research Part F: Traffic Psychology and Behaviour, 71, 8–22. https://doi.org/10.1016/j.trf.2020.04.002

Arsenio, E., Dias, J. V., Lopes, S. A., & Pereira, H. I. (2018). Assessing the market potential of electric bicycles and ICT for low carbon school travel: A case study in the Smart City of ÁGUEDA. *European Transport Research Review*, 10(1). https://doi.org/10.1007/s12544-017-0279-z

Avila-Palencia, I., Int Panis, L., Dons, E., Gaupp-Berghausen, M., Raser, E., Götschi, T., Gerike, R., Brand, C., de Nazelle, A., Orjuela, J. P., Anaya-Boig, E., Stigell, E., Kahlmeier, S., Iacorossi, F., & Nieuwenhuijsen, M. J. (2018). The effects of transport mode use on self-perceived health, mental health, and social contact measures: A cross-sectional and longitudinal study. *Environment International*, 120, 199–206. https://doi.org/10.1016/j.envint.2018.08.002

Awais, M., Mellone, S., & Chiari, L. (2015). Physical activity classification meets daily life: Review on existing methodologies and open challenges. 2015 37th *Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, 5050–5053. https://doi.org/10.1109/EMBC.2015.7319526

Babin, B. J., Darden, W. R., & Griffin, M. (1994). Work and/or Fun: Measuring Hedonic and Utilitarian Shopping Value. *Journal of Consumer Research*, 20(4), 644–656. https://doi.org/10.1086/209376

Badeau, A., Carman, C., Newman, M., Steenblik, J., Carlson, M., & Madsen, T. (2019). Emergency department visits for electric scooter-related injuries after introduction of an urban rental program. *American Journal of Emergency Medicine*, 37(8), 1531–1533. https://doi.org/10.1016/j.ajem.2019.05.003

Bahrami, F., & Rigal, A. (2021). Planning for plurality of streets: A spheric approach to micromobilities. *Mobilities.* https://doi.org/10.1080/17450101.2021.1984850

Bai, L., Liu, P., Chen, Y., Zhang, X., & Wang, W. (2013). Comparative analysis of the safety effects of electric bikes at signalized intersections. *Transportation Research Part D: Transport and Environment*, 20, 48–54. https://doi.org/10.1016/j.trd.2013.02.001

Bai, S., Jiao, J., Chen, Y., & Guo, J. (2021). The relationship between E-scooter travels and daily leisure activities in Austin, Texas. *Transportation Research Part D-Transport and Environment*, 95. https://doi.org/10.1016/j.trd.2021.102844

Barajas, J. M., & Braun, L. M. (2021). Are cycling and walking good for all? Tracking differences in associations among active travel, socioeconomics, gentrification, and self-reported health. *Journal of Transport & Health*, 23, 101246. https://doi.org/10.1016/j.jth.2021.101246

Barnett, A., Sit, C. H. P., Mellecker, R. R., & Cerin, E. (2019). Associations of socio-demographic, perceived environmental, social and psychological factors with active travel in Hong Kong adolescents: The iHealt(H) cross-sectional study. *Journal of Transport & Health*, 12, 336–348.https://doi.org/10.1016/j.jth.2018.08.002

Bateman, L. B., Fouad, M. N., Sullivan, A., Heider, L., & Oates, G. R. (2021). Barriers and facilitators to bikeshare programs: A qualitative study in an urban environment. *Journal of Transport & Health*, 21, 101062. https://doi.org/10.1016/j.jth.2021.101062

Bates, D., Mächler, M., Bolker, B. M., & Walker, S. C. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, 67(1). https://doi.org/10.18637/jss.v067.i01

Batista Ferrer, H., Cooper, A., & Audrey, S. (2018). Associations of mode of travel to work with physical activity, and individual, interpersonal, organisational, and environmental characteristics. *Journal of Transport & Health*, 9, 45–55. https://doi.org/10.1016/J.JTH.2018.01.009

Beaudoin, J., Farzin, Y. H., & Lin Lawell, C.-Y. C. (2015). Public transit investment and sustainable transportation: A review of studies of transit's impact on traffic congestion and air quality. *Research in Transportation Economics*, 52, 15–22. https://doi.org/10.1016/j.retrec.2015.10.004

Beck, S., Barker, L., Chan, A., & Stanbridge, S. (2020). Emergency department impact following the introduction of an electric scooter sharing service. *Emergency Medicine Australasia*, 32(3), 409–415. https://doi.org/10.1111/1742-6723.13419

Beecham, R., & Wood, J. (2014). Exploring gendered cycling behaviours within a large-scale behavioural data-set. *Transportation Planning and Technology*, 37(1), 83–97. https://doi.org/10.1080/03081060.2013.844903

Behrendt, F. (2018). Why cycling matters for electric mobility: Towards diverse, active and sustainable e-mobilities. *Mobilities*, 13(1), 64–80. https://doi.org/10.1080/17450101.2017.1335463

Bekhit, M. N., Le Fevre, J., & Bergin, C. J. (2020). Regional healthcare costs and burden of injury associated with electric scooters. *Injury*, 51(2), pp 271-277. http://dx.doi.org/10.1016/j.injury.2019.10.026

Berge, S. H. (2019). Kickstarting Micromobility –a Pilot Study on e-Scooters. In TØI Report(p. 68p). *Institute of Transport Economics (TØI)*. https://www.toi.no/getfile.php/1350932/Publikasjoner/T{\O}I rapporter/2019/1721-2019/1721-2019-elektronisk.pdf

Berjisian, E., & Bigazzi, A. (2022). Evaluation of methods to distinguish trips from activities in walking and cycling GPS data. *Transportation Research Part C: Emerging Technologies*, 137, 103588. https://doi.org/10.1016/j.trc.2022.103588

Bernstein, E. E., & McNally, R. J. (2017a). Acute aerobic exercise hastens emotional recovery from a subsequent stressor. *Health Psychology*, 36(6), 560–567. https://doi.org/10.1037/hea0000482

Berntsen, S., Malnes, L., Langåker, A., & Bere, E. (2017b). Physical activity when riding an electric assisted bicycle. *International Journal of Behavioral Nutrition and Physical Activity*, 14(1). https://doi.org/10.1186/S12966-017-0513-Z

Biegańska, J., Grzelak-Kostulska, E., & Kwiatkowski, M. A. (2021). A typology of attitudes towards the e-bike against the background of the traditional bicycle and the car. *Energies*, 14(24). https://doi.org/10.3390/en14248430

Bieliński, T., Dopierała, Ł., Tarkowski, M., & Ważna, A. (2020). Lessons from Implementing a Metropolitan Electric Bike Sharing System. *Energies*, 13(23), 6240. https://doi.org/10.3390/en13236240

Bieliński, T., Kwapisz, A., & Ważna, A. (2021). Electric bike-sharing services mode substitution for driving, public transit, and cycling. *Transportation Research Part D: Transport and Environment, 96*. https://doi.org/10.1016/j.trd.2021.102883

Bieliński, T., & Ważna, A. (2020). Electric scooter sharing and bike sharing user behaviour and characteristics. *Sustainability* (Switzerland), 12(22), 1–13. https://doi.org/10.3390/su12229640

Bini, R. R., & Bini, A. F. (2020). Effects of exercise mode in knee cartilage thickness. *Journal of Bodywork and Movement Therapies*, 24(4), 490–495. https://doi.org/10.1016/J.JBMT.2020.05.006

Bird, E. L., Panter, J., Baker, G., Jones, T., & Ogilvie, D. (2018). Predicting walking and cycling behaviour change using an extended Theory of Planned Behaviour.

Journal of Transport & Health, 10, 11–27. https://doi.org/10.1016/j.jth.2018.05.014

Bjornara, H. B., Berntsen, S., te Velde, S. J., Fegran, L., Fyhri, A., Deforche, B., Andersen, L. B., Bere, E., Bjørnarå, H. B., Berntsen, S., te Velde, S. J., Fegran, L., Fyhri, A., Deforche, B., Andersen, L. B., & Bere, E. (2017). From cars to bikes—The feasibility and effect of using e-bikes, longtail bikes and traditional bikes for transportation among parents of children attending kindergarten: Design of a randomized cross-over trial. *BMC Public Health*, 17(1), 9p. https://doi.org/10.1186/s12889-017-4995-z

Bjornara, H. B., Berntsen, S., te Velde, S. J., Fyhri, A., Deforche, B., Andersen, L. B., & Bere, E. (2019). From cars to bikes—The effect of an intervention providing access to different bike types: A randomized controlled trial. *PLOS ONE*, 14(7). https://doi.org/10.1371/journal.pone.0219304

Blomberg, S. N. F., Rosenkrantz, O. C. M., Lippert, F., & Collatz Christensen, H. (2019). Injury from electric scooters in Copenhagen: A retrospective cohort study. *BMJ Open*, 9(12). https://doi.org/10.1136/BMJOPEN-2019-033988

Bloom, M. B., Noorzad, A., Lin, C., Little, M., Lee, E. Y., Margulies, D. R., & Torbati, S. S. (2021). Standing electric scooter injuries: Impact on a community. *The American Journal of Surgery*, 221(1), 227–232. https://doi.org/10.1016/j.amjsurg.2020.07.020

Boland, P., Connell, L., Thetford, C., & Janssen, J. (2020). Exploring the factors influencing the use of electrically assisted bikes (e-bikes) by stroke survivors: A mixed methods multiple case study. *Disability and Rehabilitation*. https://doi.org/10.1080/09638288.2020.1817986

Bondemark, A. (2023). Walk this way how do individuals with different preferences for active travel modes respond to walkability? *Transportation Research Part A: Policy and Practice*, 175, 103760. https://doi.org/10.1016/j.tra.2023.103760

Börjesson, M., Eliasson, J., & Rubensson, I. (2020). Distributional effects of public transport subsidies. *Journal of Transport Geography*, 84, 102674. https://doi.org/10.1016/j.jtrangeo.2020.102674

Bourne, J. E., Cooper, A. R., Kelly, P., Kinnear, F. J., England, C., Leary, S., & Page, A. (2020). The impact of e-cycling on travel behaviour: A scoping review. *Journal of Transport and Health*, 19, 100910. https://doi.org/10.1016/j.jth.2020.100910

Bourne, J. E., Sauchelli, S., Perry, R., Page, A., Leary, S., England, C., & Cooper, A. R. (2018). Health benefits of electrically-assisted cycling: A systematic review 11

Medical and Health Sciences 1117 Public Health and Health Services. *International Journal of Behavioral Nutrition and Physical Activity*, 15(1). https://doi.org/10.1186/s12966-018-0751-8

Bozzi, A. D., & Aguilera, A. (2021). Shared e-scooters: A review of uses, health and environmental impacts, and policy implications of a new micromobility service. *Sustainability* (Switzerland), 13(16). https://doi.org/10.3390/su13168676

Bretones, A., & Marquet, O. (2022). Sociopsychological factors associated with the adoption and usage of electric micromobility. A literature review. *Transport Policy,* 127, 230–249. https://doi.org/10.1016/j.tranpol.2022.09.008

Bretones, A., Marquet, O., Daher, C., Hidalgo, L., Nieuwenhuijsen, M., Miralles-Guasch, C., & Mueller, N. (2023). Public Health-Led Insights on Electric Micromobility Adoption and Use: A Scoping Review. *Journal of Urban Health*, 100(3), 612–626. https://doi.org/10.1007/s11524-023-00731-0

Brinks, R., Hoyer, A., Kuss, O., & Rathmann, W. (2015). Projected Effect of Increased Active Travel in German Urban Regions on the Risk of Type 2 Diabetes. *PLOS ONE*, 10(4), e0122145. https://doi.org/10.1371/journal.pone.0122145

Brondeel, R., Pannier, B., & Chaix, B. (2015). Using GPS, GIS, and Accelerometer Data to Predict Transportation Modes. *Medicine and Science in Sports and Exercise*, 47(12), 2669–2675. https://doi.org/10.1249/mss.0000000000000704

Brondeel, R., Pannier, B., & Chaix, B. (2016). Associations of socioeconomic status with transport-related physical activity: Combining a household travel survey and accelerometer data using random forests. *Journal of Transport & Health*, 3(3), 287–296. https://doi.org/10.1016/J.JTH.2016.06.002

Brondeel, R., Wasfi, R., Perchoux, C., Chaix, B., Gerber, P., Gauvin, L., Richard, L., Gaudreau, P., Thierry, B., Chevrier, M., Hoj, S., & Kestens, Y. (2019). Is older adults' physical activity during transport compensated during other activities? Comparing 4 study cohorts using GPS and accelerometer data. *Journal of Transport & Health*, 12, 229–236. https://doi.org/10.1016/J.JTH.2019.02.006

Brown, M. E., & Treviño, L. K. (2014). Do Role Models Matter? An Investigation of Role Modeling as an Antecedent of Perceived Ethical Leadership. *Journal of Business Ethics*, 122(4), 587–598. https://doi.org/10.1007/s10551-013-1769-0

Brownson, A. B. S., Fagan, P. V. B., Dickson, S., & Civil, I. D. S. (2019). Electric scooter injuries at Auckland City Hospital. *New Zealand Medical Journal*, 132(1505), 62–72.

Bruce, J. M. (2020). Local micromobility regulations: Implications for equity and data privacy in four U.S. cities. *UT Electronic Theses and Dissertations*. http://dx.doi.org/10.26153/tsw/10169

Buehler, R., Broaddus, A., Sweeney, T., Zhang, W., White, E., & Mollenhauer, M. (2021). Changes in Travel Behavior, Attitudes, and Preferences among E-Scooter Riders and Nonriders: First Look at Results from Pre and Post E-Scooter System Launch Surveys at Virginia Tech. *Transportation Research Record.* https://doi.org/10.1177/03611981211002213

bureau de recherche, 6t. (2019). Uses and Users of Free-floating Electric Scooters in France, 158p. *Agence de l'Environnement et de la Maitrise de l'Energie*. https://www.mobilservice.ch/admin/data/files/news_section_file/file/4908/6t_trottinettes_synthese_eng.pdf?lm=1581430095

Button, K., Frye, H., & Reaves, D. (2020). Economic regulation and E-scooter networks in the USA. *Research In Transportation Economics*, 84. https://doi.org/10.1016/j.retrec.2020.100973

Cairns, S., Behrendt, F., Raffo, D., Beaumont, C., & Kiefer, C. (2017). Electrically-assisted bikes: Potential impacts on travel behaviour. *Transportation Research Part A: Policy and Practice*, 103, 327–342. https://doi.org/10.1016/j.tra.2017.03.007

Campbell, A. A., Cherry, C. R., Ryerson, M. S., & Yang, X. (2016). Factors influencing the choice of shared bicycles and shared electric bikes in Beijing. *Transportation Research Part C-Emerging Technologies*, 67, 399–414. https://doi.org/10.1016/j.trc.2016.03.004

Campbell, A., Wong, N., Monk, P., Munro, J., & Bahho, Z. (2019). The cost of electric-scooter related orthopaedic surgery. *New Zealand Medical Journal*, 132(1501), 57–63.

Campisi, T., Akgün-Tanbay, N., Md Nahiduzzaman, K., & Dissanayake, D. (2021). Uptake of e-Scooters in Palermo, Italy: Do the Road Users Tend to Rent, Buy or Share? *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 12953 LNCS, 669–682. https://doi.org/10.1007/978-3-030-86976-2_46

Campisi, T., Skoufas, A., Kaltsidis, A., & Basbas, S. (2021). Gender Equality and E-Scooters: Mind the Gap! A Statistical Analysis of the Sicily Region, Italy. *Social Sciences-Basel*, 10(10). https://doi.org/10.3390/socsci10100403

Cao, X. (Jason), Mokhtarian, P. L., & Handy, S. L. (2009). The relationship between the built environment and nonwork travel: A case study of Northern California. *Transportation Research Part A: Policy and Practice*, 43(5), 548–559. https://doi.org/10.1016/j.tra.2009.02.001

Cao, Z., Zhang, X., Chua, K., Yu, H., & Zhao, J. (2021). E-scooter sharing to serve short-distance transit trips: A Singapore case. *Transportation Research Part A: Policy and Practice*, 147, 177–196. https://doi.org/10.1016/j.tra.2021.03.004

Castro, A., Gaupp-Berghausen, M., Dons, E., Standaert, A., Laeremans, M., Clark, A., Anaya-Boig, E., Cole-Hunter, T., Avila-Palencia, I., Rojas-Rueda, D., Nieuwenhuijsen, M., Gerike, R., Panis, L. I., de Nazelle, A., Brand, C., Raser, E., Kahlmeier, S., & Götschi, T. (2019). Physical activity of electric bicycle users compared to conventional bicycle users and non-cyclists: Insights based on health and transport data from an online survey in seven European cities. *Transportation Research Interdisciplinary Perspectives*, 1, 100017. https://doi.org/10.1016/j.trip.2019.100017

Cerin, E., Nathan, A., van Cauwenberg, J., Barnett, D. W., Barnett, A., on Environment, C., & Working group, P. A. (CEPA)-O. A. (2017). The neighbourhood physical environment and active travel in older adults: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, 14(1). https://doi.org/10.1186/s12966-017-0471-5

Cervero, R. (2006). Alternative Approaches to Modeling the Travel-Demand Impacts of Smart Growth. *Journal of the American Planning Association*, 72(3), 285–295. https://doi.org/10.1080/01944360608976751

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment*, 2(3), 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6

Chabanas, B., Praznoczy, C., & Duclos, M. (2019). Commuter e-bike use is associated with increased total physical activity over time. *European Journal of Public Health,* 29(Supplement_4), ckz187.092. https://doi.org/10.1093/eurpub/ckz187.092

Chaix, B., Benmarhnia, T., Kestens, Y., Brondeel, R., Perchoux, C., Gerber, P., & Duncan, D. T. (2019). Combining sensor tracking with a GPS-based mobility survey to better measure physical activity in trips: Public transport generates walking. *International Journal of Behavioral Nutrition and Physical Activity*, 16(1), 1–13. https://doi.org/10.1186/s12966-019-0841-2

Chandrabose, M., Rahim Mohammad Forkan, A., Abe, T., Owen, N., & Sugiyama, T. (2023). Joint associations of environmental and sociodemographic attributes with active and sedentary travel. *Transportation Research Part D: Transport and Environment*, 116, 103643. https://doi.org/10.1016/j.trd.2023.103643

Chapman, D., & Larsson, A. (2021). Practical urban planning for winter cycling; lessons from a Swedish pilot study. *Journal of Transport & Health*, 21, 101060. https://doi.org/10.1016/j.jth.2021.101060

Chavis, C. & Martinez, V. F., (2021). E-bikes' Effect on Mode and Route Choice: A Case Study of Richmond, VA Bike Share (Final Report). *Urban Mobility & Equity Center*. https://rosap.ntl.bts.gov/view/dot/59877/dot_59877_DS1.pdf

