Highlights

- An increase in electric micromobility (EMM) (i.e. e-bike/e-scooter/e-moped) is expected
- We studied health impacts of a 5% (S1) and 10% (S2) EMM increase in Barcelona
- Shifting from cars and motorcycles to EMMs led to 13 (S1)/ 26 (S2) preventable deaths annually
- Shifting from walking and cycling to EMMs led to 17 (S1)/ 35 (S2) additional deaths annually
- EMM use can be beneficial for health if mode shifts occur from passive transport modes

Health impacts of electric micromobility transitions in Barcelona: a scenario analysis

Inés López-Dóriga[a,b], Guillem Vich[a,c,d,e], Sarah Koch[a,d,e], Sasha Khomenko[a,d,e], Oriol Marquet[c], Oriol Roig[c], Carolyn Daher[a,d,e], Davide Rasella[a,d,e], Mark Nieuwenhuijsen[a,d,e], Natalie Mueller[a,d,e]

[a]Institute for Global Health (ISGlobal), Barcelona, Spain

[b]Department of Pediatrics, Obstetrics, Gynecology, Preventive Medicine and Public Health, Faculty of Medicine, Universitat Autònoma de Barcelona (UAB), Spain

[c]Research Group on Mobility, Transportation and Territory (GEMOTT), Universitat Autònoma de Barcelona (UAB), Spain

[d]Department of Experimental and Health Sciences, Universitat Pompeu Fabra (UPF), Barcelona, Spain

[e]CIBER Epidemiología y Salud Pública (CIBERESP), Madrid, Spain

Correspondence to:

Natalie Mueller, Dr. Aiguader 88, 08003 Barcelona

natalie.mueller@isglobal.org

Tel.: +34 93 214 7317

Abbreviations

BAU	Business as usual
CI	Confidence interval
ERF	Exposure response function
EMM	Electric micromobility
HIA	Health Impact Assessment
MaaS	Mobility-as-a-Service
METs	Metabolic Equivalent of Task
MI	Myocardial infarction
PA	Physical activity
PAF	Population attributable fraction
PM2.5	Particulate matter with diameter less than 2.5 µm
RR	Relative Risk
S1	Scenario 1
S2	Scenario 2
WHO	World Health Organization

Abstract

Background and Aim: Mobility in cities is changing with the appearance of electric micromobilities (EMMs), i.e. e-bikes, e-scooters, e-mopeds. Given the links between transport and health, it is relevant to understand the health implications of these new forms of mobility.

Methods: We conducted a health impact assessment (HIA), following the comparative risk assessment framework, to study the impacts of EMM use on the health of Barcelona adults. We used local transport, health and NewMob project data. Through two scenarios, assuming a 5% (S1) and 10% (S2) increase in EMM use, we modelled associated changes in physical activity (PA) levels, personal air pollution exposure and the risk of fatal traffic accidents. We estimated attributable mortality and morbidity (i.e. anxiety, depression, stroke, myocardial infarction (MI)) burdens.

Results: Health impacts depended on the specific mode shift studied. For S1 and S2, respectively, shifting from cars and motorcycles to EMMs translated into 13 (95% CI: 10;16) and 26 (95% CI: 20;32) preventable deaths annually. Shifting from walking and cycling to EMMs, translated into 17 (95% CI: 20;15) and 35 (95% CI: 41;29) additional deaths annually. Shifting from public transport to e-bikes and e-scooters resulted in 23 (95% CI: 34;12) and 46 (95% CI: 67;24), and 4 (95% CI: 5;3) and 8 (95% CI: 10;5) preventable deaths, respectively, while shifting to e-mopeds resulted in 7 (95% CI: 5;9) and 14 (95% CI: 9;18) additional deaths annually. The gain/ loss of PA when shifting from passive/ active transport modes to EMMs, contributed strongly to the overall health impact and outweighed air pollution and traffic accident impacts. Trends for anxiety, depression, stroke and MI impacts were similar.