Chen, X., Ma, Z., Ye, G., & Li, Z. (2021). Usage behavior and satisfaction analysis of free-floating bicycle sharing system service: Evidence from a Chinese university campus. *Research in Transportation Business & Management*, 100703. https://doi.org/10.1016/j.rtbm.2021.100703

Chi, C.-F., Chen, P.-L., Saleh, W., Tsai, S.-H., & Pai, C.-W. (2019). Helmet non-use by users of bikeshare programs, electric bicycles, racing bicycles, and personal bicycles: An observational study in Taipei, Taiwan. *International Journal of Sustainable Transportation*, 13(2), 93–99. https://doi.org/10.1080/15568318.2018.1441470

Christoforou, Z., Gioldasis, C., de Bortoli, A., & Seidowsky, R. (2021). Who is using e-scooters and how? Evidence from Paris. *Transportation Research Part D: Transport and Environment*, 92, 102708. https://doi.org/10.1016/j.trd.2021.102708

Cicchino, J. B., Kulie, P. E., & McCarthy, M. L. (2021). Injuries related to electric scooter and bicycle use in a Washington, DC, emergency department. *Traffic Injury Prevention*, 22(5), 401–406. https://doi.org/10.1080/15389588.2021.1913280

Clark, A. F., Scott, D. M., & Yiannakoulias, N. (2014). Examining the relationship between active travel, weather, and the built environment: A multilevel approach using a GPS-enhanced dataset. *Transportation*, 41(2), 325–338. https://doi.org/10.1007/s11116-013-9476-3

Cleland, C. L., Baker, G., Turner, K., Jepson, R., Kee, F., Milton, K., Kelly, M. P., Nightingale, G., & Hunter, R. F. (2021). A qualitative exploration of the mechanisms, pathways and public health outcomes of a city centre 20mph speed limit intervention:The case of Belfast, United Kingdom. *Health & Place*, 70, 102627. https://doi.org/10.1016/j.healthplace.2021.102627

Clewlow, R., & Mishra, G. S. (2017). Shared Mobility: Current Adoption, Use, and Potential Impacts on Travel Behavior (17–05729). Article 17–05729. *Transportation Research Board 96th Annual Meeting.* https://trid.trb.org/View/1439277

Coelho, A., Feito, P., Corominas, L., Sánchez-Soler, J. F., Pérez-Prieto, D., Martínez-Diaz, S., Alier, A., & Monllau, J. C. (2021). Electric Scooter-Related Injuries: A New Epidemic in Orthopedics. *Journal of Clinical Medicine*, 10(15). https://doi.org/10.3390/jcm10153283

Commission, C. P. S. (2020). Safety Concerns Associated with Micromobility Products (p. 12p). *Consumer Product Safety Commission. Office of Hazard Identification and Reduction.* https://rosap.ntl.bts.gov/view/dot/53424

Compostella, J., Fulton, L. M., De Kleine, R., Kim, H. C., & Wallington, T. J. (2020). Near-(2020) and long-term (2030–2035) costs of automated, electrified, and shared mobility in the United States. *Transport Policy*, 85, 54–66. https://doi.org/10.1016/J.TRANPOL.2019.10.001

Cook, S., Stevenson, L., Aldred, R., Kendall, M., & Cohen, T. (2022). More than walking and cycling: What is 'active travel'? *Transport Policy*, 126, 151–161. https://doi.org/10.1016/j.tranpol.2022.07.015

Craig, C. L., Marshall, A. L., Sjöström, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., Pratt, M., Ekelund, U., Yngve, A., Sallis, J. F., & Oja, P. (2003). International physical activity questionnaire: 12-Country reliability and validity. *Medicine and Science in Sports and Exercise*, 35(8), 1381–1395. https://doi.org/10.1249/01.MSS.0000078924.61453.FB

Cubells, J., Miralles-Guasch, C., & Marquet, O. (2023). Gendered travel behaviour in micromobility? Travel speed and route choice through the lens of intersecting identities. *Journal of Transport Geography*, 106, 103502. https://doi.org/10.1016/j.jtrangeo.2022.103502

Cusack, M. (2021). Individual, social, and environmental factors associated with active transportation commuting during the COVID-19 pandemic. *Journal of Transport & Health*, 22, 101089. https://doi.org/10.1016/j.jth.2021.101089

Darlow, S. D., & Xu, X. (2011). The influence of close others' exercise habits and perceived social support on exercise. *Psychology of Sport and Exercise*, 12(5), 575–578. https://doi.org/10.1016/j.psychsport.2011.04.004

de Bortoli, A. (2021). Environmental performance of shared micromobility and personal alternatives using integrated modal LCA. *Transportation Research Part D: Transport and Environment*, 93. https://doi.org/10.1016/j.trd.2021.102743

de Bortoli, A., & Christoforou, Z. (2020). Consequential LCA for territorial and multimodal transportation policies: Method and application to the free-floating e-scooter disruption in Paris. *Journal of Cleaner Production*, 273. https://doi.org/10.1016/j.jclepro.2020.122898

de Bruijn, G.-J., Kremers, S. P. J., Singh, A., van den Putte, B., & van Mechelen, W. (2009). Adult Active Transportation: Adding Habit Strength to the Theory of Planned Behavior. *American Journal of Preventive Medicine*, 36(3), 189–194. https://doi.org/10.1016/j.amepre.2008.10.019

De Ceunynck, T., Wijlhuizen, G. J., Fyhri, A., Gerike, R., Koehler, D., Ciccone, A., Dijkstra, A., Dupont, E., Cools, M., Köhler, D., Ciccone, A., Dijkstra, A., Dupont, E., & Cools, M. (2021). Assessing the willingness to use personal e-transporters (PeTs): Results from a cross-national survey in nine European cities. *Sustainability* (Switzerland), 13(7). https://doi.org/10.3390/su13073844

De Geus, B., & Hendriksen, I. (2015). Cycling for transport, physical activity and health: What about pedelecs? In Cycling Futures: From Research into Practice. *Routledge, Taylor and Francis*. https://doi.org/10.4324/9781315575742-9

de Guerre, L. E. V. M., Sadiqi, S., Leenen, L. P. H., Oner, C. F., & van Gaalen, S. M. (2020). Injuries related to bicycle accidents: An epidemiological study in The Netherlands. *European Journal of Trauma and Emergency Surgery*, 46(2), 413–418.

de Haas, M., Kroesen, M., Chorus, C., Hoogendoorn-Lanser, S., & Hoogendoorn, S. (2021). Causal relations between body-mass index, self-rated health and active travel: An empirical study based on longitudinal data. *Journal of Transport & Health*, 22, 101113. https://doi.org/10.1016/j.jth.2021.101113

de Kruijf, J., Ettema, D., Kamphuis, C. B. M., & Dijst, M. (2018). Evaluation of an Incentive Program to Stimulate the Shift from Car Commuting to E-Cycling in the Netherlands. *Journal of Transport & Health*, 10, pp 74-83. https://doi.org/10.1016/j.jth.2018.06.003

De Vos, J. (2015). The influence of land use and mobility policy on travel behavior: A comparative case study of Flanders and the Netherlands. *Journal of Transport and Land Use*, 8(1), 171–190.

De Vos, J., Cheng, L., Kamruzzaman, Md., & Witlox, F. (2021). The indirect effect of the built environment on travel mode choice: A focus on recent movers. *Journal of Transport Geography*, 91, 102983. https://doi.org/10.1016/j.jtrangeo.2021.102983

De Vos, J., Schwanen, T., Van Acker, V., & Witlox, F. (2019). Do satisfying walking and cycling trips result in more future trips with active travel modes? An exploratory study. *International Journal of Sustainable Transportation*, 13(3), 180–196. https://doi.org/10.1080/15568318.2018.1456580

De Vos, J., Singleton, P. A., & Gärling, T. (2021). From attitude to satisfaction: Introducing the travel mode choice cycle. *Transport Reviews*, 42(2), 204–2021. https://doi.org/10.1080/01441647.2021.1958952

De Witte, A., Hollevoet, J., Dobruszkes, F., Hubert, M., & Macharis, C. (2013). Linking modal choice to motility: A comprehensive review. *Transportation Research Part A: Policy and Practice,* 49, 329–341. https://doi.org/10.1016/J.TRA.2013.01.009

Delclòs-Alió, X., Marquet, O., Vich, G., Schipperijn, J., Zhang, K., Maciejewska, M., & Miralles-Guasch, C. (2019). Temperature and Rain Moderate the Effect of Neighborhood Walkability on Walking Time for Seniors in Barcelona. *International Journal of Environmental Research and Public Health*, 17(1). https://doi.org/10.3390/IJERPH17010014

Dias, G., Arsenio, E., & Ribeiro, P. (2021). The Role of Shared E-Scooter Systems in Urban Sustainability and Resilience during the Covid-19 Mobility Restrictions. *Sustainability*, 13(13), 7084. https://doi.org/10.3390/su13137084

Dill, J., & McNeil, N. (2021). Are Shared Vehicles Shared by All? A Review of Equity and Vehicle Sharing. *Journal of Planning Literature*, 36(1), 5–30. https://doi.org/10.1177/0885412220966732

Dill, J., Mohr, C., & Ma, L. (2014). How can psychological theory help cities increase walking and bicycling? *Journal of the American Planning Association*, 80(1), 36–51. https://doi.org/10.1080/01944363.2014.934651

Dill, J., & Rose, G. (2012). Electric Bikes and Transportation Policy: Insights from Early Adopters. *Transportation Research Record: Journal of the Transportation Research Board*, 2314, pp 1-6. https://doi.org/10.3141/2314-01

DiMaggio, C. J., Bukur, M., Wall, S. P., Frangos, S. G., & Wen, A. Y. (2019). Injuries associated with electric-powered bikes and scooters: Analysis of US consumer product data. *Injury Prevention*, 26(6), pp 524-528. http://dx.doi.org/10.1136/injuryprev-2019-043418

Ding, C., & Cao, X. (2019). How does the built environment at residential and work locations affect car ownership? An application of cross-classified multilevel model. *Journal of Transport Geography*, 75, 37–45. https://doi.org/10.1016/j.jtrangeo.2019.01.012

Ding, C., Cao, X., Dong, M., Zhang, Y., & Yang, J. (2019). Non-linear relationships between built environment characteristics and electric-bike ownership in Zhongshan, China. *Transportation Research Part D: Transport and Environment*, 75, 286–296. https://doi.org/10.1016/j.trd.2019.09.005

Dons, E., Rojas-Rueda, D., Anaya-Boig, E., Avila-Palencia, I., Brand, C., Cole-Hunter, T., de Nazelle, A., Eriksson, U., Gaupp-Berghausen, M., Gerike, R., Kahlmeier, S., Laeremans, M., Mueller, N., Nawrot, T., Nieuwenhuijsen, M. J., Orjuela, J. P., Racioppi, F., Raser, E., Standaert, A., … Götschi, T. (2018). Transport mode choice and body mass index: Cross-sectional and longitudinal evidence from a European-wide study. *Environment International*, 119, 109–116. https://doi.org/10.1016/j.envint.2018.06.023

Doorley, R., Pakrashi, V., & Ghosh, B. (2015). Quantifying the Health Impacts of Active Travel: Assessment of Methodologies. *Transport Reviews*, 35(5), 559–582. https://doi.org/10.1080/01441647.2015.1037378

Dowling, R., Irwin, J. D., Faulks, I. J., & Howitt, R. (2015). Use of personal mobility devices for first-and-last mile travel: The Macquarie-Ryde trial. In Cameron, I, Haworth, N, & McIntosh, L (Eds.) *Proceedings of the 2015 Australasian Road Safety Conference (ARSC2015). Australasian College of Road Safety (ACRS)*, Australia, pp. 1-13.

Dozza, M., Bianchi Piccinini, G. F., & Werneke, J. (2016). Using Naturalistic Data to Assess E-Cyclist Behavior. *Transportation Research Part F: Traffic Psychology and Behaviour*, 41, Part B, pp 217-226. https://doi.org/10.1016/j.trf.2015.04.003

Duncan, D. T., Méline, J., Kestens, Y., Day, K., Elbel, B., Trasande, L., & Chaix, B. (2016). Walk Score, Transportation Mode Choice, and Walking Among French Adults: A GPS, Accelerometer, and Mobility Survey Study. *International Journal of Environmental Research and Public Health*, 13(6), 1–14. https://doi.org/10.3390/IJERPH13060611

Eccarius, T., Leung, A., Shen, C.-W., Burke, M., & Lu, C.-C. (2021). Prospects for shared electric velomobility: Profiling potential adopters at a multi-campus university. *Journal of Transport Geography*, 96, 103190. https://doi.org/10.1016/j.jtrangeo.2021.103190

Eccarius, T., & Lu, C.-C. (2018). Exploring consumer reasoning in usage intention for electric scooter sharing. *Transportation Planning Journal*, 47(4), 271–295. https://doi.org/10.6402/TPJ

Edel, F., Wassmer, S., & Kern, M. (2021). Potential analysis of E-Scooters for commuting paths. *World Electric Vehicle Journal*, 12(2). https://doi.org/10.3390/wevj12020056

Edge, S., Dean, J., Cuomo, M., & Keshav, S. (2018). Exploring e-bikes as a mode of sustainable transport: A temporal qualitative study of the perspectives of a sample of novice riders in a Canadian city. *Canadian Geographer*, 62(3), 384–397. https://doi.org/10.1111/cag.12456

EIT Urban Mobility. (2020). Living lab e-micromobility—MOBY Guideline of best practices, and results of e-micromobile integration potentials. *EIT Urban Mobility*. https://www.eiturbanmobility.eu/projects/living-lab-e-micromobility/

Eldeeb, G., Mohamed, M., & Páez, A. (2021). Built for active travel? Investigating the contextual effects of the built environment on transportation mode choice. *Journal of Transport Geography*, 96, 103158. https://doi.org/10.1016/j.jtrangeo.2021.103158

Elias, W., & Gitelman, V. (2018). Youngsters' opinions and attitudes toward the use of electric bicycles in Israel. *Sustainability* (Switzerland), 10(12). https://doi.org/10.3390/su10124352

Ellis, K., Godbole, S., Marshall, S., Lanckriet, G., Staudenmayer, J., & Kerr, J. (2014). Identifying Active Travel Behaviors in Challenging Environments Using GPS, Accelerometers, and Machine Learning Algorithms. *Frontiers in Public Health*, 2. https://www.frontiersin.org/articles/10.3389/fpubh.2014.00036

Esztergár-Kiss, D., & Lopez Lizarraga, J. C. (2021). Exploring user requirements and service features of e-micromobility in five European cities. *Case Studies on Transport Policy*, 9(4), 1531–1541. https://doi.org/10.1016/j.cstp.2021.08.003

Ewing, R., & Cervero, R. (2001). Travel and the Built Environment: A Synthesis. *Transportation Research Record: Journal of the Transportation Research Board*, 1780(1), 87–114. https://doi.org/10.3141/1780-10

Ewing, R., & Cervero, R. (2010). Travel and the Built Environment: A Meta-Analysis. *Journal of the American Planning Association*, 76(3), 265–294. https://doi.org/10.1080/01944361003766766

Fang, K. (2022). Micromobility injury events: Motor vehicle crashes and other transportation systems factors. *Transportation Research Interdisciplinary Perspectives*, 14. https://doi.org/10.1016/j.trip.2022.100574

Fang, K., Agrawal, A. W. & Hooper, A. M. (2019). How and Where Should I Ride This Thing? 'Rules Of The Road' for Personal Transportation Devices. *Mineta Transportation Institute Publications*. https://transweb.sjsu.edu/sites/default/files/1713-Fang-Agrawal-Hooper-Rules-Personal-Transportation-Devices.pdf

Faraji, F., Lee, J. H., Faraji, F., MacDonald, B., Oviedo, P., Stuart, E., Baxter, M., Vuong, C. L., Lance, S. H., Gosman, A. A., Castillo, E. M., & Hom, D. B. (2020). Electric scooter craniofacial trauma. *Laryngoscope Investigative Otolaryngology*, 5(3), 390–395. https://doi.org/10.1002/lio2.380

Fearnley, N. (2020). Micromobility –Regulatory Challenges and Opportunities. In A. Paulsson & C. Hedegaard Sørensen (Eds.), Shaping Smart Mobility Futures: Governance and Policy Instruments in times of Sustainability Transitions (pp. 169–186). *Emerald Publishing Limited*. https://doi.org/10.1108/978-1-83982-650-420201010

Fearnley, N., Berge, S. H. & Johnsson, E. (2020). Shared E-Scooters in Oslo. In TØI Report (Issue 1748/2020). *Institute of Transport Economics (TØI)*. https://www.toi.no/getfile.php/1352254-1581347359/Publikasjoner/T%C3%98I%20rapporter/2020/1748-2020/1748-2020-elektronisk.pdf

Fearnley, N., Johnsson, E., & Berge, S. H. (2020). Patterns of E-Scooter Use in Combination with Public Transport. *Findings*. https://doi.org/10.32866/001c.13707

Felipe-Falgas, P., Madrid-Lopez, C., & Marquet, O. (2022). Assessing Environmental Performance of Micromobility Using LCA and Self-Reported Modal Change: The Case of Shared E-Bikes, E-Scooters, and E-Mopeds in Barcelona. *Sustainability*, 14(7), Article 7. https://doi.org/10.3390/su14074139

Feng, J. (2017). The influence of built environment on travel behavior of the elderly in urban China. *Transportation Research Part D: Transport and Environment*, 52, 619–633. https://doi.org/10.1016/j.trd.2016.11.003

Feng, Y., Zhong, D., Sun, P., Zheng, W., Cao, Q., Luo, X., & Lu, Z. (2021). Micromobility in Smart Cities: A Closer Look at Shared Dockless E-Scooters via Big Social Data. *ICC 2021 -IEEE International Conference on Communications*, 1–6. https://doi.org/10.1109/ICC42927.2021.9500821

Ferrari, G. L. de M., Kovalskys, I., Fisberg, M., Gómez, G., Rigotti, A., Cortés Sanabria, L. Y., Yépez García, M. C., Pareja Torres, R. G., Herrera-Cuenca, M., Zimberg, I. Z., Guajardo, V., Pratt, M., Gonçalves, P. B., Rosales-Salas, J., Cristi-Montero, C., Rodríguez-Rodríguez, F., Waddell, H., Petermann-Rocha, F., Celis-Morales, C. A., … Luis de Moraes Ferrari, G. (2020). Socio-demographic patterns of public, private and active travel in Latin America: Cross-sectional findings from the ELANS study. *Journal of Transport & Health*, 16, 100788. https://doi.org/10.1016/j.jth.2019.100788

Fishbein, M., & Ajzen, I. (1975). Belief, attitude, intention and behavior: An introduction to theory and research. *Addison-Wesley, Reading MA.* https://people.umass.edu/aizen/f&a1975.html

Fitch, D., Mohiuddin, H. & Handy, S. (2020). Investigating the Influence of Dockless Electric Bike-share on Travel Behavior, Attitudes, Health, and Equity. *UC Office of the President: University of California Institute of Transportation Studies*. http://dx.doi.org/10.7922/G2F18X0W

Fitch, D. T., Mohiuddin, H., & Handy, S. L. (2021). Examining the Effects of the Sacramento Dockless E-Bike Share on Bicycling and Driving. *Sustainability*, 13(1). https://doi.org/10.3390/su13010368

Fitt, H., & Curl, A. (2019). E-scooter use in New Zealand: Insights around some frequently asked questions. *UC Library*. https://doi.org/10.13140/RG.2.2.13510.93761

Fitt, H., & Curl, A. (2020). The early days of shared micromobility: A social practices approach. *Journal of Transport Geography*, 86. https://doi.org/10.1016/j.jtrangeo.2020.102779

f.k.a. Andersson, A., Adell, E., Winslott Hiselius, L., Söderberg f.k.a. Andersson, A., Adell, E., & Winslott Hiselius, L. (2021). What is the substitution effect of e-bikes? A randomised controlled trial. *Transportation Research Part D: Transport and Environment*, 90, 102648. https://doi.org/10.1016/j.trd.2020.102648

Flores, P. J., & Jansson, J. (2021). The role of consumer innovativeness and green perceptions on green innovation use: The case of shared e-bikes and e-scooters. *Journal of Consumer Behaviour*, cb.1957. https://doi.org/10.1002/cb.1957

Forsythe, S., Liu, C., Shannon, D., & Gardner, L. C. (2006). Development of a scale to measure the perceived benefits and risks of online shopping. *Journal of Interactive Marketing*, 20(2), 55–75. https://doi.org/10.1002/DIR.20061

Freedson, P. S., Melanson, E., & Sirard, J. (1998). Calibration of the Computer Science and Applications, Inc. *Accelerometer. Medicine & Science in Sports & Exercise*, 30(5), 777–781.