Conclusions: Long-term increase of EMM use is expected in cities. If mode shifts happen from passive modes of transport, these new forms of mobility can provide health (and environmental) benefits.

Keywords: air pollution, electric micro-mobility, health impact assessment, mental health, mortality, physical activity

1.INTRODUCTION

It is expected that by 2050 two thirds of the global population will live in cities (United Nations, 2018). The increase in urban populations and their demands for services challenge urban designs and their supportive systems, such as the transport system. Transport is understood as fundamental to cities' economic and social development, as it moves goods and connects people. However, the negative consequences of current car-oriented transport planning have become well documented and relate to decreased physical activity (PA) levels, high air and noise pollution levels, environmental degradation, heat island effects, land take and congestion (Mueller et al., 2017a; Nieuwenhuijsen et al., 2017; Van den Brenk, 2018) that have been associated with considerable physical and mental health burdens (Mueller et al., 2017b, 2017a).

A significant shift in the current transport paradigm is needed to provide sustainable and healthy ways of travelling and to help prevent ill-health. Within this context, transport authorities with local accountability are responsible for defining measures to reduce motorized vehicle fleets and congestion in cities. Examples include implementing low-emission zones, congestion charging, reducing on-road parking, or urban designs, such as superblocks (Mueller et al., 2020; Nieuwenhuijsen and Khreis, 2016), while at the same time fostering the availability of alternative modes of transport, such as walking, cycling and public transport, and also more recently, electric micromobility (EMM).

Over the last years, EMMs, i.e. e-bikes, e-mopeds and e-scooters, have emerged in many cities worldwide, including Barcelona, Spain, both, as privately owned vehicles and as Mobility-as-a-Service (MaaS) operations (Roig-Costa et al., 2021). The use of these new modes has increased rapidly to almost 32,000 daily trips, representing 0.7% of total trips made in the city in 2018 (ATM, 2019). The increasing uptake of these EMMs, if managed correctly, could potentially help put the transport sector on a more sustainable trajectory, by reducing emissions (de Bortoli, 2021; McQueen et al., 2021; Winslott Hiselius and Svensson, 2017). Moreover, the shared use of these vehicles is increasingly becoming popular, as it enables users to have convenient, individual, short-duration access to transport, without the burdens of ownership.

Given the foreseen long-term increase in the use of EMMs in cities post COVID-19 pandemic (McKinsey & Company, 2020), and the links between transport and health (Nieuwenhuijsen et al., 2016), it is relevant to understand the health implications of these emerging, at times shared, EMMs. Until now, findings are mixed and health and well-being benefits appear to depend largely on the exact modal shift: Previous studies suggested potential reductions in air pollution and noise levels in the city (Pietrzak and Pietrzak, 2020; Shaheen and Chan, 2016, Weiss et al., 2015), both increases and decreases in PA levels, (Berntsen et al., 2017; Gojanovic et al., 2011; Winslott Hiselius and Svensson, 2017, Ognissanto et al. 2019), a potentially increased injury risk (Glenn et al. 2020) and possibly improved connectivity and accessibility (Milakis et al., 2020).

Currently, there is a lack of evidence on the most likely modal shift from conventional modes of transport to EMMs in cities, which appear to depend largely on local policies and regulations and the existing transport system (McQueen et al., 2021). At the same time, negative impacts of EMM use in cities are becoming evident and are related to: lack of regulations or awareness for appropriate use, road space assignment, conflicts with other transport modes, engagement in risky behaviours and increased injury risk, 'cluttering' of public space, vandalism, unequal city service coverage and lack of access to data, with cities being concerned to lose control over these private services operating in their city (Gössling, 2020; Ruhrort, 2020; Zagorskas and Burinskiene, 2020, McQueen et al., 2021).

Given the scarce evidence base for the health benefit-risk trade-off for modal shifts to EMMs, we conducted a health impact assessment (HIA) to study physical and mental health impacts associated with an uptake of EMMs for transport in Barcelona. We used real-world modal shift data and assessed health impacts of changes in PA levels, personal air pollution exposure, and the risk for fatal traffic accidents.

2. METHODS

2.1 The NewMob project

This HIA study is part of the NewMob project, funded by the Barcelona City Council, which aims to analyse mobility patterns and gain insights into user profiles and the environmental and social impacts of EMM use in Barcelona (Ajuntament de Barcelona, 2019). In September 2020, the NewMob project surveyed 902 EMM users, aged 16-65 years, on current and former travel behaviours and preferences, together with questions on sociodemographic profile (Roig-Costa et al., 2021). Recruitment was done in different areas of the city and participants were randomly intercepted and invited to participate before they would start a trip, during an ongoing trip or after finishing their trip. Initially, NewMob project recruitment and data collection were foreseen for spring 2020, however, this had to be delayed due to the Covid-19 pandemic. The incidence of Covid-19 was reduced in September 2020, as Spain just overcame its first infection wave in early summer 2020. In early September 2020, mobility in the city had returned to some normality, with people returning to work and the start of the academic year. To not delay the project any further, recruitment of participants was rolled-out in September

2020. Resulting potential limitations in the generalizability of our findings due to pandemic effects are acknowledged in the discussion.

2.2 Health impact assessment

To study the health benefits and risks associated with an uptake of EMMs for transportation in Barcelona, we followed the WHO comparative risk assessment framework (Ezzati et al., 2004), using standard HIA methodologies (Mueller et al., 2018, 2017a). Baseline transport, sociodemographic and health data were obtained through the NewMob survey (Roig-Costa et al., 2021), local transport data (ATM, 2019) and health statistics (Generalitat de Catalunya, 2017-2019). The health impacts of EMM uptake were simulated through scenario analyses and corresponding changes in mobility patterns. All HIA analyses were performed for Barcelona adults aged 16-65 years (N=999,810), because according to the NewMob survey (Roig-Costa et al., 2021), this subpopulation represents EMM users in Barcelona.

2.3 Transport data

Baseline transport data such as mode share and trip characteristics (i.e. distance, duration, speed) were obtained from the 2018 Workday Mobility Survey (ATM, 2019), local studies (Mueller et al., 2018; Rojas-Rueda et al., 2016), and Bicing, the local bike-sharing system operator (Bicing, 2021) (**Table 1**). We defined the following transport categories for our study: cars (including taxis, vans and trucks); private motorcycle (including smaller motorcycles and mopeds); public transport (including bus, metro, tram, trains, others); walking; private bike; shared bike (Bicing); shared e-bike (Bicing); shared e-moped (various private operators); private e-scooters. The distinction between private and shared bikes (Bicing) was made because trip characteristics vary in distance and durations (Bicing, 2021; Mueller et al., 2018; D. Rojas-Rueda et al., 2012; Rojas-Rueda et al., 2016) (**Table 1**). Moreover, it was assumed that e-bikes and e-mopeds in Barcelona are generally accessed through the sharing-systems, managed by different operators (i.e. Bicing and various private e-moped operators), as ownership of e-bikes and e-mopeds in Barcelona is uncommon (except for occupational purposes, such as on-demand courier services) because of issues related to acquisition costs, secure parking and fear of theft, in comparison to the relatively cheap and convenient access through the sharing-systems. E-scooters on the other hand, were assumed to be privately owned as in Barcelona permits for dockless e-scooter sharing-systems (such as Lime or Bird that pioneered in the US) are currently not granted. Shared bikes (mechanic and electric) operated by Bicing have fixed docking stations. Shared e-mopeds, operated by private companies, are free-floating, meaning that they can be parked anywhere according to current parking regulations. E-mopeds were included as EMM, because motorcycle use (including smaller motorcycles and mopeds) is very common in Barcelona (i.e. >6% modal share, **Table 1**) and other Southern European cities (Marquet and Miralles-Guasch, 2016), and the increasing uptake of shared e-mopeds represents an important form of new mobility in the city, with a currently scarce evidence base of environmental and health implications.