Frings, D., Rose, A., & Ridley, A. M. (2012). Bicyclist Fatalities Involving Heavy Goods Vehicles: Gender Differences in Risk Perception, Behavioral Choices, and Training. *Traffic Injury Prevention*, 13(5), 493–498. https://doi.org/10.1080/15389588.2012.664796

Fyhri, A., & Fearnley, N. (2015). Effects of e-bikes on bicycle use and mode share. *Transportation Research Part D-Transport and Environment*, 36, 45–52. https://doi.org/10.1016/j.trd.2015.02.005

Fyhri, A., Heinen, E., Fearnley, N., Sundfør, H. B., & Sundfor, H. B. (2017). A push to cyclingexploring the e-bike's role in overcoming barriers to bicycle use with a survey and an intervention study. *International Journal of Sustainable Transportation*, 11(9), 681–695. https://doi.org/10.1080/15568318.2017.1302526

Fyhri, A., Johansson, O., & Bjørnskau, T. (2019). Gender Differences in Accident Risk with E-Bikes—Survey Data from Norway. *Accident Analysis & Prevention*, 132. https://doi.org/10.1016/j.aap.2019.07.024

Galdames, C., Tudela, A., & Carrasco, J. A. (2011). Exploring the Role of Psychological Factors in Mode Choice Models by a Latent Variables Approach. *Transportation Research Record: Journal of the Transportation Research Board,* 2230(1), 68-74. https://doi.org/10.3141/2230-08

Garber, C. E., Blissmer, B., Deschenes, M. R., Franklin, B. A., Lamonte, M. J., Lee, I.-M., Nieman, D. C., & Swain, D. P. (2011). Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise. *Medicine & Science in Sports & Exercise*, 43(7), 1334. https://doi.org/10.1249/MSS.0b013e318213fefb

Gehrke, S. R., & Wang, L. (2020). Operationalizing the neighborhood effects of the built environment on travel behavior. *Journal of Transport Geography*, 82, 102561. https://doi.org/10.1016/j.jtrangeo.2019.102561

Giné-Garriga, M., Sansano-Nadal, O., Tully, M. A., Caserotti, P., Coll-Planas, L., Rothenbacher, D., Dallmeier, D., Denkinger, M., Wilson, J. J., Martin-Borràs, C., Skjødt, M., Ferri, K., Farche, A. C., McIntosh, E., Blackburn, N. E., Salvà, A., Roqué-I-Figuls, M., & Newman, A. (2020). Accelerometer-Measured Sedentary and Physical Activity Time and Their Correlates in European Older Adults: The SITLESS Study. *Journals of Gerontology -Series A Biological Sciences and Medical Sciences*, 75(9), 1754–1762. https://doi.org/10.1093/gerona/glaa016

Gioldasis, C., Christoforou, Z., & Seidowsky, R. (2021). Risk-taking behaviors of e-scooter users: A survey in Paris. *Accident; Analysis and Prevention*, 163, 106427.

Gitelman, V., Korchatov, A., Carmel, R., & Elias, W. (2018). Young e-cyclists in Israeli cities: A characterization of typical behaviours and risk factors based on field observations. *Transactions on Transport Sciences*, 9(1), 58–72. https://doi.org/10.5507/tots.2018.007

Gitelman, V., Korchatov, A., & Hakkert, S. (2020). Alternative transport means in city centers: Exploring the levels of use, typical behaviours and risk factors. *European Transport -Trasporti Europei*, 77. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85087338795&partnerID=40&md5=f30df50da2b6682c44b45f57b61cc8c3

Glavić, D., Trpković, A., Milenković, M., & Jevremović, S. (2021). The e-scooter potential to change urban mobility—Belgrade case study. *Sustainability* (Switzerland), 13(11). https://doi.org/10.3390/su13115948

Glazener, A., Sanchez, K., Ramani, T., Zietsman, J., Nieuwenhuijsen, M. J., Mindell, J. S., Fox, M., & Khreis, H. (2021). Fourteen pathways between urban transportation and health: A conceptual model and literature review. *Journal of Transport & Health*, 21, 101070. https://doi.org/10.1016/j.jth.2021.101070

Glenn, J., Bluth, M., Christianson, M., Pressley, J., Taylor, A., Macfarlane, G. S., & Chaney, R. A. (2020). Considering the potential health impacts of electric scooters: An analysis of user reported behaviors in provo, Utah. *International Journal of Environmental Research and Public Health*, 17(17), 1–15. https://doi.org/10.3390/ijerph17176344

Gojanovic, B., Welker, J., Daucourt, C., & Gremion, G. (2011). The Electric Bike: A New Way Towards a Better Health for People and Environment. *Medicine and Science in Sports and Exercise*, 43. https://doi.org/10.1249/01.MSS.0000401256.52713.20

Gojanovic, B., Welker, J., Iglesias, K., Daucourt, C., & Gremion, G. (2011). Electric bicycles as a new active transportation modality to promote health. *Medicine and Science in Sports and Exercise*, 43(11), 2204–2210. https://doi.org/10.1249/MSS.0b013e31821cbdc8

Goralzik, A., König, A., Alčiauskaitė, L., & Hatzakis, T. (2022). Shared mobility services: An accessibility assessment from the perspective of people with disabilities. *European Transport Research Review*, 14(1), 34. https://doi.org/10.1186/s12544-022-00559-w

Gordon-Larsen, P., Boone-Heinonen, J., Sidney, S., Sternfeld, B., Jacobs, D. R., Jr, & Lewis, C. E. (2009). Active Commuting and Cardiovascular Disease Risk: The CARDIA Study. *Archives of Internal Medicine*, 169(13), 1216–1223. https://doi.org/10.1001/archinternmed.2009.163

Gorenflo, C., Rios, I., Golab, L., & Keshav, S. (2017). Usage Patterns of Electric Bicycles: An Analysis of the WeBike Project. *Journal of Advanced Transportation*, 2017. https://doi.org/10.1155/2017/3739505

Gössling, S. (2020). Integrating e-scooters in urban transportation: Problems, policies, and the prospect of system change. *Transportation Research Part D: Transport and Environment*, 79, 102230. https://doi.org/10.1016/J.TRD.2020.102230

Götschi, T., de Nazelle, A., Brand, C., Gerike, R., Alasya, B., Anaya, E., Avila-Palencia, I., Banister, D., Bartana, I., Benvenuti, F., Boschetti, F., Brand, C., Buekers, J., Carniel, L., Carrasco Turigas, G., Castro, A., Cianfano, M., Clark, A., Cole-Hunter, T., … on behalf of the PASTA Consortium. (2017). Towards a Comprehensive Conceptual Framework of Active Travel Behavior: A Review and Synthesis of Published Frameworks. *Current Environmental Health Reports,* 4(3), 286–295. https://doi.org/10.1007/s40572-017-0149-9

Grant-Muller, S., Yang, Y., Panter, J., & Woodcock, J. (2023). Does the Use of E-Scooters Bring Well-Being Outcomes for the User?: A Study Based on UK Shared E-Scooter Trials. *Active Travel Studies*, 3(1), Article 1. https://doi.org/10.16997/ats.1298

Graystone, M., Mitra, R., & Hess, P. M. (2022). Gendered perceptions of cycling safety and on-street bicycle infrastructure: Bridging the gap. *Transportation Research Part D: Transport and Environment*, 105. https://doi.org/10.1016/j.trd.2022.103237

Greaves, S., Beck, M., Cobbold, A., Standen, C., Rissel, C., & Crane, M. (2024). Working from home, active travel, health and wellbeing: Legacies of a pandemic. *Travel Behaviour and Society*, 34, 100707. https://doi.org/10.1016/j.tbs.2023.100707

Gwinner, K. P., Gremler, D. D., & Bitner, M. J. (1998). Relational benefits in services industries: The customer's perspective. *Journal of the Academy of Marketing Science*, 26(2), 101–114. https://doi.org/10.1177/0092070398262002

Hajna, S., White, T., Panter, J., Brage, S., Wijndaele, K., Woodcock, J., Ogilvie, D., Imamura, F., & Griffin, S. J. (2019). Driving status, travel modes and accelerometer-assessed physical activity in younger, middle-aged and older adults: A prospective study of 90 810 UK Biobank participants. *International Journal of Epidemiology*, 48(4), 1175–1186. https://doi.org/10.1093/IJE/DYZ065

Hamer, M., & Chida, Y. (2008). Active commuting and cardiovascular risk: A meta-analytic review. *Preventive Medicine*, 46(1), 9–13. https://doi.org/10.1016/j.ypmed.2007.03.006

Han, L., Wang, S., Zhao, D., & Li, J. (2017). The intention to adopt electric vehicles: Driven by functional and non-functional values. *Transportation Research Part A: Policy and Practice*, 103, 185–197. https://doi.org/10.1016/J.TRA.2017.05.033

Handy, S., Cao, X., & Mokhtarian, P. (2005). Correlation or causality between the built environment and travel behavior? Evidence from Northern California. *Transportation Research Part D: Transport and Environment*, 10(6), 427–444. https://doi.org/10.1016/j.trd.2005.05.002

Hardt, C., & Bogenberger, K. (2019). Usage of e-Scooters in Urban Environments. *21st Euro Working Group on Transportation Meeting (Ewgt 2018)* (Vol. 37, pp. 155–162). https://doi.org/10.1016/j.trpro.2018.12.178

Haustein, S., & Møller, M. (2016a). Age and attitude: Changes in cycling patterns of different e-bike user segments. *International Journal of Sustainable Transportation*, 10(9), 836–846. https://doi.org/10.1080/15568318.2016.1162881

Haustein, S., & Møller, M. (2016b). E-bike safety: Individual-level factors and incident characteristics. *Journal of Transport & Health*, 3(3), 386–394. https://doi.org/10.1016/j.jth.2016.07.001

Hawa, L., Cui, B., Sun, L., & El-Geneidy, A. (2021). Scoot over: Determinants of shared electric scooter presence in Washington D.C. *Case Studies on Transport Policy*, 9(2), 418–430. https://doi.org/10.1016/j.cstp.2021.01.003

Haybatollahi, M., Czepkiewicz, M., Laatikainen, T., & Kyttä, M. (2015). Neighbourhood preferences, active travel behaviour, and built environment: An exploratory study. *Transportation Research Part F: Traffic Psychology and Behaviour*, 29, 57–69. https://doi.org/10.1016/j.trf.2015.01.001

Haynes, E., Green, J., Garside, R., Kelly, M. P., & Guell, C. (2019). Gender and active travel: A qualitative data synthesis informed by machine learning. *International Journal of Behavioral Nutrition and Physical Activity*, 16(1), 135. https://doi.org/10.1186/s12966-019-0904-4

Heineke, K., Kloss, B., & Scurtu, D. (2020). The future of micromobility: Ridership and revenue after a crisis. *McKinsey & Company*. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-micromobility-ridership-and-revenue-after-a-crisis

Henriques-Neto, D., Peralta, M., Garradas, S., Pelegrini, A., Pinto, A. A., Sánchez-Miguel, P. A., & Marques, A. (2020). Active commuting and physical fitness: A systematic review. *International Journal of Environmental Research and Public Health*, 17(8). https://doi.org/10.3390/ijerph17082721

Hertach, P., Uhr, A., Niemann, S., & Cavegn, M. (2018). Characteristics of single-vehicle crashes with e-bikes in Switzerland. *Accident Analysis and Prevention*, 117, 232–238. https://doi.org/10.1016/J.AAP.2018.04.021

Hills, A. P., Mokhtar, N., & Byrne, N. M. (2014). Assessment of Physical Activity and Energy Expenditure: An Overview of Objective Measures. *Frontiers in Nutrition*, 1. https://www.frontiersin.org/articles/10.3389/fnut.2014.00005

Hiselius, L. W., & Svenssona, Å. (2014). Could the increased use of e-bikes (pedelecs) in Sweden contribute to a more sustainable transport system? *9th International Conference on Environmental Engineering, ICEE 2014*. https://doi.org/10.3846/enviro.2014.119

Hoj, T. H., Bramwell, J. J., Lister, C., Grant, E., Crookston, B. T., Hall, C., & West, J. H. (2018). Increasing active transportation through e-bike use: Pilot study comparing the health benefits, attitudes, and beliefs surrounding e-bikes and conventional bikes. *JMIR Public Health and Surveillance*, 4(4). https://doi.org/10.2196/10461

Hoj, T. H., Bramwell, J. J., Lister, C., Grant, E., Crookston, B. T., Hall, C., & West, J. H. (2018b). Increasing active transportation through e-bike use: Pilot study comparing the health benefits, attitudes, and beliefs surrounding e-bikes and conventional bikes. *JMIR Public Health and Surveillance*, 4(4). https://doi.org/10.2196/10461

Holbrook, M. B., & Hirschman, E. C. (1982). The Experiential Aspects of Consumption: Consumer Fantasies, Feelings, and Fun. *Journal of Consumer Research*, 9(2), 132–140. https://doi.org/10.1086/208906

Hollingsworth, J., Copeland, B., & Johnson, J. X. (2019). Are e-scooters polluters? The environmental impacts of shared dockless electric scooters. *Environmental Research Letters*, 14(8). https://doi.org/10.1088/1748-9326/ab2da8

Holtermann, A., Krause, N., Beek, A. J. van der, & Straker, L. (2018). The physical activity paradox: Six reasons why occupational physical activity (OPA) does not confer the cardiovascular health benefits that leisure time physical activity does. *British Journal of Sports Medicine*, 52(3), 149–150. https://doi.org/10.1136/bjsports-2017-097965

Hong, J., Shen, Q., & Zhang, L. (2014). How do built-environment factors affect travel behavior? A spatial analysis at different geographic scales. *Transportation*, 41(3), 419–440. https://doi.org/10.1007/s11116-013-9462-9

Hosseinzadeh, A., Algomaiah, M., Kluger, R., & Li, Z. (2021). Spatial analysis of shared e-scooter trips. *Journal of Transport Geography*, 92. https://doi.org/10.1016/j.jtrangeo.2021.103016

Hsieh, P. Y., Chang, L. F. W., Yu, T. Y., & Wu, K. C. (2018). Evaluation of mitigation effects on air pollutants for electric scooters in Taiwan with the energy flow analysis and system dynamics approach. *In P. Li (Ed.), 4th International Conference on Water Resource and Environment (WRE 2018)* (Vol. 191). https://doi.org/10.1088/1755-1315/191/1/012136

Huang, F.-H. (2021). User behavioral intentions toward a scooter-sharing service: An empirical study. *Sustainability* (Switzerland), 13(23). https://doi.org/10.3390/su132313153

Hulkkonen, M., Mielonen, T., & Prisle, N. L. (2020). The atmospheric impacts of initiatives advancing shifts towards low-emission mobility: A scoping review.

Science of The Total Environment, 713, 136133. https://doi.org/10.1016/j.scitotenv.2019.136133

Hunecke, M., Haustein, S., Böhler, S., & Grischkat, S. (2010). Attitude-based target groups to reduce the ecological impact of daily mobility behavior. *Environment and Behavior*, 42(1), 3–43. https://doi.org/10.1177/0013916508319587

Hyvönen, K., Repo, P., & Lammi, M. (2016). Light electric vehicles: Substitution and future uses. In J. Wulfhorst, G and Kinigadner (Ed.), *Transforming Urban Mobility*, 19, 258–268. https://doi.org/10.1016/j.trpro.2016.12.085

IERMB. (2021). Resum executiu. Enquesta de Mobilitat en Dia Feiner 2021 (EMEF 2021). *Institut Metròpoli*. https://iermb.uab.cat/wp-content/uploads/2022/05/EMEF-2021_Informe-Resum-Executiu.pdf

IERMB. (2023). Resum executiu. Enquesta de Mobilitat en Dia Feiner 2022 (EMEF 2022). *Institut Metròpoli*. http://iermb.uab.cat/wp-content/uploads/2023/11/EMEF_2022_Informe-Resum_Executiu_DEF.pdf

Institute for Transportation and Development Policy. (2021). Maximizing Micromobility.https://www.itdp.org/publication/maximizing-micromobility/

Instituto Nacional de Estadística (INE). (2022). Ejercicio físico regular y sedentarismo en el tiempo libre. Encuesta de Condiciones de Vida.https://www.ine.es/ss/Satellite?param1=PYSDetalleFichaIndicador&c=INESeccion_C&param3=1259947308577&p=1254735110672&pagename=ProductosYServicios%2FPYSLayout&cid=1259944495973&L=0

Jahre, A. B., Bere, E., Nordengen, S., Solbraa, A., Andersen, L. B., Riiser, A., & Bjørnarå, H. B. (2019). Public employees in South-Western Norway using an e-bike or a regular bike for commuting –A cross-sectional comparison on sociodemographic factors, commuting frequency and commuting distance. *Preventive Medicine Reports*, 14, 100881. https://doi.org/10.1016/J.PMEDR.2019.100881

James, O., Swiderski, J. I., Hicks, J., Teoman, D., & Buehler, R. (2019). Pedestrians and E-Scooters: An Initial Look at E-Scooter Parking and Perceptions by Riders and Non-Riders. *Sustainability*, 11(20), Article 20. https://doi.org/10.3390/su11205591

Jarrett, J., Woodcock, J., Griffiths, U. K., Chalabi, Z., Edwards, P., Roberts, I., & Haines, A. (2012). Effect of increasing active travel in urban England and

Wales on costs to the National Health Service. *The Lancet*, 379(9832), 2198–2205. https://doi.org/10.1016/S0140-6736(12)60766-1

Jetté, M., Sidney, K., & Blümchen, G. (1990). Metabolic equivalents (METS) in exercise testing, exercise prescription, and evaluation of functional capacity. *Clinical Cardiology*, 13(8), 555–565. https://doi.org/10.1002/clc.4960130809

Ji, S., Cherry, C. R., Han, L. D., & Jordan, D. A. (2014). Electric bike sharing: Simulation of user demand and system availability. *Journal Of Cleaner Production*, 85, 250–257. https://doi.org/10.1016/j.jclepro.2013.09.024

Johnson, M., & Rose, G. (2013). Electric bikes—Cycling in the New World City: An investigation of Australian electric bicycle owners and the decision making process for purchase. *Australasian Transport Research Forum, ATRF 2013 - Proceedings.* https://australasiantransportresearchforum.org.au/wp-content/uploads/2022/03/2013_johnson_rose.pdf

Johnson, M., & Rose, G. (2015). Extending life on the bike: Electric bike use by older Australians. *Journal of Transport & Health*, 2(2), 276–283. https://doi.org/10.1016/j.jth.2015.03.001

Johnson, R. (2018). Mobility scooters in the UK: Public perception of their role. *Proceedings of the Institution of Civil Engineers -Transport*, 171(4), 207–215. https://doi.org/10.1680/jtran.16.00140

Jones, T., & Chatterjee, K. (2023). Introduction to the Special Issue—Electric Micromobility Futures. *Active Travel Studies*, 3(1), Article 1. https://doi.org/10.16997/ats.1415

Jones, T., Harms, L., & Heinen, E. (2016). Motives, perceptions and experiences of electric bicycle owners and implications for health, wellbeing and mobility. *Journal of Transport Geography*, 53, 41–49. https://doi.org/10.1016/j.jtrangeo.2016.04.006

Kang, B., Moudon, A. V., Hurvitz, P. M., & Saelens, B. E. (2017). Differences in behavior, time, location, and built environment between objectively measured utilitarian and recreational walking. *Transportation Research Part D: Transport and Environment*, 57, 185–194. https://doi.org/10.1016/j.trd.2017.09.026

Kaplan, M. F., & Miller, C. E. (1987). Group decision making and normative versus informational influence: Effects of type of issue and assigned decision rule. *Journal of Personality and Social Psychology*, 53(2), 306–313. https://doi.org/10.1037/0022-3514.53.2.306

Kaplan, S., Manca, F., Nielsen, T. A. S., & Prato, C. G. (2015). Intentions to use bike-sharing for holiday cycling: An application of the Theory of Planned Behavior. *Tourism Management,* 47, 34–46. https://doi.org/10.1016/j.tourman.2014.08.017

Kaplan, S., Wrzesinska, D. K., & Prato, C. G. (2018). The role of human needs in the intention to use conventional and electric bicycle sharing in a driving-oriented country. *Transport Policy*, 71, pp 138-146. https://doi.org/10.1016/j.tranpol.2018.09.010

Katzmarzyk, P. T., Friedenreich, C., Shiroma, E. J., & Lee, I.-M. (2022). Physical inactivity and non-communicable disease burden in low-income, middle-income and high-income countries. *British Journal of Sports Medicine*, 56(2), 101–106. https://doi.org/10.1136/bjsports-2020-103640

Kazemzadeh, K., & Koglin, T. (2021). Electric bike (non)users' health and comfort concerns pre and peri a world pandemic (COVID-19): A qualitative study. *Journal of Transport & Health*, 20, 101014. https://doi.org/10.1016/j.jth.2021.101014

Kazemzadeh, K., & Sprei, F. (2024). The effect of shared e-scooter programs on modal shift: Evidence from Sweden. *Sustainable Cities and Society*, 101, 105097. https://doi.org/10.1016/j.scs.2023.105097

Kazmaier, M., Taefi, T., & Hettesheimer, T. (2020). Techno-economical and ecological potential of electrical scooters: A life cycle analysis. *European Journal of Transport and Infrastructure Research*, 20(4), 233–251. https://doi.org/10.18757/ejtir.2020.20.4.4912

Kerr, J., Patterson, R. E., Ellis, K., Godbole, S., Johnson, E., Lanckriet, G., & Staudenmayer, J. (2016). Objective Assessment of Physical Activity: Classifiers for Public Health. *Medicine and Science in Sports and Exercise*, 48(5), 951. https://doi.org/10.1249/MSS.0000000000000841

Khreis, H., & Nieuwenhuijsen, M. J. (2019). 8 -The health impacts of urban transport: Linkages, tools and research needs. In K. Lucas, K. Martens, F. Di Ciommo, & A. Dupont-Kieffer (Eds.), *Measuring Transport Equity*, 131–142. https://doi.org/10.1016/B978-0-12-814818-1.00008-1

Kiewiet, H., Bulsink, V. E., Beugels, F., & Koopman, H. F. J. M. (2017). The co-contraction index of the upper limb for young and old adult cyclists. *Accident Analysis and Prevention*, 105, 95–101. https://doi.org/10.1016/j.aap.2016.04.036

Kim, M., Lee, S., Ko, D. R., Kim, D. H., Huh, J. K., & Kim, J. Y. (2021). Craniofacial and dental injuries associated with stand-up electric scooters. *Dental Traumatology*, 37(2), 229–233. https://doi.org/10.1111/EDT.12620

Kim, S., Lee, G., Sangho, C., & hun Kim, S. (2021). Study on Shared E-scooter Usage Characteristics and Influencing Factors. *The Journal of The Korea Institute of Intelligent Transportation Systems*, 20(1), 40–53. https://doi.org/10.12815/kits.2021.20.1.40

King, C. C. S., Liu, M., Patel, S., Goo, T. T., Lim, W. W., & Toh, H. C. (2020). Injury patterns associated with personal mobility devices and electric bicycles: An analysis from an acute general hospital in Singapore. *Singapore Medical Journal*, 61(2), 96–101. https://doi.org/10.11622/SMEDJ.2019084

Kjaerup, M., Skov, M. B., van Berkel, N., Kjærup, M., Skov, M. B., & van Berkel, N. (2021). E-Scooter Sustainability—A Clash of Needs, Perspectives, and Experiences. *International Conference on Human-Computer Interaction (INTERACT)*, 365–383. https://doi.org/10.1007/978-3-030-85613-7_26

Klier, T., & Linn, J. (2015). Using Taxes to Reduce Carbon Dioxide Emissions Rates of New Passenger Vehicles: Evidence from France, Germany, and Sweden. *American Economic Journal: Economic Policy*, 7(1), 212–242. https://doi.org/10.1257/pol.20120256

Klöckner, C. A., & Matthies, E. (2004). How habits interfere with norm-directed behaviour: A normative decision-making model for travel mode choice. *Journal of Environmental Psychology*, 24(3), 319–327. https://doi.org/10.1016/J.JENVP.2004.08.004

Knott, C. S., Panter, J., Foley, L., & Ogilvie, D. (2018). Changes in the mode of travel to work and the severity of depressive symptoms: A longitudinal analysis of UK Biobank. *Preventive Medicine*, 112, 61–69. https://doi.org/10.1016/j.ypmed.2018.03.018

Ko, J., Lee, S., & Byun, M. (2019). Exploring factors associated with commute mode choice: An application of city-level general social survey data. *Transport Policy*, 75, 36–46. https://doi.org/10.1016/J.TRANPOL.2018.12.007

Kobayashi, L. M., Williams, E., Brown, C. V., Emigh, B. J., Bansal, V., Badiee, J., Checchi, K. D., Castillo, E. M., & Doucet, J. (2019). The e-merging e-pidemic of e-scooters. *Trauma Surgery & Acute Care Open*, 4(1). https://doi.org/10.1136/tsaco-2019-000337

Koohsari, M. J., & Oka, K. (2020). Walkable Neighborhoods: The Link between Public Health, Urban Design, and Transportation. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/books978-3-03921-931-5

Kopplin, C. S., Brand, B. M., & Reichenberger, Y. (2021). Consumer acceptance of shared e-scooters for urban and short-distance mobility. *Transportation Research Part D: Transport and Environment,* 91. https://doi.org/10.1016/j.trd.2020.102680

Krauss, K., Krail, M., & Axhausen, K. W. (2022). What drives the utility of shared transport services for urban travellers? A stated preference survey in German cities. *Travel Behaviour and Society*, 26, 206–220. https://doi.org/10.1016/j.tbs.2021.09.010

Krier, C., Chretien, J., Lagadic, M., & Louvet, N. (n.d.). How Do Shared Dockless E-Scooter Services Affect Mobility Practices in Paris? A Survey-Based Estimation of Modal Shift. *Transportation Research Record*. https://doi.org/10.1177/03611981211017133

Kroesen, M. (2017). To what extent do e-bikes substitute travel by other modes? Evidence from the Netherlands. *Transportation Research Part D: Transport and Environment,* 53, 377–387. https://doi.org/10.1016/j.trd.2017.04.036

Kroesen, M., & Chorus, C. (2020). A new perspective on the role of attitudes in explaining travel behavior: A psychological network model. *Transportation Research Part A: Policy and Practice,* 133, 82–94. https://doi.org/10.1016/J.TRA.2020.01.014

Kwiatkowski, M. A., Grzelak-Kostulska, E., & Biegańska, J. (2021). Could it be a bike for everyone? The electric bicycle in Poland. *Energies*, 14(16). https://doi.org/10.3390/en14164878

Laa, B., & Leth, U. (2020). Survey of E-scooter users in Vienna: Who they are and how they ride. *Journal of Transport Geography*, 89. https://doi.org/10.1016/j.jtrangeo.2020.102874

Lades, L. K., Kelly, A., & Kelleher, L. (2020). Why is active travel more satisfying than motorized travel? Evidence from Dublin. *Transportation Research Part A: Policy and Practice*, 136, 318–333. https://doi.org/10.1016/j.tra.2020.04.007

Landolfi, N. C., & Dragan, A. D. (2018). Social Cohesion in Autonomous Driving. *2018 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 8118–8125. https://doi.org/10.1109/IROS.2018.8593682

Langford, B. C., Cherry, C. R., Bassett, D. R., Fitzhugh, E. C., & Dhakal, N. (2017). Comparing physical activity of pedal-assist electric bikes with walking and conventional bicycles. *Journal of Transport & Health*, 6, 463–473. https://doi.org/10.1016/j.jth.2017.06.002

Langford, B. C., Cherry, C. R., Bassett, D. R., Fitzhugh, E. C., Dhakal, N., Bassett Jr., D. R., Fitzhugh, E. C., Dhakal, N., Bassett, D. R., Fitzhugh, E. C., Dhakal, N., Bassett Jr., D. R., Fitzhugh, E. C., Dhakal, N., Bassett, D. R., Fitzhugh, E. C., & Dhakal, N. (2017). Comparing physical activity of pedal-assist electric bikes with walking and conventional bicycles. *Journal Of Transport & Health*, 6, 463–473. https://doi.org/10.1016/j.jth.2017.06.002

Latinopoulos, C., Patrier, A., & Sivakumar, A. (2021). Planning for e-scooter use in metropolitan cities: A case study for Paris. *Transportation Research Part D: Transport and Environment*, 100, 103037. https://doi.org/10.1016/J.TRD.2021.103037

Laurischkat, K., & Jandt, D. (2018). Techno-economic analysis of sustainable mobility and energy solutions consisting of electric vehicles, photovoltaic systems and battery storages. *Journal of Cleaner Production*, 179, 642–661. https://doi.org/10.1016/J.JCLEPRO.2017.11.201

Laverty, A. A., Palladino, R., Lee, J. T., & Millett, C. (2015). Associations between active travel and weight, blood pressure and diabetes in six middle income countries: A cross-sectional study in older adults. *International Journal of Behavioral Nutrition and Physical Activity*, 12(1), 65. https://doi.org/10.1186/s12966-015-0223-3

Lavoie-Gagne, O., Siow, M., Harkin, W. E., Flores, A. R., Politzer, C. S., Mitchell, B. C., Girard, P. J., Schwartz, A. K., & Kent, W. T. (2021). Financial impact of electric scooters: A review of injuries over 27 months at an urban level 1 trauma center (cost of e-scooter injuries at an urban level 1 trauma center). *Trauma Surgery and Acute Care Open*, 6(1), e000634. https://doi.org/10.1136/TSACO-2020-000634

Lavoie-Gagne, O., Siow, M., Harkin, W., Flores, A. R., Girard, P. J., Schwartz, A. K., & Kent, W. T. (2021). Characterization of electric scooter injuries over 27 months at an urban level 1 trauma center. *American Journal of Emergency Medicine*, 45, 129–136. https://doi.org/10.1016/J.AJEM.2021.02.019

Lawlor, E. R., Hunter, R. F., Adlakha, D., Kee, F., & Tully, M. A. (2021). Individual Characteristics Associated with Active Travel in Low and High Income

Groups in the UK. *International Journal of Environmental Research and Public Health*, 18(19), Article 19. https://doi.org/10.3390/ijerph181910360

Lee, H., Baek, K., Chung, J.-H., & Kim, J. (2021). Factors affecting heterogeneity in willingness to use e-scooter sharing services. *Transportation Research Part D-Transport and Environment*, 92. https://doi.org/10.1016/j.trd.2021.102751

Lee, I. M., Shiroma, E. J., Lobelo, F., Puska, P., Blair, S. N., Katzmarzyk, P. T., Alkandari, J. R., Andersen, L. B., Bauman, A. E., Brownson, R. C., Bull, F. C., Craig, C. L., Ekelund, U., Goenka, S., Guthold, R., Hallal, P. C., Haskell, W. L., Heath, G. W., Inoue, S., … Wells, J. C. (2012). Effect of physical inactivity on major non-communicable diseases worldwide: An analysis of burden of disease and life expectancy. *The Lancet*, 380(9838), 219–229. https://doi.org/10.1016/S0140-6736(12)61031-9

Lee, J., Baig, F., Talpur, M. A. H., & Shaikh, S. (2021). Public intentions to purchase electric vehicles in Pakistan. *Sustainability* (Switzerland), 13(10). https://doi.org/10.3390/su13105523

Lee, K., & Kwan, M.-P. (2018). Automatic physical activity and in-vehicle status classification based on GPS and accelerometer data: A hierarchical classification approach using machine learning techniques. *Transactions in GIS*, 22(6), 1522–1549. https://doi.org/10.1111/tgis.12485

Leger, S. J., Dean, J. L., Edge, S., & Casello, J. M. (2019). “If I had a regular bicycle, I wouldn’t be out riding anymore”: Perspectives on the potential of e-bikes to support active living and independent mobility among older adults in Waterloo, Canada. *Transportation Research Part A: Policy and Practice*, 123, 240–254. https://doi.org/10.1016/j.tra.2018.10.009

Lemieux, M., & Godin, G. (2009). How well do cognitive and environmental variables predict active commuting? *International Journal of Behavioral Nutrition and Physical Activity*, 6(1), 12. https://doi.org/10.1186/1479-5868-6-12

Leroi-Werelds, S., Streukens, S., Brady, M. K., & Swinnen, G. (2014). Assessing the value of commonly used methods for measuring customer value: A multi-setting empirical study. *Journal of the Academy of Marketing Science*, 42(4), 430–451. https://doi.org/10.1007/S11747-013-0363-4

Levin, I. P., Mosell, M. K., Lamka, C. M., Savage, B. E., & Gray, M. J. (1977). Measurement of psychological factors and their role in travel behavior. *Transportation Research Record*.

https://www.semanticscholar.org/paper/MEASUREMENT-OF-PSYCHOLOGICAL-FACTORS-AND-THEIR-ROLE-Levin-Mosell/115951fe971aa5ff477438d43daecb1fcbe42fdb

Leyland, L. A. L.-A., Spencer, B., Beale, N., Jones, T., & van Reekum, C. M. (2019). The effect of cycling on cognitive function and well-being in older adults. *PLoS ONE*, 14(2). https://doi.org/10.1371/journal.pone.0211779

Li, X., Tang, J., Hu, X., & Wang, W. (2020). Assessing intercity multimodal choice behavior in a Touristy City: A factor analysis. *Journal of Transport Geography*, 86, 102776. https://doi.org/10.1016/j.jtrangeo.2020.102776

Liao, F., & Correia, G. (2022). Electric carsharing and micromobility: A literature review on their usage pattern, demand, and potential impacts. *International Journal of Sustainable Transportation*, 16(3), 269–286. https://doi.org/10.1080/15568318.2020.1861394

Liew, Y. K., Wee, C. P. J., & Pek, J. H. (2020). New peril on our roads: A retrospective study of electric scooter-related injuries. *Singapore Medical Journal*, 61(2), 92–95. https://doi.org/10.11622/SMEDJ.2019083

Lin, X., Wells, P., & Sovacool, B. K. (2018). The death of a transport regime? The future of electric bicycles and transportation pathways for sustainable mobility in China. *Technological Forecasting and Social Change*, 132, 255–267. https://doi.org/10.1016/j.techfore.2018.02.008

Lind, A., Honey-Rosés, J., & Corbera, E. (2021). Rule compliance and desire lines in Barcelona's cycling network. *Transportation Letters*, 13(10), 728–737. https://doi.org/10.1080/19427867.2020.1803542

Ling, Z., Cherry, C. R., MacArthur, J. H., & Weinert, J. X. (2017). Differences of cycling experiences and perceptions between e-bike and bicycle users in the United States? *Sustainability* (Switzerland), 9(9). https://doi.org/10.3390/su9091662

Lisco, T. E. (1968). Value of commuters travel time - A study in urban transportation. *Highway Research Record*. https://trid.trb.org/view/133908

Liu, F., Wanigatunga, A. A., & Schrack, J. A. (2021). Assessment of Physical Activity in Adults Using Wrist Accelerometers. *Epidemiologic Reviews*, 43(1), 65–93. https://doi.org/10.1093/EPIREV/MXAB004

Liu, J., Wang, B., & Xiao, L. (2021). Non-linear associations between built environment and active travel for working and shopping: An extreme gradient boosting approach. *Journal of Transport Geography*, 92. https://doi.org/10.1016/j.jtrangeo.2021.103034

Liu, L., Silva, E. A., & Yang, Z. (2021). Similar outcomes, different paths: Tracing the relationship between neighborhood-scale built environment and travel behavior using activity-based modelling. *Cities*, 110, 103061. https://doi.org/10.1016/j.cities.2020.103061