2.4 Scenarios and mode shifts

A recent data-driven projection suggests a long-term increase in EMM use by 5-10% by 2030 post COVID-19 pandemic, and argues that people learnt to appreciate individualized transport that facilitates physical distancing and reduces air and noise pollution, as people experienced associated benefits during COVID-19 related lockdowns (McKinsey & Company, 2020). Therefore, in this study we assessed the health impacts in terms of changes in PA levels, air pollution exposure for the traveller, and the risk of traffic accidents related to a 5% (Scenario 1 (S1)) and 10% (S2) increase in EMM use, respectively (**Figure 1**). Following the results from the NewMob project survey (Roig-Costa et al., 2021), the EMM mode shifts were constructed and extrapolated to the Barcelona adult population aged 16-65 years. In relative terms, 4.1% of travellers switched from cars; 8.9% switched from private motorcycles; 55.3% switched from public transport; 19.6% switched from walking; 6.1% switched from private bike; 6.0% switched from shared bike (i.e. Bicing). We assumed a uniformly-distributed increase in EMM trips across the e-bike (shared), e-moped (shared) and e-scooter (private). It was assumed that the new e-bike, e-moped or e-scooter trip would replace the distance of the substituted conventional mode of transport.

2.5 Health outcomes

We modelled the associated changes in PA levels, air pollution exposure and the risk of a traffic accident and their impact on mortality (**Figure 2**). Mortality was chosen as the main health outcome as it has been associated with all three considered health pathways (Chen and Hoek, 2020; Woodcock et al., 2011). Because of lack of data and for simplicity, we assumed the mortality risk to be equally distributed across all ages. Moreover, for PA and air pollution, we additionally included the health outcomes of anxiety, depression, stroke and myocardial infarction (MI) (**Figure 2**) (**Table 3**).

2.6 Physical activity

Metabolic equivalents of task (METs) were used as a measure of energy expenditure during PA. We calculated the gain or loss in marginal METs for people switching from conventional modes of transport to an EMM (e-bike, e-moped, e-scooter), considering baseline median PA levels obtained from the 2017 Barcelona Health Survey (n=2550, aged 16-65 years) (**Table S1**) (Bartoll et al., 2018). The Barcelona Health Survey studies the health status, lifestyles and use of health services of a population-based random sample of Barcelona residents and was assumed to well represent the baseline PA distribution of the Barcelona general population.

We assigned 1.3 METs to car and public transport, 6.8 METs to bike, 3.5 METs to walking and motorcycle, all obtained from the validated Compendium of Physical Activities (Ainsworth et al., 2011). Furthermore, we assigned 3.5 METs to e-moped and e-scooter, reasoning that users must keep an upright, tense body position and resist gravitation force, and finally, 5.8 METs to e-bike based on averaging the MET values of recent studies on e-biking (**Table S2, Table S3**) (Castro et al., 2019; Gojanovic et al., 2011; Peterman et al., 2016; Simons et al., 2009; Sperlich et al., 2012). Additionally, we assumed a public transport trip to include a 10 minute walk (with a speed of 5 km/h, a distance of 850 m and a physical intensity of 2.5 METs) to and from public transport stops (Ainsworth et al., 2011; Rojas-Rueda et al., 2012). We also assumed the shared bike and shared e-bike (i.e. Bicing) to include a 600 m walk (with at a speed of 5 km/h, a duration of 7.2 min and a physical intensity of 2.5 METs) to and from sharing stations (Ainsworth et al., 2011; Ajuntament de Barcelona, 2018), and the e-moped to include a 300 m walk (with a speed of 5 km/h, a duration of 3.2 min and physical intensity of 2.5 METs) to the next free-floating vehicle (Ainsworth et al., 2011) (**Table S2**).