López-Dóriga, I., Vich, G., Koch, S., Khomenko, S., Marquet, O., Roig-Costa, O., Daher, C., Rasella, D., Nieuwenhuijsen, M., & Mueller, N. (2022). Health impacts of electric micromobility transitions in Barcelona: A scenario analysis. *Environmental Impact Assessment Review*, 96, 106836. https://doi.org/10.1016/j.eiar.2022.106836

Lorenzo, E., Szeszulski, J., Shin, C.-N., Todd, M., & Lee, R. E. (2020). Relationship between walking for active transportation and cardiometabolic health among adults: A systematic review. *Journal of Transport & Health*, 19, 100927. https://doi.org/10.1016/j.jth.2020.100927

Louis, J., Brisswalter, J., Morio, C., Barla, C., & Temprado, J.-J. (2012). The electrically assisted bicycle an alternative way to promote physical activity. *American Journal of Physical Medicine and Rehabilitation*, 91(11), 931–940. https://doi.org/10.1097/PHM.0b013e318269d9bb

Lüdecke, D. (2018). ggeffects: Tidy Data Frames of Marginal Effects from Regression Models. *Journal of Open Source Software*, 3(26), 772. https://doi.org/10.21105/joss.00772

Luo, P., Guo, G., & Zhang, W. (2022). The role of social influence in green travel behavior in rural China. *Transportation Research Part D: Transport and Environment*, 107, 103284. https://doi.org/10.1016/j.trd.2022.103284

Ma, L., Ye, R., & Wang, H. (2021). Exploring the causal effects of bicycling for transportation on mental health. *Transportation Research Part D: Transport and Environment*, 93, 102773. https://doi.org/10.1016/J.TRD.2021.102773

Macarthur, J. (2017). Evaluation of an Electric Bike Pilot Project at Three Employment Campuses in Portland, Oregon. *Transportation Research and Education Center (TREC).* http://dx.doi.org/10.15760/trec.158

MacArthur, J., Harpool, M., Schepke, D., & Cherry, C. (2018). A North American Survey of Electric Bicycle Owners. *Transportation Research and Education Center (TREC).* https://doi.org/10.15760/trec.197

Marquet, O., Aaron Hipp, J., Alberico, C., Huang, J. H., Fry, D., Mazak, E., Lovasi, G. S., & Floyd, M. F. (2019). Park use preferences and physical activity among ethnic minority children in low-income neighborhoods in New York City. *Urban Forestry & Urban Greening*, 38, 346–353. https://doi.org/10.1016/J.UFUG.2019.01.018

Marquet, O., Floyd, M. F., James, P., Glanz, K., Jennings, V., Jankowska, M. M., Kerr, J., & Hipp, J. A. (2018). Associations Between Worksite Walkability, Greenness, and Physical Activity Around Work. *Environment and Behavior*, 52(2), 139-163. https://doi.org/10.1177/0013916518797165

Marquet, O., Hirsch, J. A., Kerr, J., Jankowska, M. M., Mitchell, J., Hart, J. E., Laden, F., Hipp, J. A., & James, P. (2022). GPS-based activity space exposure to greenness and walkability is associated with increased accelerometer-based physical activity. *Environment International*, 165, 107317. https://doi.org/10.1016/J.ENVINT.2022.107317

Marquet, O., MacIejewska, M., Delclòs-Alió, X., Vich, G., Schipperijn, J., & Miralles-Guasch, C. (2020). Physical activity benefits of attending a senior center depend largely on age and gender: A study using GPS and accelerometry data. *BMC Geriatrics*, 20(1), 1–10. https://doi.org/10.1186/s12877-020-01527-6

Marquet, O., & Miralles-Guasch, C. (2015). The Walkable city and the importance of the proximity environments for Barcelona's everyday mobility. *Cities*, 42, 258–266. https://doi.org/10.1016/j.cities.2014.10.012

Marquet, O., & Miralles-Guasch, C. (2018). Resilient territories and mobility adaptation strategies in times of economic recession: Evidence from the metropolitan region of Barcelona, Spain 2004–2012. *European Urban and Regional Studies*, 25(4), 345–359. https://doi.org/10.1177/0969776417703158/ASSET/IMAGES/LARGE/10.1177_0969776417703158-FIG2.JPEG

Matthews, C. E., Moore, S. C., George, S. M., Sampson, J., & Bowles, H. R. (2012). Improving self-reports of active and sedentary behaviors in large epidemiologic studies. *Exercise and Sport Sciences Reviews*, 40(3), 118–126. https://doi.org/10.1097/JES.0B013E31825B34A0

Mattioli, G., Anable, J., & Vrotsou, K. (2016). Car dependent practices: Findings from a sequence pattern mining study of UK time use data. *Transportation Research Part A: Policy and Practice*, 89, 56–72. https://doi.org/10.1016/j.tra.2016.04.010

May, E., Garrett, R., & Ballantyne, A. (2010). Being mobile: Electric mobility-scooters and their use by older people. *Ageing & Society*, 30(7), 1219–1237. https://doi.org/10.1017/S0144686X10000334

Mayer, A. (2020). Motivations and barriers to electric bike use in the U.S.: Views from online forum participants. *International Journal of Urban Sustainable Development,* 12(2), 160–168. https://doi.org/10.1080/19463138.2019.1672696

McDonald, N. C. (2007). Travel and the social environment: Evidence from Alameda County, California. *Transportation Research Part D: Transport and Environment*, 12(1), 53–63. https://doi.org/10.1016/j.trd.2006.11.002

McGinn, A. P., Evenson, K. R., Herring, A. H., & Huston, S. L. (2007). The relationship between leisure, walking, and transportation activity with the natural environment. *Health & Place*, 13(3), 588–602. https://doi.org/10.1016/j.healthplace.2006.07.002

McGuinness, M. J., Tiong, Y., & Bhagvan, S. (2021). Shared electric scooter injuries admitted to Auckland City Hospital: A comparative review one year after their introduction. *New Zealand Medical Journal*, 134(1530), 21–29. PMID: 33651774

McQueen, M., Abou-Zeid, G., MacArthur, J., & Clifton, K. (2021). Transportation Transformation: Is Micromobility Making a Macro Impact on Sustainability? *Journal of Planning Literature*, 36(1), 46–61. https://doi.org/10.1177/0885412220972696

McQueen, M., MacArthur, J., & Cherry, C. (2020). The E-Bike Potential: Estimating regional e-bike impacts on greenhouse gas emissions. *Transportation Research Part D: Transport and Environment*, 87. https://doi.org/10.1016/j.trd.2020.102482

Meireles, M., Robaina, M., & Magueta, D. (2021). The Effectiveness of Environmental Taxes in Reducing CO2 Emissions in Passenger Vehicles: The Case of Mediterranean Countries. *International Journal of Environmental Research and Public Health*, 18(10), Article 10. https://doi.org/10.3390/ijerph18105442

Melia, S., & Bartle, C. (2021). Who uses e-bikes in the UK and why? *International Journal of Sustainable Transportation.* https://doi.org/10.1080/15568318.2021.1956027

Mendes de Leon, C. F., Cagney, K. A., Bienias, J. L., Barnes, L. L., Skarupski, K. A., Scherr, P. A., & Evans, D. A. (2009). Neighborhood Social Cohesion and Disorder in Relation to Walking in Community-Dwelling Older Adults: A

Multilevel Analysis. *Journal of Aging and Health*, 21(1), 155–171. https://doi.org/10.1177/0898264308328650

Mendes, M. de A., Silva, I. da, Ramires, V., Reichert, F., Martins, R., Ferreira, R., & Tomasi, E. (2018). Metabolic equivalent of task (METs) thresholds as an indicator of physical activity intensity. *PLOS ONE*, 13(7), e0200701. https://doi.org/10.1371/journal.pone.0200701

Mendinueta, A., Esnal, H., Arrieta, H., Arrue, M., Urbieta, N., Ubillos, I., Whitworth, K. W., Delclòs-Alió, X., Vich, G., & Ibarluzea, J. (2020). What accounts for physical activity during pregnancy? A study on the sociodemographic predictors of self-reported and objectively assessed physical activity during the 1st and 2nd trimesters of pregnancy. *International Journal of Environmental Research and Public Health*, 17(7). https://doi.org/10.3390/ijerph17072517

Metz, D. (2008). The Myth of Travel Time Saving. *Transport Reviews*, 28(3), 321–336. https://doi.org/10.1080/01441640701642348

Metz, D. (2017). Future transport technologies for an ageing society: Practice and policy. *Transport and Sustainability*, 10, 207–220. https://doi.org/10.1108/S2044-994120170000010009

Milakis, D., Gedhardt, L., Ehebrecht, D., & Lenz, B. (2020). Is micromobility sustainable? An overview of implications for accessibility, air pollution, safety, physical activity and subjective wellbeing. *Handbook of Sustainable Transport*, 180–189. https://doi.org/10.4337/9781789900477.00030

Mildestvedt, T., Hovland, O., Berntsen, S., Bere, E., & Fegran, L. (2020). Getting physically active by e-bike: An active commuting intervention study. *Physical Activity and Health*, 4(1), 120–129. https://doi.org/10.5334/paah.63

Miller, H. J., Tribby, C. P., Brown, B. B., Smith, K. R., Werner, C. M., Wolf, J., Wilson, L., & Oliveira, M. G. S. (2015). Public transit generates new physical activity: Evidence from individual GPS and accelerometer data before and after light rail construction in a neighborhood of Salt Lake City, Utah, USA. *Health & Place,* 36, 8–17. https://doi.org/10.1016/J.HEALTHPLACE.2015.08.005

Millett, C., Agrawal, S., Sullivan, R., Vaz, M., Kurpad, A., Bharathi, A. V., Prabhakaran, D., Reddy, K. S., Kinra, S., Smith, G. D., Ebrahim, S., & Group, for the I. M. S. (2013). Associations between Active Travel to Work and Overweight, Hypertension, and Diabetes in India: A Cross-Sectional Study. *PLOS Medicine*, 10(6), e1001459. https://doi.org/10.1371/journal.pmed.1001459

Miralles-Guasch, C., & Tulla Pujol, A. F. (2012). La región metropolitana de Barcelona. Dinámicas territoriales recientes. *Boletín de La Asociación de Geógrafos Españoles*. https://bage.age-geografia.es/ojs//index.php/bage/article/view/2069

Mitra, R., & Hess, P. M. (2021). Who are the potential users of shared e-scooters? An examination of socio-demographic, attitudinal and environmental factors. *Travel Behaviour and Society*, 23, 100–107. https://doi.org/10.1016/j.tbs.2020.12.004

Mitropoulos, L., Stavropoulou, E., Tzouras, P., Karolemeas, C., & Kepaptsoglou, K. (2023). E-scooter micromobility systems: Review of attributes and impacts. *Transportation Research Interdisciplinary Perspectives*, 21, 100888. https://doi.org/10.1016/j.trip.2023.100888

Moftakhar, T., Wanzel, M., Vojcsik, A., Kralinger, F., Mousavi, M., Hajdu, S., Aldrian, S., & Starlinger, J. (2021). Incidence and severity of electric scooter related injuries after introduction of an urban rental programme in Vienna: A retrospective multicentre study. *Archives of Orthopaedic and Trauma Surgery,* 141(7), 1207–1213. https://doi.org/10.1007/s00402-020-03589-y

Mooney, S. J., Hosford, K., Howee, B., Yan, A., Winters, M., Bassok, A., & Hirsch, J. A. (2019). Freedom from the station: Spatial equity in access to dockless bike share. *Journal of Transport Geography*, 74, 91–96. https://doi.org/10.1016/j.jtrangeo.2018.11.009

Moran, M. E., Laa, B., & Emberger, G. (2020). Six scooter operators, six maps: Spatial coverage and regulation of micromobility in Vienna, Austria. *Case Studies on Transport Policy*, 8(2), 658–671. https://doi.org/10.1016/j.cstp.2020.03.001

Moreau, H., de Meux, L. de J., Zeller, V., D'Ans, P., Ruwet, C., & Achten, W. M. J. (2020). Dockless e-scooter: A green solution for mobility? Comparative case study between dockless e-scooters, displaced transport, and personal e-scooters. *Sustainability* (Switzerland), 12(5). https://doi.org/10.3390/su12051803

Moser, C., Blumer, Y., & Hille, S. L. (2018). E-bike trials' potential to promote sustained changes in car owners mobility habits. *Environmental Research Letters*, 13(4), 044025. https://doi.org/10.1088/1748-9326/AAAD73

Mouratidis, K. (2022). Bike-sharing, car-sharing, e-scooters, and Uber: Who are the shared mobility users and where do they live? Sustainable Cities and Society, 86, 104161. https://doi.org/10.1016/j.scs.2022.104161

Muehlegger, E., & Rapson, D. S. (2022). Subsidizing low-and middle-income adoption of electric vehicles: Quasi-experimental evidence from California. *Journal of Public Economics*, 216, 104752. https://doi.org/10.1016/j.jpubeco.2022.104752

Mueller, N., Rojas-Rueda, D., Basagaña, X., Cirach, M., Cole-Hunter, T., Dadvand, P., Donaire-Gonzalez, D., Foraster, M., Gascon, M., Martinez, D., Tonne, C., Triguero-Mas, M., Valentín, A., & Nieuwenhuijsen, M. (2017). Health impacts related to urban and transport planning: A burden of disease assessment. *Environment International*, 107, 243–257. https://doi.org/10.1016/j.envint.2017.07.020

Mueller, N., Rojas-Rueda, D., Cole-Hunter, T., de Nazelle, A., Dons, E., Gerike, R., Götschi, T., Int Panis, L., Kahlmeier, S., & Nieuwenhuijsen, M. (2015). Health impact assessment of active transportation: A systematic review. *Preventive Medicine*, 76, 103–114. https://doi.org/10.1016/j.ypmed.2015.04.010

Munkácsy, A., & Monzón, A. (2017). Impacts of smart configuration in pedelec-sharing: Evidence from a panel survey in madrid. *Journal of Advanced Transportation*, 2017. https://doi.org/10.1155/2017/4720627

Murphy, S. L. (2008). Review of physical activity measurement using accelerometers in older adults: Considerations for research design and conduct. *Preventive Medicine*, 48(2), 108–114. https://doi.org/10.1016/J.YPMED.2008.12.001

Nasri, A., & Zhang, L. (2012). Impact of Metropolitan-Level Built Environment on Travel Behavior. *Transportation Research Record*, 2323(1), 75–79. https://doi.org/10.3141/2323-09

National Center for Chronic Disease Prevention and Health. (2022). About Adult BMI: Healthy Weight, Nutrition, and Physical Activity. https://www.cdc.gov/healthyweight/assessing/bmi/adult_bmi/index.html

Nehme, E. K., Pérez, A., Ranjit, N., Amick, B. C., & Kohl, H. W. (2016). Sociodemographic Factors, Population Density, and Bicycling for Transportation in the United States. *Journal of Physical Activity and Health*, 13(1), 36–43. https://doi.org/10.1123/jpah.2014-0469

Nematchoua, M., Deuse, C., Cools, M., & Reiter, S. (2020). Evaluation of the potential of classic and electric bicycle commuting as an impetus for the transition towards environmentally sustainable cities: A case study of the university campuses in Liege, Belgium. *Renewable and Sustainable Energy Reviews*, 119, 109544. https://doi.org/10.1016/j.rser.2019.109544

Newson, C., & Sloman, L. (2019). The Case for a UK Incentive for E-bikes.Bicycle Association. https://www.bicycleassociation.org.uk/wp-content/uploads/2019/07/The-Case-for-a-UK-Incentive-for-E-bikes-FINAL.pdf

Nieuwenhuijsen, M. J., Khreis, H., Verlinghieri, E., Mueller, N., & Rojas-Rueda, D. (2017). Participatory quantitative health impact assessment of urban and transport planning in cities: A review and research needs. *Environment International*, 103, 61–72. https://doi.org/10.1016/j.envint.2017.03.022

Nikiforiadis, A., Paschalidis, E., Stamatiadis, N., Raptopoulou, A., Kostareli, A., & Basbas, S. (2021). Analysis of attitudes and engagement of shared e-scooter users. *Transportation Research Part D: Transport and Environment*, 94, 102790. https://doi.org/10.1016/j.trd.2021.102790

Noland, R. B. (2019). Trip Patterns and Revenue of Shared E-Scooters in Louisville, Kentucky. *Findings*. https://doi.org/10.32866/7747

Nordfjærn, T., & Rundmo, T. (2018). Acceptance of disincentives to driving and pro-environmental transport intentions: The role of value structure, environmental beliefs and norm activation. *Transportation*, 46(6), 2381–2396. https://doi.org/10.1007/S11116-018-9950-Z

Oeschger, G., Carroll, P. P., & Caulfield, B. (2020). Micromobility and public transport integration: The current state of knowledge. *Transportation Research Part D: Transport and Environment*, 89, 102628. https://doi.org/10.1016/j.trd.2020.102628

Ognissanto, F., Hopkin, J., Stevens, A., Millard, K., & Jones, M. (2018). An evaluation of innovative active travel solutions. *TRL*. https://trl.co.uk/publications/an-evaluation-of-innovative-active-travel-solutions

Oja, P., Titze, S., Bauman, A., de Geus, B., Krenn, P., Reger-Nash, B., & Kohlberger, T. (2011). Health benefits of cycling: A systematic review. *Scandinavian Journal of Medicine and Science in Sports*, 21(4), 496–509. https://doi.org/10.1111/J.1600-0838.2011.01299.X

Oksanen, E., Turunen, A., & Thorén, H. (2020). Assessment of Craniomaxillofacial Injuries After Electric Scooter Accidents in Turku, Finland, in 2019. *Journal of Oral and Maxillofacial Surgery,* 78(12), 2273–2278. https://doi.org/10.1016/j.joms.2020.05.038

Oliver, M., Badland, H., Mavoa, S., Duncan, M. J., & Duncan, S. (2010). Combining GPS, GIS, and Accelerometry: Methodological Issues in the Assessment of

Location and Intensity of Travel Behaviors. *Journal of Physical Activity and Health*, 7(1), 102–108. https://doi.org/10.1123/JPAH.7.1.102

Oort, C. J. (1969). The evaluation of travelling time. *Journal of Transport Economics and Policy,* 3(3), 279–286. http://www.jstor.org/stable/20052155

Otero, I., Nieuwenhuijsen, M. J., & Rojas-Rueda, D. (2018). Health impacts of bike sharing systems in Europe. *Environment International*, 115, 387–394. https://doi.org/10.1016/j.envint.2018.04.014

Padeiro, M., Louro, A., & da Costa, N. M. (2019). Transit-oriented development and gentrification: A systematic review. *Transport Reviews*, 39(6), 733–754. https://doi.org/10.1080/01441647.2019.1649316

Páez, A., & Scott, D. M. (2007). Social Influence on Travel Behavior: A Simulation Example of the Decision to Telecommute. *Environment and Planning A: Economy and Space*, 39(3), 647–665. https://doi.org/10.1068/a37424

Panter, J. R., & Jones, A. (2010). Attitudes and the Environment as Determinants of Active Travel in Adults: What Do and Don't We Know? *Journal of Physical Activity and Health,* 7(4), 551–561. https://doi.org/10.1123/jpah.7.4.551

Panwinkler, T., & Holz-Rau, C. (2021). Causes of pedelec (pedal electric cycle) single accidents and their influence on injury severity. *Accident Analysis & Prevention*, 154. https://doi.org/10.1016/j.aap.2021.106082

Patil, M., & Majumdar, B. B. (2021). Prioritizing key attributes influencing electric two-wheeler usage: A multi criteria decision making (MCDM) approach –A case study of Hyderabad, India. *Case Studies on Transport Policy*, 9(2), 913–929. https://doi.org/10.1016/j.cstp.2021.04.011

Pavlenko, N., Slowik, P., & Lutsey, N. (2019). When does electrifying shared mobility make economic sense? *The International Council on Clean Transportation (icct)*. https://theicct.org/wp-content/uploads/2021/06/Electric_shared_mobility_20190114.pdf

Peterman, J. E., Morris, K. L., Kram, R., & Byrnes, W. C. (2016). Pedelecs as a physically active transportation mode. *European Journal of Applied Physiology,* 116(8), 1565–1573. https://doi.org/10.1007/s00421-016-3408-9

Pettersson, I., Hagberg, L., Fredriksson, C., & Hermansson, L. N. (2016). The effect of powered scooters on activity, participation and quality of life in elderly users. *Disability and Rehabilitation: Assistive Technology*, 11(7), 558–563. https://doi.org/10.3109/17483107.2015.1027301

Pétursdóttir, S. G., Kristjánsson, J. M., & Björnsson, H. M. (2021). Emergency department visits in Reykjavik for electric scooter related injuries during the summer of 2020. *Laeknabladid*, 107(5), 234–238. https://doi.org/10.17992/LBL.2021.05.635

Petzoldt, T., Schleinitz, K., Heilmann, S., & Gehlert, T. (2017). Traffic conflicts and their contextual factors when riding conventional vs. Electric bicycles. *Transportation Research Part F: Traffic Psychology and Behaviour*, 46, 477–490. https://doi.org/10.1016/j.trf.2016.06.010

Pietrzak, O., & Pietrzak, K. (2021). The economic effects of electromobility in sustainable urban public transport. *Energies*, 14(4). https://doi.org/10.3390/en14040878

Pike, S., & Lubell, M. (2018). The conditional effects of social influence in transportation mode choice. *Research in Transportation Economics*, 68, 2–10. https://doi.org/10.1016/j.retrec.2018.05.010

Pimentel, R. W., & Lowry, M. B. (2020). If You Provide, Will They Ride? Motivators and Deterrents to Shared Micromobility (Final Project Report). *Pacific Northwest Transportation Consortium (PacTrans).* https://rosap.ntl.bts.gov/view/dot/54013#:~:text=Convenience%20and%20social%20good%20were,insufficient%20bike%20lanes%20and%20paths.

Pizarro, A. N., Schipperijn, J., Andersen, H. B., Ribeiro, J. C., Mota, J., & Santos, M. P. (2016). Active commuting to school in Portuguese adolescents: Using PALMS to detect trips. *Journal of Transport & Health*, 3(3), 297–304. https://doi.org/10.1016/J.JTH.2016.02.004

Plasqui, G., Bonomi, A. G., & Westerterp, K. R. (2013). Daily physical activity assessment with accelerometers: New insights and validation studies. *Obesity Reviews*, 14(6), 451–462. https://doi.org/10.1111/OBR.12021

Plazier, P. A., Weitkamp, G., & van den Berg, A. E. (2017). The potential for e-biking among the younger population: A study of Dutch students. *Travel Behaviour and Society*, 8, 37–45. https://doi.org/10.1016/j.tbs.2017.04.007

Popovich, N., Gordon, E., Shao, Z., Xing, Y., Wang, Y., & Handy, S. (2014). Experiences of Electric Bicycle Users in the Davis/Sacramento, California Area. *Travel Behaviour and Society*, 1(2), 17p. https://doi.org/10.1016/j.tbs.2013.10.006

Porcelli, P., Ungar, M., Liebenberg, L., & Trépanier, N. (2014). (Micro)mobility, disability and resilience: Exploring well-being among youth with physical disabilities. *Disability & Society*, 29(6), 863–876. https://doi.org/10.1080/09687599.2014.902360

Prati, G., Fraboni, F., De Angelis, M., Pietrantoni, L., Johnson, D., & Shires, J. (2019). Gender differences in cycling patterns and attitudes towards cycling in a sample of European regular cyclists. *Journal of Transport Geography*, 78, 1–7. Scopus. https://doi.org/10.1016/j.jtrangeo.2019.05.006

Pucher, J. (1988). Urban Travel Behavior as the Outcome of Public Policy: The Example of Modal-Split in Western Europe and North America. *Journal of the American Planning Association*, 54(4), 509–520. https://doi.org/10.1080/01944368808976677

Puzio, T. J., Murphy, P. B., Gazzetta, J., Dineen, H. A., Savage, S. A., Streib, E. W., & Zarzaur, B. L. (2020). The Electric Scooter: A Surging New Mode of Transportation That Comes with Risk to Riders. *Traffic Injury Prevention*, 21(2), pp 175-178. https://doi.org/10.1080/15389588.2019.1709176

Qian, Y., Sun, Q., Fei, G., Li, X., Stallones, L., Xiang, H., & Zhang, X. (2020). Riding Behavior and Electric Bike Traffic Crashes: A Chinese Case-Control Study. *Traffic Injury Prevention*, 21(1), pp 24-28. https://doi.org/10.1080/15389588.2019.1696963

Quarmby, D. A. (1967). Choice of travel Mode for the Journey to Work: Some Findings. *Journal of Transport Economics and Policy*, 1(3), 273–314. http://www.jstor.org/stable/20052067

Queiroz, M. M., Celeste, P., & Moura, F. (2020). School commuting: The influence of soft and hard factors to shift to public transport. *Transportation Research Procedia*, 47, 625–632. https://doi.org/10.1016/J.TRPRO.2020.03.140

Raustorp, J., & Koglin, T. (2019). The potential for active commuting by bicycle and its possible effects on public health. *Journal of Transport and Health*, 13, 72–77. https://doi.org/10.1016/j.jth.2019.03.012

Rayaprolu, S., & Venigalla, M. (2020). Motivations and Mode-choice Behavior of Micromobility Users in Washington, DC. *Journal of Modern Mobility Systems*, 1, 110–118. https://doi.org/10.13021/jmms.2020.2894

Raza, W., Krachler, B., Forsberg, B., & Sommar, J. N. (2020). Health benefits of leisure time and commuting physical activity: A meta-analysis of effects on morbidity. *Journal of Transport & Health*, 18, 100873. https://doi.org/10.1016/J.JTH.2020.100873

Reck, D. J., Haitao, H., Guidon, S., & Axhausen, K. W. (2021). Explaining shared micromobility usage, competition and mode choice by modelling empirical data from Zurich, Switzerland. *Transportation Research Part C: Emerging Technologies*, 124. https://doi.org/10.1016/j.trc.2020.102947

Reck, D. J., Martin, H., & Axhausen, K. W. (2022). Mode choice, substitution patterns and environmental impacts of shared and personal micro mobility. *Transportation Research Part D: Transport and Environment*, 102, 103134. https://doi.org/10.1016/j.trd.2021.103134

Reinhardt, K. & Deakin, E. (2020). Best Practices for the Public Management of Electric Scooters (Research Report). *Institute of Transportation Studies, University of California*. https://escholarship.org/uc/item/8x67x360

Rejali, S., Aghabayk, K., Mohammadi, A., & Shiwakoti, N. (2021). Assessing a priori acceptance of shared dockless e scooters in Iran. *Transportation Research Part D: Transport and Environment*, 100. https://doi.org/10.1016/j.trd.2021.103042

Requia, W. J., Mohamed, M., Higgins, C. D., Arain, A., & Ferguson, M. (2018). How clean are electric vehicles? Evidence based review of the effects of electric mobility on air pollutants, greenhouse gas emissions and human health. *Atmospheric Environment*, 185, 64–77. https://doi.org/10.1016/j.atmosenv.2018.04.040

Rérat, P. (2021). The rise of the e-bike: Towards an extension of the practice of cycling? *Mobilities*, 16 (3), 423–439. https://doi.org/10.1080/17450101.2021.1897236

Rissel, C., Petrunoff, N., Wen, L. M., & Crane, M. (2014). Travel to work and self-reported stress: Findings from a workplace survey in southwest Sydney, Australia. *Journal of Transport & Health*, 1 (1), 50–53. https://doi.org/10.1016/j.jth.2013.09.001

Roig-Costa, O., Gómez Varo, I., Cubells, J., & Marquet, O. (2021). La movilidad post pandemia: Perfiles y usos de la micromovilidad en Barcelona. *Revista Transporte y Territorio*, 25 (25), 72–96. https://doi.org/10.34096/rtt.i25.10958

Rojas-Rueda, D., De Nazelle, A., Andersen, Z. J., Braun Fahrländer, C., Bruha, J., Bruhova Foltynova, H., Desqueyroux, H., Praznoczy, C., Ragettli, M. S., Tainio, M., & Nieuwenhuijsen, M. J. (2016). Health Impacts of Active Transportation in Europe. *PLOS ONE*, 11 (3), e0149990. https://doi.org/10.1371/JOURNAL.PONE.0149990

Rowlands, A. V. (2018). Moving Forward With Accelerometer Assessed Physical Activity: Two Strategies to Ensure Meaningful, Interpretable, and

Comparable Measures. *Pediatric Exercise Science*, 30 (4), 450–456. https://doi.org/10.1123/PES.2018 0201

Roy, A. (1994). Correlates of mall visit frequency. *Journal of Retailing*, 70(2), 139–161. https://doi.org/10.1016/0022-4359(94)90012-4

Ruan, Y., Hang, C. C., & Wang, Y. M. (2014). Government's role in disruptive innovation and industry emergence: The case of the electric bike in China. *Technovation*, 34(12), 785–796. https://doi.org/10.1016/J.TECHNOVATION.2014.09.003

SAE International. (2019). J3194_201911: Taxonomy and Classification of Powered Micromobility Vehicles. https://www.sae.org/standards/content/j3194_201911/

Sallis, J. F., Cervero, R. B., Ascher, W., Henderson, K. A., Kraft, M. K., & Kerr, J. (2006). An Ecological Approach to Creating Active Living Communities. *Annual Review of Public Health*, 27(1), 297–322. https://doi.org/10.1146/annurev.publhealth.27.021405.102100

Sanders, R. L., Branion-Calles, M., & Nelson, T. A. (2020). To scoot or not to scoot: Findings from a recent survey about the benefits and barriers of using E-scooters for riders and non-riders. *Transportation Research Part A: Policy and Practice*, 139, 217–227. https://doi.org/10.1016/j.tra.2020.07.009

Sanders, R. L., da Silva Brum-Bastos, V., & Nelson, T. A. (2022). Insights from a pilot investigating the impacts of shared E-scooter use on physical activity using a single-case design methodology. *Journal of Transport & Health*, 25, 101379. https://doi.org/10.1016/J.JTH.2022.101379

Santacreu, A., Yannis, G., de Saint Leon, O., & Crist, P. (2020). Safe micromobility. *International Transport Forum*. https://www.itf-oecd.org/sites/default/files/docs/safe-micromobility_1.pdf

Saunders, L. E., Green, J. M., Petticrew, M. P., Steinbach, R., & Roberts, H. (2013). What Are the Health Benefits of Active Travel? A Systematic Review of Trials and Cohort Studies. *PLOS ONE*, 8(8), e69912. https://doi.org/10.1371/journal.pone.0069912

Savitsky, B., Radomislensky, I., Goldman, S., Kaim, A., & Bodas, M. (2021). Electric bikes and motorized scooters—Popularity and burden of injury. Ten years of National trauma registry experience. *Journal of Transport & Health*, 22, 101235. https://doi.org/10.1016/j.jth.2021.101235

Schuitema, G., Anable, J., Skippon, S., & Kinnear, N. (2013). The role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles. *Transportation Research Part A: Policy and Practice*, 48, 39–49. https://doi.org/10.1016/J.TRA.2012.10.004

Seemüller, S., Beck, F., Tristram, C., Marzi, I., Renninger, D., Demetriou, Y., & Reimers, A. K. (2023). The role of parental environmental self-identity in active travel behavior within parent–adolescent dyads. *German Journal of Exercise and Sport Research*. https://doi.org/10.1007/s12662-023-00923-5

Sellaouti, A., Arslan, O., & Hoffmann, S. (2020). Analysis of the use or non-use of e-scooters, their integration in the city of Munich (Germany) and their potential as an additional mobility system. *2020 IEEE 23rd International Conference on Intelligent Transportation Systems, ITSC 2020*. https://doi.org/10.1109/ITSC45102.2020.9294224

Şengül, B., & Mostofi, H. (2021). Impacts of E-Micromobility on the Sustainability of Urban Transportation—A Systematic Review. *Applied Sciences*, 11(13), Article 13. https://doi.org/10.3390/app11135851

Seto, E., Hua, J., Wu, L., Shia, V., Eom, S., Wang, M., & Li, Y. (2016). Models of individual dietary behavior based on smartphone data: The influence of routine, physical activity, emotion, and food environment. *PLoS ONE*, 11(4), 1–16. https://doi.org/10.1371/journal.pone.0153085

Severengiz, S., Finke, S., Schelte, N., & Forrister, H. (2020). Assessing the Environmental Impact of Novel Mobility Services using Shared Electric Scooters as an Example. *Procedia Manufacturing*, 43, 80–87. https://doi.org/10.1016/j.promfg.2020.02.114

Severengiz, S., Finke, S., Schelte, N., & Wendt, N. (2020). Life Cycle Assessment on the Mobility Service E-Scooter Sharing. *2020 IEEE European Technology and Engineering Management Summit* (E-TEMS 2020). http://doi.org/10.1109/E-TEMS46250.2020.9111817

Shaer, A., Rezaei, M., Moghani Rahimi, B., & Shaer, F. (2021). Examining the associations between perceived built environment and active travel, before and after the COVID-19 outbreak in Shiraz city, Iran. *Cities*, 115, 103255. https://doi.org/10.1016/j.cities.2021.103255

Shaheen, S. A., Zhang, H., Martin, E., & Guzman, S. (2011). China's Hangzhou Public Bicycle: Understanding Early Adoption and Behavioral Response to

Bikesharing. *Transportation Research Record*, 2247(1), 33–41. https://doi.org/10.3141/2247-05

Shaheen, S., & Chan, N. (2016). Mobility and the sharing economy: Potential to facilitate the first-and last-mile public transit connections. *Built Environment*, 42(4), 573–588. https://doi.org/10.2148/benv.42.4.573

Shaheen, S., & Cohen, A. (2019). Mobility on demand (MOD) and mobility as a service (MaaS): Early understanding of shared mobility impacts and public transit partnerships. *In Demand for Emerging Transportation Systems: Modeling Adoption, Satisfaction, and Mobility Patterns*. https://doi.org/10.1016/B978-0-12-815018-4.00003-6

Shaheen, S., Cohen, A., Chan, N., & Bansal, A. (2019). Sharing strategies: Carsharing, shared micromobility (bikesharing and scooter sharing), transportation network companies, microtransit, and other innovative mobility modes. *In Transportation, Land Use, and Environmental Planning.* https://doi.org/10.1016/B978-0-12-815167-9.00013-X

Shaheen, S., Cohen, A., Chan, N., & Bansal, A. (2020). Chapter 13 - Sharing strategies: Carsharing, shared micromobility (bikesharing and scooter sharing), transportation network companies, microtransit, and other innovative mobility modes. In E. Deakin (Ed.), *Transportation, Land Use, and Environmental Planning* (pp. 237–262). https://doi.org/10.1016/B978- 0-12-815167-9.00013-X

Sharma, T., & Jain, S. (2023). Nexus between built environment, travel behaviour and human health: An integrated framework to reinform transport system. *Journal of Cleaner Production*, 416, 137744. https://doi.org/10.1016/j.jclepro.2023.137744

Shen, X., & Feng, S. (2020). How public transport subsidy policies in China affect the average passenger load factor of a bus line. *Research in Transportation Business & Management,* 36, 100526. https://doi.org/10.1016/j.rtbm.2020.100526

Shephard, R. J. (2003). Limits to the measurement of habitual physical activity by questionnaires. *British Journal of Sports Medicine*, 37(3), 197–206. https://doi.org/10.1136/BJSM.37.3.197

Sheth, J. N. (1983). Cross-cultural influences on the buyer-seller interaction/negotiation process. *Asia Pacific Journal of Management*, 1(1), 46–55. https://doi.org/10.1007/BF01734310

Sheth, J. N., Newman, B. I., & Gross, B. L. (1991). Why we buy what we buy: A theory of consumption values. *Journal of Business Research*, 22(2), 159–170. https://doi.org/10.1016/0148-2963(91)90050-8

Shiftan, Y. (2008). The use of activity-based modeling to analyze the effect of land-use policies on travel behavior. *The Annals of Regional Science*, 42(1), 79–97. https://doi.org/10.1007/s00168-007-0139-1

Shirgaokar, M. (2019). Operationalizing gendered transportation preferences: A psychological framework incorporating time constraints and risk aversion. *Transport Policy*, 75, 10–18. https://doi.org/10.1016/J.TRANPOL.2018.12.010

Siebert, F. W., Hoffknecht, M., Englert, F., Edwards, T., Useche, S. A., & Rötting, M. (2021). Safety Related Behaviors and Law Adherence of Shared E-Scooter Riders in Germany. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 12791 LNCS, 446–456. https://doi.org/10.1007/978-3-030-78358-7_31

Sikka, N., Vila, C., Stratton, M., Ghassemi, M., & Pourmand, A. (2019). Sharing the sidewalk: A case of E-scooter related pedestrian injury. *The American Journal of Emergency Medicine*, 37(9), 1807.e5-1807.e7. https://doi.org/10.1016/j.ajem.2019.06.017

Simsekoglu, Ö., & Klöckner, C. (2019a). Factors related to the intention to buy an e-bike: A survey study from Norway. *Transportation Research Part F: Traffic Psychology and Behaviour,* 60, 573–581. https://doi.org/10.1016/j.trf.2018.11.008

Simsekoglu, Ö., & Klöckner, C. A. (2019b). The role of psychological and socio-demographical factors for electric bike use in Norway. *International Journal of Sustainable Transportation*, 13(5), 315–323. https://doi.org/10.1080/15568318.2018.1466221