The associations between PA and health outcomes, including all-cause mortality, anxiety, depression, stroke and MI were quantified using curvilinear exposure-response functions (ERF), applying a 0.375 power transformation to the PA exposure (Woodcock et al., 2011) (**Table 2**). Relative risks (RRs) were scaled to mode shift corresponding changes in PA levels.

We calculated the RR and the population attributable fraction (PAF) for both baseline PA and change in PA for each change in mode of transport. The estimated health impacts for baseline PA were subtracted from the estimated health impacts for the change in PA.

2.7 Traveller´s air pollution exposure

The air pollution impact assessment focused on the exposure to particulate matter less than 2.5 µm ($PM_{2.5}$), as $PM_{2.5}$ is a good proxy for exposure to air pollution from all fossil fuel combustion sources and due to low spatial dispersion well represents the overall air pollution burden in a city (Mueller et al., 2015). $PM_{2.5}$ is associated with a variety of ill-health outcomes, including all-cause mortality (Bowe et al., 2019), anxiety (Power et al., 2015), depression (Fan et al., 2020), stroke (Fu et al., 2019) and MI (Cesaroni et al., 2014). In 2019, the mean background $PM_{2.5}$ concentration in Barcelona was 17 µg/m^3 (Agència de Salut Pública de Barcelona, 2019). We considered the altered personal air pollution exposure for switching from conventional modes of transport to EMMs. $PM_{2.5}$ concentrations that car drivers, motorcyclists, public transport riders, cyclists and pedestrians are exposed to were set 2.5, 2.5, 1.9, 2.0, 1.9 times higher, respectively, than the background concentration, based on assumed physical locations while in transit and proximity to exhaust pipes (de Nazelle et al., 2017). Minute ventilation rates for different leisure (i.e. sleep, rest) and transport activities were available from previous studies (Bourne et al., 2018; Buekers et al., 2015; David Rojas-Rueda et al., 2012). For the motorcycle, e-moped and e-scooter, we calculated the minute ventilation rates ourselves, based on the PA intensities (i.e. MET values) assigned (**Table S4**). The daily inhaled $PM_{2.5}$ dose (µm/m^3/24-h) by activity and the total dose (µm/m^3/24-h) were calculated and stratified by transport mode.

We calculated the equivalent change in $PM_{2.5}$ dose, resulting of the change in transport mode (de Hartog et al., 2010). We used existing ERFs to quantify the association between the change in $PM_{2.5}$ and health, assuming linearity in the dose-response associations (**Table 2**).

We did not consider the expected changes in air and noise pollution exposure and related health impacts for the Barcelona general population that can be expected with a change in the overall mobility pattern and mode shifts towards EMMs.

2.8 Road traffic fatalities

Attributable road traffic fatalities were estimated using averaged police reported annual traffic fatalities by mode of transport for years 2015-2019 (Ajuntament de Barcelona, 2021a) (**Table 4**). For each mode of transport, the risk for a fatal traffic incident was normalized by billion km travelled, using the averaged reported number of fatalities and km travelled per year. The risk for the EMM trips was then compared to the risk estimated for the mode of transport which the trip was previously made by.

2.9 Sensitivity analyses

As there remains uncertainty regarding PA levels associated with EMM use, we additionally considered a MET value of 2.15 METs assigned to the e-scooter, based on an experimental field study in the US, including riding the e-scooter uphill, downhill, flat and over segments (Wen et al., 2019).