Smit, R. B., Graham, D. O., & Erasmus, J. (2021). E-scooter injuries referred to the oral and maxillofacial surgical service at Christchurch Hospital: A retrospective observational study and cost analysis of 17-months of data. *British Journal of Oral & Maxillofacial Surgery,* 59(4), 439–444. https://doi.org/10.1016/j.bjoms.2020.08.112

Smith, C. S., & Schwieterman, P. J. (2018). E-Scooter Scenarios: Evaluating the Potential Mobility Benefits of Shared Dockless Scooters in Chicago. *Chaddick Institute Policy Series*, 1, 6–8. https://las.depaul.edu/centers-and-institutes/chaddick-institute-for-metropolitan-development/research-and-publications/Documents/E-ScooterScenariosMicroMobilityStudy_FINAL_20181212.pdf

Sniehotta, F. F., Presseau, J., & Araújo-Soares, V. (2014). Time to retire the theory of planned behaviour. *Health Psychology Review*, 8(1), 1–7. https://doi.org/10.1080/17437199.2013.869710

Söderberg f.k.a. Andersson, A., Adell, E., & Winslott Hiselius, L. (2021). What is the substitution effect of e-bikes? A randomised controlled trial. *Transportation Research Part D: Transport and Environment*, 90, 102648. https://doi.org/10.1016/j.trd.2020.102648

Song, Y., Li, G., Wang, Q., Meng, X., & Wang, H. (2020). Scenario analysis on subsidy policies for the uptake of electric vehicles industry in China. *Resources, Conservation and Recycling*, 161, 104927. https://doi.org/10.1016/j.resconrec.2020.104927

Soria-Lara, J. A., Miralles- Guasch, C., & Marquet, O. (2017). The influence of lifestyle and built environment factors on transport CO2 emissions: The case study of Autonomous University of Barcelona. *ACE: Architecture, City and Environment*, 12(34), 11–28. https://doi.org/10.5821/ACE.12.34.4756

Soriguera, F., & Jiménez-Meroño, E. (2020). A continuous approximation model for the optimal design of public bike-sharing systems. *Sustainable Cities and Society*, 52, 101826. https://doi.org/10.1016/j.scs.2019.101826

Sousa-Zomer, T. T., & Miguel, P. A. C. (2016). Exploring the Critical Factors for Sustainable Product-service Systems Implementation and Diffusion in Developing Countries: An Analysis of two PSS Cases in Brazil. *Procedia CIRP*, 47, 454–459. https://doi.org/10.1016/j.procir.2016.03.061

Sperlich, B., Zinner, C., Hebert-Losier, K., Born, D.-P., & Holmberg, H.-C. (2012). Biomechanical, cardiorespiratory, metabolic and perceived responses to electrically assisted cycling. *European Journal of Applied Physiology*, 112(12), 4015–4025. https://doi.org/10.1007/s00421-012-2382-0

Stark, J., Meschik, M., Singleton, P. A., & Schützhofer, B. (2018). Active school travel, attitudes and psychological well-being of children. *Transportation Research Part F: Traffic Psychology and Behaviour*, 56, 453–465. https://doi.org/10.1016/j.trf.2018.05.007

Stoermann, P., Klug, A., Nau, C., Verboket, R. D. R. D., Leiblein, M., Mueller, D., Schweigkofler, U., Hoffmann, R., Marzi, I., Lustenberger, T., Störmann, P., Klug, A., Nau, C., Verboket, R. D. R. D., Leiblein, M., Müller, D., Schweigkofler, U., Hoffmann, R., Marzi, I., & Lustenberger, T. (2020). Characteristics and Injury Patterns in Electric-Scooter Related Accidents-A Prospective Two-Center Report from Germany. *Journal of Clinical Medicine*, 9(5). https://doi.org/10.3390/jcm9051569

Suchanek, M., & Wolek, M. (2018). The Relations Between the Bikesharing Systems and Public Expenditures. Cluster Analysis of the Polish Bikesharing Systems. In Suchanek, M (Ed.), *New Research Trends in Transport Sustainability And Innovation* (pp. 37–45). https://doi.org/10.1007/978-3-319-74461-2_4

Sulikova, S., & Brand, C. (2021). Investigating what makes people walk or cycle using a socio-ecological approach in seven European cities. *Transportation Research Part F: Traffic Psychology and Behaviour,* 83, 351–381. https://doi.org/10.1016/j.trf.2021.10.008

Sun, Q., Feng, T., Kemperman, A., & Spahn, A. (2020). Modal shift implications of e-bike use in the Netherlands: Moving towards sustainability? *Transportation Research Part D: Transport and Environment*, 78. https://doi.org/10.1016/j.trd.2019.102202

Sundfør, H. B., & Fyhri, A. (2017). A push for public health: The effect of e-bikes on physical activity levels. *BMC Public Health*, 17(1), 809. https://doi.org/10.1186/s12889-017-4817-3

Sundfør, H. B., & Fyhri, A. (2022). The effects of a subvention scheme for e-bikes on mode share and active mobility. *Journal of Transport & Health*, 26, 101403. https://doi.org/10.1016/J.JTH.2022.101403

Sylvia, L. G., Bernstein, E. E., Hubbard, J. L., Keating, L., & Anderson, E. J. (2014). Practical Guide to Measuring Physical Activity. *Journal of the Academy of Nutrition and Dietetics*, 114(2), 199–208. https://doi.org/10.1016/J.JAND.2013.09.018

Tao, T., Wu, X., Cao, J., Fan, Y., Das, K., & Ramaswami, A. (2020). Exploring the Nonlinear Relationship between the Built Environment and Active Travel in the Twin Cities. *Journal of Planning Education and Research*, 0739456X20915765. https://doi.org/10.1177/0739456X20915765

Teixeira, J. F., Silva, C., & e Sá, F. (2021). The motivations for using bike sharing during the COVID-19 pandemic: Insights from Lisbon. *Transportation Research Part F: Traffic Psychology and Behaviour*, 82, 378–399. https://doi.org/10.1016/j.trf.2021.09.016

Thao, V. T., & Ohnmacht, T. (2020). The impact of the built environment on travel behavior: The Swiss experience based on two National Travel Surveys. *Research in Transportation Business & Management*, 36, 100386. https://doi.org/10.1016/j.rtbm.2019.100386

The European Parliament and The Council of the European Union (2013). Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the Approval and Market Surveillance of Two or Three Wheel Vehicles and Quadricycles. *Official Journal of the European Union*. https://eurlex.europa.eu/legalcontent/EN/TXT/PDF/?uri=CELEX:32013R0168

Thomas, A. (2021). Electric bicycles and cargo bikes—Tools for parents to keep on biking in auto-centric communities? Findings from a US metropolitan area. *International Journal of Sustainable Transportation*. https://doi.org/10.1080/15568318.2021.1914787

Tracy, A. J., Su, P., Sadek, A. W., & Wang, Q. (2011). Assessing the impact of the built environment on travel behavior: A case study of Buffalo, New York. *Transportation*, 38(4), 663–678. https://doi.org/10.1007/s11116-011-9337-x Tran, P. T. M., Adam, M. G., Tham, K. W., Schiavon, S., Pantelic, J., Linden, P. F.,

Sofianopoulou, E., Sekhar, S. C., Cheong, D. K. W., & Balasubramanian, R. (2021). Assessment and mitigation of personal exposure to particulate air pollution in cities: An exploratory study. *Sustainable Cities and Society*, 72. https://doi.org/10.1016/j.scs.2021.103052

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*. https://onlinelibrary.wiley.com/doi/abs/10.1111/1467-8551.00375

Traynor M.D., Jr., Lipsitz, S., Schroeder, T. J., Zielinski, M. D., Rivera, M., Hernandez, M. C., Stephens, D. J., Traynor, M. D., Lipsitz, S., Schroeder, T. J., Zielinski, M. D., Rivera, M., Hernandez, M. C., & Stephens, D. J. (2021). Association of scooter-related injury and hospitalization with electronic scooter sharing systems in the United States. *American Journal of Surgery*. https://doi.org/10.1016/j.amjsurg.2021.06.006

Trivedi, T. K., Liu, C., Antonio, A. L. M., Wheaton, N., Kreger, V., Yap, A., Schriger, D., & Elmore, J. G. (2019). Injuries Associated With Standing Electric Scooter

Use. *JAMA Network Open*, 2(1), e187381. https://doi.org/10.1001/jamanetworkopen.2018.7381

Troiano, R. P., Berrigan, D., Dodd, K. W., Mâsse, L. C., Tilert, T., & Mcdowell, M. (2008). Physical Activity in the United States Measured by Accelerometer. *Medicine & Science in Sports & Exercise*, 40(1), 181. https://doi.org/10.1249/mss.0b013e31815a51b3

Troiano, R. P., McClain, J. J., Brychta, R. J., & Chen, K. Y. (2014). Evolution of accelerometer methods for physical activity research. *British Journal of Sports Medicine*, 48(13), 1019–1023. https://doi.org/10.1136/BJSPORTS-2014-093546

van Acker, V., van Wee, B., & Witlox, F. (2010). When Transport Geography Meets Social Psychology: Toward a Conceptual Model of Travel Behaviour. *Transport Reviews*, 30:2, 219-240. https://doi.org/10.1080/01441640902943453

Van Cauwenberg, J., De Bourdeaudhuij, I., Clarys, P., De Geus, B., & Deforche, B. (2018). Older E-bike Users: Demographic, Health, Mobility Characteristics, and Cycling Levels. *Medicine & Science in Sports & Exercise*, 50(9), 1780-1789. https://doi.org/10.1249/MSS.0000000000001638

Van Cauwenberg, J., De Bourdeaudhuij, I., Clarys, P., de Geus, B., & Deforche, B. (2019). E-bikes among older adults: Benefits, disadvantages, usage and crash characteristics. *Transportation*, 46(6), pp 2151-2172. https://doi.org/10.1007/s11116-018-9919-y

Van Cauwenberg, J., de Geus, B., & Deforche, B. (2018). Cycling for transport among older adults: Health benefits, prevalence, determinants, injuries and the potential of e-bikes. *Geographies of Transport and Ageing*. https://doi.org/10.1007/978-3-319-76360-6_6

van den Berg, P., Sharmeen, F., & Weijs-Perrée, M. (2017). On the subjective quality of social Interactions: Influence of neighborhood walkability, social cohesion and mobility choices. *Transportation Research Part A: Policy and Practice*, 106, 309–319. https://doi.org/10.1016/j.tra.2017.09.021

van Hees, V. T., Renström, F., Wright, A., Gradmark, A., Catt, M., Chen, K. Y., Löf, M., Bluck, L., Pomeroy, J., Wareham, N. J., Ekelund, U., Brage, S., & Franks, P. W. (2011). Estimation of Daily Energy Expenditure in Pregnant and Non-Pregnant Women Using a Wrist-Worn Tri-Axial Accelerometer. *PLOS ONE*, 6(7), e22922. https://doi.org/10.1371/JOURNAL.PONE.0022922

Verplanken, B., Walker, I., Davis, A., & Jurasek, M. (2008). Context change and travel mode choice: Combining the habit discontinuity and self-activation hypotheses. *Journal of Environmental Psychology*, 28(2), 121–127. https://doi.org/10.1016/J.JENVP.2007.10.005

Verstappen, E. M. J., Vy, D. T., Janzing, H. M., Janssen, L., Vos, R., Versteegen, M. G. J., & Barten, D. G. (2021). Bicycle-related injuries in the emergency department: A comparison between E-bikes and conventional bicycles: A prospective observational study. *European Journal of Trauma and Emergency Surgery*, 47(6), 1853–1860. https://doi.org/10.1007/s00068-020-01366-5

Vich, G., Delclòs, X., Maciejewska, M., Marquet, O., Schipperjin, J., & Miralles-Guasch, C. (2021). Contribution of park visits to daily physical activity levels among older adults: Evidence using GPS and accelerometery data. *Urban Forestry and Urban Greening*, 63(2021), 127225. https://doi.org/10.1016/j.ufug.2021.127225

Vich, G., Marquet, O., & Miralles- Guasch, C. (2019). "Is there any time left for walking?" Physical activity implications of suburban commuting in the Barcelona metropolitan region. *Geografisk Tidsskrift - Danish Journal of Geography*, 119(2), 136–145. https://doi.org/10.1080/00167223.2019.1589386

Vinayaga-Sureshkanth, N., Wijewickrama, R., Maiti, A., & Jadliwala, M. (2020). Security and Privacy Challenges in Upcoming Intelligent Urban Micromobility Transportation Systems. *Proceedings of the Second ACM Workshop on Automotive and Aerial Vehicle Security*, 31–35. https://doi.org/10.1145/3375706.3380559

Voss, C., Sims- Gould, J., Ashe, M. C., McKay, H. A., Pugh, C., & Winters, M. (2016). Public transit use and physical activity in community-dwelling older adults: Combining GPS and accelerometry to assess transportation-related physical activity. *Journal of Transport & Health*, 3(2), 191–199. https://doi.org/10.1016/J.JTH.2016.02.011

Waka Kotahi NZ Transport Agency (2021). Impacts of a public sector e-bike scheme: Final evaluation report. https://www.nzta.govt.nz/assets/resources/research/reports/678/678-impacts-of-a-public-sector-e-bike-scheme.pdf

Wang, K., Qian, X., Circella, G., Lee, Y., Malik, J., Fitch, D. T., & Board, T. R. (2021). What Mobility Modes Do Shared E-Scooters Displace? A Review of Recent Research Findings. *Transport Reviews*, 43(1), 5-31. https://doi.org/10.1080/01441647.2021.2015639

Wang, M., Liu, K., Choi, T.-M., & Yue, X. (2015). Effects of Carbon Emission Taxes on Transportation Mode Selections and Social Welfare. *IEEE Transactions on Systems, Man, and Cybernetics: Systems,* 45(11), 1413–1423. https://doi.org/10.1109/TSMC.2015.2411577

Wang, T., Chen, J., Wang, C., & Ye, X. (2018). Understand e-bicyclist safety in China: Crash severity modeling using a generalized ordered logit model. *Advances in Mechanical Engineering,* 10(6), 11p. https://doi.org/10.1177/1687814018781625

Washington, T., Heesch, K., & Ng, A. (2018). Would you consider using an electric bicycle (e-bike) to make work-related or personal trips? Report on Survey and Focus Groups with TMR employees. *Queensland University of Technology*. https://eprints.qut.edu.au/215443/

Watson, H. N., Garman, C. M. R., Wishart, J., & Zimmermann, J. (2020). Patient Demographics and Injury Characteristics of ER Visits Related to Powered-Scooters. *SAE Technical Papers*. https://doi.org/10.4271/2020- 01-0933

Weber, T., Scarmuzza, G., & Schmitt, K.-U. (2014). Evaluation of e-bike accidents in Switzerland. *Accident Analysis & Prevention*, 73, pp 47-52. https://doi.org/10.1016/j.aap.2014.07.020

Webster, J., & Watson, R. T. (2002). Analyzing the Past to Prepare for the Future: Writing a Literature Review. *MIS Quarterly*, 26(2), xiii–xxiii. http://www.jstor.org/stable/4132319

Weiss, M., Dekker, P., Moro, A., Scholz, H., & Patel, M. K. (2015). On the electrification of road transportation – A review of the environmental, economic, and social performance of electric two-wheelers. *Transportation Research Part D: Transport and Environment*, 41, 348–366. https://doi.org/10.1016/j.trd.2015.09.007

Weiss, M., Irrgang, L., Kiefer, A. T., Roth, J. R., & Helmers, E. (2020). Mass- and power-related efficiency trade-offs and CO2 emissions of compact passenger cars. *Journal of Cleaner Production*, 243. https://doi.org/10.1016/j.jclepro.2019.118326

Weschke, J., Oostendorp, R., & Hardinghaus, M. (2022). Mode shift, motivational reasons, and impact on emissions of shared e-scooter usage. *Transportation Research Part D: Transport and Environment*, 112, 103468. https://doi.org/10.1016/j.trd.2022.103468

White, T., Westgate, K., Hollidge, S., Venables, M., Olivier, P., Wareham, N., & Brage, S. (2019). Estimating energy expenditure from wrist and thigh accelerometry in free-living adults: A doubly labelled water study. *International Journal of Obesity*, 43(11), 2333–2342. https://doi.org/10.1038/S41366-019-0352-X

White, T., Westgate, K., Wareham, N. J., & Brage, S. (2016). Estimation of Physical Activity Energy Expenditure during Free-Living from Wrist Accelerometry in UK Adults. *PLOS ONE*, 11(12), e0167472. https://doi.org/10.1371/JOURNAL.PONE.0167472

Whitelock, W. H. (1989). Motives must be differentiated from needs, drives, wants: Strategy implications. *European Journal of Marketing*, 23(3), 29–36. https://doi.org/10.1108/EUM0000000000558/FULL/PDF

Wijndaele, K., Westgate, K., Stephens, S. K., Blair, S. N., Bull, F. C., Chastin, S. F. M., Dunstan, D. W., Ekelund, U., Esliger, D. W., Freedson, P. S., Granat, M. H., Matthews, C. E., Owen, N., Rowlands, A. V., Sherar, L. B., Tremblay, M. S., Troiano, R. P., Brage, Sø., & Healy, G. N. (2015). Utilization and Harmonization of Adult Accelerometry Data: Review and Expert Consensus. *Medicine and Science in Sports and Exercise*, 47(10), 2129–2139. https://doi.org/10.1249/MSS.0000000000000661

Wikstrøm, R. D., & Böcker, L. (2020). Changing suburban daily mobilities in response to a mobility intervention: A qualitative investigation of an E-bike trial. *Sustainability* (Switzerland), 12(6). https://doi.org/10.3390/su12062413

Wild, K., & Woodward, A. (2019). Why are cyclists the happiest commuters? Health, pleasure and the e-bike. *Journal of Transport & Health*, 14, 100569. https://doi.org/10.1016/j.jth.2019.05.008

Will, S., Luger-Bazinger, C., Schmitt, M., & Zankl, C. (2021). Towards the future of sustainable mobility: Results from a european survey on (electric) powered-two wheelers. *Sustainability* (Switzerland), 13(13). https://doi.org/10.3390/su13137151

Williams, M. (1978). Factors affecting modal choice decisions in urban travel: Some further evidence. *Transportation Research*, 12(2), 91–96. https://doi.org/10.1016/0041-1647(78)90047-3

Wilson, O. W. A., Elliott, L. D., Duffey, M., Papalia, Z., & Bopp, M. (2020). The contribution of active travel to meeting physical activity recommendations among college students. *Journal of Transport & Health*, 18, 100890. https://doi.org/10.1016/j.jth.2020.100890

Winslott Hiselius, L., & Svensson, Å. (2017). E-bike use in Sweden – CO2 effects due to modal change and municipal promotion strategies. *Journal of Cleaner Production*, 141, 818–824. https://doi.org/10.1016/j.jclepro.2016.09.141