From a sustainability point of view, there are arguments that particularly car and motorcycle travel implies a larger carbon footprint than any EMM (de Bortoli, 2021; McQueen et al., 2021). However, currently, previous car and motorcycle users represent only a small proportion of new EMM users in Barcelona (i.e. only 4.1% and 8.9% of NewMob survey respondents reported to have substituted a previous car or motorcycle trip, respectively) (Roig-Costa et al., 2021). Therefore, to demonstrate the full potential of health in addition to environmental co-benefits of reduced car travel in the city, we additionally considered the scenario of switching all car trips (i.e. 436,699 daily car trips) and all motorcycle trips (i.e. 310,777) to EMMs.

Finally, we estimated health impacts under the scenario of changed trip purpose and destination, assuming that EMMs would replace trips of their own typical distance and duration.

3. RESULTS

The 5% (S1) and 10% (S2) EMM increase scenarios represent an increase from 31,885 current daily trips made in EMMs to 276,693 and 521,500 daily trips, respectively (**Table 1**).

Given the above-described mode shift assumptions, shifting from the most passive modes of transport, i.e. cars and motorcycles, translates into 13 (95% CI: 10;16) and 26 (95% CI: 20;32) preventable premature deaths annually, for S1 and S2, respectively (**Table 5**). However, shifting from the most active modes of transport, i.e. walking and cycling, to EMMs, translates into 17 (95% CI: 20;15) and 35 (95% CI: 41;29) additional premature deaths annually, for S1 and S2, respectively. The changes in PA contributed strongly to the overall health impact and outweighed the impacts of air pollution exposure (and traffic accidents) (**Table 5**).

For public transport, the health impacts depended on the exact EMM mode shift: Shifting to e-bikes and e-scooters resulted in health benefits (i.e. for e-bikes 23 (95% CI: 34;12) and 46 (95% CI: 67;24) preventable deaths, and for e-scooters 4 (95% CI: 5;3) and 8 (95%CI: 10;5) preventable deaths, for S1 and S2, respectively), driven by gains in PA, while shifting to e-mopeds resulted in health harms (7 (95% CI: 5;9) and 14 (95% CI: 9;18) additional deaths, for S1 and S2, respectively), driven by losses in PA (**Table 5**).

As no traffic fatalities were reported among any EMM for 2015-2019 (**Table 4**), shifting from any mode of transport to EMMs resulted in health gains (**Table 5**).

For the other health outcomes, the same trend in mode shift specific health impacts was found: shifting from cars and motorcycles to EMMs was estimated to result in 51 (95% CI: 25;76) and 102 (95% CI: 50;153) preventable cases of anxiety, 11 (95% CI: 15;-37) and 22 (95% CI: 29;-74) preventable cases of depression, and 0.3 (95% CI: 25;-26) and 0.5 (95% CI: 51;-52) preventable cases of stroke, for S1 and S2, respectively (**Tables S5-S7**). Shifting from walking and cycling to EMMs was estimated to result in 118 (95% CI: 163;73) and 237 (95% CI: 326;147) additional cases of anxiety, 45 (95% CI: 90;1) and 91 (95% CI: 181;1) additional cases of depression, 2 (95% CI: 47;-43) and 4 (95% CI: 94;-85) additional cases of stroke, for S1 and S2, respectively. Shifting from public transport to e-bikes and e-scooters was beneficial for health, while shifting to e-mopeds was harmful to health (**Tables S5-S7**).

Due to a strong association between air pollution and MI (i.e. RR 1.13 per 5 $\mu g/m^3$), even shifting from passive modes of transport to EMMs (except for switching to e-scooters) was not beneficial for health, due to the risks of increased air pollution exposure outweighing the benefits of gained PA (**Table S8**).

3.1 Sensitivity analyses

Reducing the MET value for the e-scooter from 3.5 METs to 2.15 METs reduced health benefits when switching from cars and motorcycles, and increased health losses when switching from public transport, walking or cycling (compare **Table 5 and Table S9**). Shifting all car and motorcycle trips to EMMs was estimated to result in 200 (95% CI: 146;254) and 58 (95% CI: 46;71) preventable deaths, respectively (**Tables S10-S11**). Finally, assuming that EMMs replaced trips with the distance and duration of their own (i.e. typical e-bike, e-scooter, e-moped trip) did not change the conclusion that mode shifts from passive modes of transport to EMMs most likely are beneficial for health, while mode shifts from public and active modes of transport are not (**Table S12**).