Winters, M., Buehler, R., & Götschi, T. (2017). Policies to Promote Active Travel: Evidence from Reviews of the Literature. *Current Environmental Health Reports*, 4(3), 278–285. https://doi.org/10.1007/s40572-017-0148-x

Wood, J., Bradley, S., & Hamidi, S. (2019). Preparing for Progress: Establishing Guidelines for the Regulation, Safe Integration, and Equitable Usage of Dockless Electric Scooters in American Cities. *University of Texas, A., Center for Transportation Decisions & Dollars (CTEDD).* https://ctedd.uta.edu/wp-content/uploads/2020/01/wood_final.pdf

Woodcock, J., Franco, O. H., Orsini, N., & Roberts, I. (2011). Non-vigorous physical activity and all-cause mortality: Systematic review and meta-analysis of cohort studies. *International Journal of Epidemiology*, 40(1), 121–138. Scopus. https://doi.org/10.1093/ije/dyq104

Woodcock, J., Tainio, M., Cheshire, J., O'Brien, O., & Goodman, A. (2014). Health effects of the London bicycle sharing system: Health impact modelling study. *BMJ*, 348. https://doi.org/10.1136/BMJ.G425

Woodruff, R. B. (1997). Customer value: The next source for competitive advantage. *Journal of the Academy of Marketing Science*, 25(2), 139–153. https://doi.org/10.1007/BF02894350

Woodward, A., & Wild, K. (2020). Chapter five—Active transportation, physical activity, and health. *Advances in Transportation and Health* (pp. 133–148). https://doi.org/10.1016/B978-0-12-819136-1.00005-X

World Health Organization. (2013). Global action plan for the prevention and control of noncommunicable diseases 2013-2020. *World Health Organization*. https://doi.org/978 92 4 1506236

World Health Organization. (2020). WHO guidelines on physical activity and sedentary behaviour. https://www.who.int/publications/i/item/9789240015128

World Health Organization. (2021). Health Promotion Glossary of Terms 2021. https://www.who.int/publications-detail-redirect/9789240038349

Wu, X., Xiao, W., Deng, C., Schwebel, D. C., & Hu, G. (2019). Unsafe riding behaviors of shared-bicycle riders in urban China: A retrospective survey. *Accident Analysis and Prevention*, 131, 1–7. https://doi.org/10.1016/j.aap.2019.06.002

Yang, J., Zhou, H., & Zhou, M. (2020). Bus transit subsidy under China's transit metropolis initiative: The case of Shenzhen. *International Journal of Sustainable Transportation*, 14(1), 56–63. https://doi.org/10.1080/15568318.2018.1519088

Yang, L., Griffin, S., Chapman, C., & Ogilvie, D. (2012). The feasibility of rapid baseline objective physical activity measurement in a natural experimental study of a commuting population. *BMC Public Health*, 12(1), 1–7. https://doi.org/10.1186/1471-2458-12-841/FIGURES/2

Yang, L., Panter, J., Griffin, S. J., & Ogilvie, D. (2012). Associations between active commuting and physical activity in working adults: Cross-sectional results from the Commuting and Health in Cambridge study. *Preventive Medicine*, 55(5), 453–457. https://doi.org/10.1016/J.YPMED.2012.08.019

Yanocha & Allan. (2021). Maximizing Micromobility: Unlocking opportunities to integrate micromobility and public transportation. *Institute for Transportation and Development Policy.* https://www.itdp.org/publication/maximizing-micromobility/

Ye, Y., Xin, F., & Wei, L. (2014). Characteristics of the electric bicycle: A comparative analysis with bicycles and public transit. *CICTP 2014: Safe, Smart, and Sustainable Multimodal Transportation Systems - Proceedings of the 14th COTA International Conference of Transportation Professionals*, 3450–3458. https://doi.org/10.1061/9780784413623.330

Yin, Y., Yu, Z., Wang, H., & Ye, J. (2021). Sharing transport in high education area of Ningbo: Examining users' characteristics and driving determinants. *Journal of Cleaner Production*, 306. https://doi.org/10.1016/j.jclepro.2021.127231

Zagorskas, J., & Burinskiene, M. (2020). Challenges Caused by Increased Use of E-Powered Personal Mobility Vehicles in European Cities. *Sustainability*, 12(1), 273. https://doi.org/10.3390/su12010273

Zhang, M., & Zhang, W. (2020). When Context Meets Self-Selection: The Built Environment–Travel Connection Revisited. *Journal of Planning Education and Research*, 40(3), 304–319. https://doi.org/10.1177/0739456X18755495

Zheng, F., Gu, F., Zhang, W., & Guo, J. (2019). Is bicycle sharing an environmental practice? Evidence from a life cycle assessment based on behavioral surveys. *Sustainability* (Switzerland), 11(6). https://doi.org/10.3390/su11061550

Zhou, M., Wang, D., & Guan, X. (2022). Co-evolution of the built environment and travel behaviour in Shenzhen, China. *Transportation Research Part D: Transport and Environment*, 107, 103291. https://doi.org/10.1016/j.trd.2022.103291

Zuev, D. (2018). Urban mobility in modern China: The growth of the E-bike. *Springer Nature*. https://doi.org/10.1007/978-3-319-76590-7

9. Annexes

9.1. Annex 1. Daily Travel Diaries

Q1. How many trips have you made today on a micromobility mode (shared bike/shared e-bike/e-scooter? Also consider the trip back home.

Q2. Could you tell us the start time of these trips? Could you also tell us the reason?

	Micromobility mode	Start time	Trip purpose
Trip 1			*
Trip 2			
Trip 3			
Trip 4			
Trip 5			
Trip 6			
Trip 7			
…			

* Options to choose → Go to work or studies or work arrangements / Visit family or friends / Accompany or care for people / Everyday purchases (food) / Non-everyday purchases / Leisure, fun, shows, cinemas, restaurants / Participate in sports activities / Back home

9.2. Annex 2. Examples of tracking raw database.

ID_UAB	userdate	trip_number	total_distance	total_mins	avgspeed_kmh	mins_sedentary	mins_light	mins_MVPA	METtotal	METactivity	total_mins_activity
2	2_2020-09-29	34	2467,40	11,50	12,87	1,00	10,50	0,25	34,50	33,00	10,75
2	2_2020-09-29	42	569,17	4,00	8,54	1,75	2,25	0,25	10,88	8,25	2,50
2	2_2020-10-01	63	430,46	3,50	7,38	0,25	1,50	2,00	16,88	16,50	3,50
2	2_2020-09-29	29	1337,46	14,75	5,44	9,50	2,00	0,00	20,25	6,00	2,00
2	2_2020-10-05	219	450,25	2,75	9,82	0,50	2,00	0,50	9,75	9,00	2,50
2	2_2020-09-29	32	5452,62	32,00	10,22	12,00	14,25	6,00	96,75	78,75	20,25
2	2_2020-10-05	183	874,98	4,25	12,35	0,00	4,25	0,25	14,25	14,25	4,50
2	2_2020-10-04	148	2030,68	15,25	7,99	5,75	5,25	4,25	49,88	41,25	9,50
2	2_2020-10-04	134	10067,67	36,00	16,78	16,00	20,25	0,00	84,75	60,75	20,25
2	2_2020-10-05	214	562,04	6,75	5,00	0,00	1,50	5,50	37,50	37,50	7,00
2	2_2020-10-03	130	762,49	6,00	7,62	1,50	4,75	0,00	16,50	14,25	4,75
2	2_2020-10-03	128	9713,11	36,75	15,86	14,25	22,50	0,25	90,38	69,00	22,75
2	2_2020-09-28	1	9110,67	25,50	21,44	5,75	14,00	6,00	86,63	78,00	20,00
2	2_2020-10-01	76	6587,51	27,50	14,37	21,75	2,00	0,50	41,63	9,00	2,50
2	2_2020-09-28	7	1645,02	26,00	3,80	16,00	6,00	1,50	51,00	27,00	7,50
2	2_2020-10-06	230	2088,07	11,00	11,39	5,00	5,50	0,75	28,50	21,00	6,25
2	2_2020-09-28	14	3999,19	6,50	36,92	0,00	2,50	0,50	10,50	10,50	3,00
5	5_2020-10-03	50	683,01	7,50	5,46	5,50	2,00	0,25	15,75	7,50	2,25
5	5_2020-10-03	37	574,47	5,00	6,89	2,50	2,50	0,25	12,75	9,00	2,75
5	5_2020-10-05	111	1962,37	9,25	12,73	5,00	4,25	0,25	21,75	14,25	4,50
5	5_2020-09-29	2	724,35	8,50	5,11	3,50	5,25	0,00	21,00	15,75	5,25
5	5_2020-10-03	38	962,76	6,75	8,56	4,50	2,25	0,25	15,00	8,25	2,50
5	5_2020-10-05	110	4312,78	23,25	11,13	14,00	9,00	0,50	51,00	30,00	9,50

METminute	METminute_activity	AGE CATEG	SEX	PROF. STATUS	EDUCATION	TRANSPORT MODE
3,00	3,07	45+	M	Actiu	College	Bike
2,72	3,30	45+	M	Actiu	College	Bike
4,82	4,71	45+	M	Actiu	College	Bike
1,37	3,00	45+	M	Actiu	College	Bike
3,55	3,60	45+	M	Actiu	College	Bike
3,02	3,89	45+	M	Actiu	College	Bike
3,35	3,17	45+	M	Actiu	College	Bike
3,27	4,34	45+	M	Actiu	College	Bike
2,35	3,00	45+	M	Actiu	College	Bike
5,56	5,36	45+	M	Actiu	College	Bike
2,75	3,00	45+	M	Actiu	College	Bike
2,46	3,03	45+	M	Actiu	College	Bike
3,40	3,90	45+	M	Actiu	College	Bike
1,51	3,60	45+	M	Actiu	College	Bike
1,96	3,60	45+	M	Actiu	College	Bike
2,59	3,36	45+	M	Actiu	College	Bike
1,62	3,50	45+	M	Actiu	College	Bike
2,10	3,33	16-24	F	Actiu	High school	E-scooter
2,55	3,27	16-24	F	Actiu	High school	E-scooter
2,35	3,17	16-24	F	Actiu	High school	E-scooter
2,47	3,00	16-24	F	Actiu	High school	E-scooter
2,22	3,30	16-24	F	Actiu	High school	E-scooter
2,19	3,16	16-24	F	Actiu	High school	E-scooter

10. Additional activities

As stated in the Preface of this dissertation, the completion of this doctoral thesis has been mainly possible thanks to the financing granted by the Generalitat de Catalunya via an AGAUR-FI grant (2021FI_B 00085). During the three-year period in which this scholarship was awarded, the doctoral student carried out the work presented in this compendium of publications, as well as other parallel activities. These activities cover the dissemination of the results of the thesis at conferences, courses and talks, participation in academic training and teaching activities, a research stay in a foreign research center and the publication of other academic works related to the research activity of the Group of Studies in Mobility, Transport and Territory (GEMOTT). These activities are detailed below.

10.1. Dissemination of the thesis results

10.1.1. Presentations at national and international conferences

1. Online oral presentation *"La movilidad post-pandemia: el potencial de los nuevos vehículos de micromovilidad eléctrica y compartida"* at **X SEMINARIO INTERNACIONAL DE RIDEAL** "Metrópolis pos pandemia. Costos y desafíos" conference, held between 22nd – 24th November 2021.
2. Oral presentation "*Is micromobility active? Daily usage of micromobility modes and accelerometer-based physical activity*" at **UGI-IGU Paris** 2022 conference, held between 18th - 22nd July 2022.
3. Poster presentation "*Micromobility as an active mode of transport? Associations between daily micromobility use and accelerometer-based physical activity*" at **Urban Transitions Sitges** 2022 conference, held between 8th – 10th November 2022.
4. Oral presentation "*Moving More in the City: The Role of Micromobility in Promoting Physical Activity*" at **EUGEO 9è Congrès Barcelona**, held between 4th – 7th September 2023.

10.1.2. Talks and presentations related to the thesis

1. Online talk in the course Mobility and Health organized by the **Fundació de Mobilitat Sostenible i Salut** (**FMSS**), November 2022.
2. Talk in the Seminar "Besòs: Recycling Territories; Caring environments in Barcelona", organized by **SOFAR Academy** at the Enric Miralles Foundation, on June 15 of 2023.

10.2. Training

10.2.1. Attendance at conferences and seminars of interest

- Online attendance to the presentation of the **CTESC Report "The transition towards a more intelligent and sustainable mobility"**, on September 28, 2021.
- **IV Conference "El transport públic és cosa de dones"**, at the CIBA in Santa Coloma, on March 30, 2022.
- **Workshop "Design of a collaborative cycling tool"**, at the Institute of Environmental Science and Technology (ICTA-UAB), on May 13, 2022.
- **Workshop "Metropolis in motion. Barcelona and Santiago de Chile"** at the Institute of Environmental Science and Technology (ICTA-UAB) on July 7, 2022.
- **Seminar "Using GPS and accelerometers to evaluate the behavioral effect of changes to the built environment"** taught by Prof. Jasper Schipperijn, from the University of Southern Denmark, organized by ICTA on March 2, 2023.
- **Workshop "Active Travel Utilization Data"**, organized by the Barcelona Institue for Global Health, on April 14, 2023.
- **Workshop on Health Impact Assessment of Urban and Transport Planning in European Cities**, organized by the Barcelona Institue for Global Health and the MRC Epidemiology Unit of the University of Cambridge, between 5th – 7th July, 2023.

10.2.2. Training activities

- **Institutional Mendeley Online Course**, on 2021, organized by the Doctoral School of the Autonomous University of Barcelona (UAB). 4 hours of dedication.
- **Information Resources for PhD training session**, on 2021, organized by the UAB Humanities Library. Session of 1 hour 30 minutes.
- **"Citizen Science" course**, held on June 28 and 29, 2021, organized by the UAB Doctoral School. 3 hours of dedication.
- **Online session "What to consider when writing a proposal to finance a research"**, given by Markku Lehtonen, on December 1, 2021.
- **"All you need to know to be a researcher in Europe" course**, on December 2021, organized by the Doctoral School of the UAB. 3 hours of dedication.
- **Online session "Creation of maps and analysis of basic data for research"**, taught by Dra. Meritxell Gisbert Traveria, December 13 and 14, 2021. 4 hours of dedication.
- **"Infographic Design" course**, on January 18 and 19, 2022, organized by the UAB Doctoral School. 8 hours of dedication.
- **Course in "Quantitative Research Methods in Social Sciences: Program R"**, taught by Prof. Josep Rialp, on February 22, March 15 and 22, 2022, organized by the School of Doctorate in Tourism and the Department of Geography of the UAB. 10 hours of dedication.
- **Course "Good Research Practices and Research Integrity at the UAB"**, on March 2022, organized by the Doctoral School of the UAB. 6 hours of dedication.
- **"Design and Creation of Maps with ArcGIS Pro" course**, June, 2022, organized by ESRI. 10 hours of dedication.
- **Virtual training in "Psychosocial risks"**, between 15th December 2022 and 20th January 2023, organized by the UAB. 3 hours of dedication.
- **Course "Physical Activity Epidemiology and Public Health"**, organized by the University of Cambridge. 4 days of dedication, Friday 21 and 28 April, and Friday 5 and 12 May 2023.
- **Course "Transfer and valuation of patents"**, organized by the UAB. April 25 and 27, 2023. 4 hours of dedication.

- **Course "Research data: publish them openly and make the data management plan"**, organized by the UAB on May 10, 2023. 2 hours of dedication.
- **Course "Análisis espacial con ArcGis Pro"**, between 23th – 25th January 2024, organized by ESRI España. 15 hours of dedication.
- **Proof of Concept Training Program**, February 2024, organized by the Parc de Recerca of UAB. Around 20 hours of dedication.

10.2.3. Teaching activities

- Field trips about technological and service networks and infrastructures in Barcelona, for the Urbanism Degree. Academic course 2021 – 2022.
- Subject "Mobility, Logistics and Transport" of the Degree in Smart Cities of the University Autonomous of Barcelona. Academic course 2022 – 2023.

10.3. Research stay

MRC Epidemiology Unit

UNIVERSITY OF CAMBRIDGE

The host university was the University of Cambridge, specifically the Public Health Modeling research group belonging to the MRC Epidemiology Unit, in Cambridge, United Kingdom. Supervisor: Professor James Woodcock. Dates: 19/04/2023 – 19/07/2023 (91 days). Funding: Mobility grant for young researchers from the Fundació Amics del País.

10.4. Other publications

- **Bretones, A.**, Marquet, O., Daher, C., Hidalgo, L., Nieuwenhuijsen, M., Miralles-Guasch, C., & Mueller, N. (2023). Public Health-Led Insights on Electric Micromobility Adoption and Use: A Scoping Review. Journal of Urban Health, 100(3), 612–626. https://doi.org/10.1007/s11524-023-00731-0

- Cubells, J., **Bretones, A.**, & Roig-Costa, O. (2023). Are E-Scooters a Threat to Active Travel? Journal of Healthy Eating and Active Living, 3(3), Article 3. https://doi.org/10.51250/jheal.v3i3.69
- Nello-Deakin, S., **Diaz, A. B.**, Roig-Costa, O., Miralles-Guasch, C., & Marquet, O. (2024). Moving beyond COVID-19: Break or continuity in the urban mobility regime? Transportation Research Interdisciplinary Perspectives, 24, 101060. https://doi.org/10.1016/j.trip.2024.101060

10.5. Letter of coauthors

GEMOTT
Grup d'Estudis de Mobilitat Transport i Territori

Estimats membres de la Comissió Acadèmica del Programa de Doctorat en Geografia:

Ens dirigim a vostès per a certificar formalment la nostra participació com co-autors en les publicacions presentades dins de la tesi per compendi de publicacions titulada " On the links between electric micromobility and health in Barcelona. A focus on physical activity", realitzada per la doctoranda Alexandra Bretones Diaz. Mitjançant la present, confirmem que cap dels materials, resultats o conclusions presentats en aquesta tesi ha estat utilitzat en un altre treball acadèmic o tesi fins a la data. Ens adherim plenament a les polítiques acadèmiques de l'Escola de Doctorat de la Universitat Autònoma de Barcelona i reconeixem la importància de preservar la integritat i autenticitat del treball de recerca.

Així mateix, ens comprometem formalment a no utilitzar cap material o resultat presentat en aquesta tesi en futurs treballs acadèmics o tesis sense la corresponent citació i reconeixement adequats.

Agraïm la seva atenció i consideració.

Atentament,

Carme Miralles-Guach

MIRALLES GUASCH MARIA CARME - 39851421B

Signat digitalment per MIRALLES GUASCH MARIA CARME - 39851421B
Data: 2024.03.11 14:18:49 +01'00'

Oriol Marquet Sardà

ORIOL MARQUET SARDA - DNI 46145311C

Digitally signed by ORIOL MARQUET SARDA - DNI 46145311C
Date: 2024.03.11 13:11:04 +01'00'