4. DISCUSSION

To our knowledge, this is the first study that quantified and compared the health impacts of EMM use in an urban environment. Our results show that health impacts are diverse and depend on which mode of transport is substituted with which EMM. Based on the mode shift distribution obtained through the NewMob survey (Roig-Costa et al., 2021), shifting from cars and motorcycles to EMMs resulted in 16 and 23 preventable deaths, while shifting from walking and cycling to EMMs resulted in 17 to 35 additionally deaths for the 5% (S1) and 10% (S2) EMM increase scenarios, respectively (**Table 5**). Shifting from public transport to e-bikes (23 and 46 preventable deaths) and e-scooters (4 and 8 preventable deaths) was beneficial for health, while shifting to e-mopeds was not (7 and 14 additional deaths). Similar trends were estimated for the studied morbidity outcomes, except for MI.

Generally, net health impacts were driven by the gained PA when shifting from passive modes of transport to EMMs (with switching to e-bike being the most beneficial, followed by e-scooter and finally e-moped), and the losses in PA when shifting from active modes of transport to EMMs. The PA impact generally outweighed the impact of increased or decreased personal air pollution exposure, except for MI, where air pollution impacts outweighed PA impacts (**Table**

S5 – Table S8). Following modelling assumptions considerably influenced the health impact magnitude and therefore need consideration: a) from which mode of transport people were shifting (i.e. most from public transport, the least from cars), b) the PA (i.e. METs) and air pollution exposure levels assigned to each mode, c) the additional consideration of walking to shared modes and public transport, d) the assumed duration of the substituted trip, e) the gradient of the exposure-health association (i.e. RR), and f) the incidence rate of each studied health outcome.

Overall, health impacts appear to be in line with environmental impacts of EMM mode shifts in cities: Replacing the most passive modes (i.e. car, motorcycle), that also have the largest carbon footprint (de Bortoli, 2021), with EMMs, especially if shared and therefore include walking, resulted generally in health benefits, and would reduce the carbon footprint. Shifting active modes (i.e. walking and cycling), that have the smallest carbon footprint (de Bortoli, 2021), to EMMs, was generally estimated to not be beneficial for health (except shifting walking to e-biking due to the considerable amount of PA assigned to e-biking), and would increase the carbon footprint. Shifting public transport trips to e-bikes and e-scooters was estimated to result in health benefits, due to considerable PA levels assigned to e-bikes and e-scooters (i.e. 5.8 and 3.5 METs, respectively), the consideration of walking to access e-bike sharing stations and the relatively long duration spent on e-scooters in order to replace a public transport trip. If indeed a 2.15 MET value is a more plausible PA proxy for e-scooters (Wen et al., 2019), then shifting public transport trips to e-scooters would not be beneficial for health anymore, as demonstrated in the sensitivity analysis (**Table S9**).

Based on the insights from the NewMob survey on EMM mode substitution in Barcelona, the largest proportions of trips are currently shifted from public transport (55.3%) and walking (19.6%), and the smallest proportion from cars (4.1%) (Roig-Costa et al., 2021). This is in line with other studies finding especially public transport users and pedestrians to switch to (shared) EMMs (Berge, 2019; Reck and Axhausen, 2021, McQueen et al. 2021, Ognissanto et al. 2019). The current local EMM ‘pull’ policies in place, i.e. the policies that make EMM use attractive in the city (e.g. the shared use, relatively-cheap access, good distribution of vehicles across the city, etc.), seem to attract especially pedestrians and public transport users, potentially exacerbated by the current COVID-19 pandemic, with people distrusting public transport and looking for viable alternatives (Li et al., 2021). However, given that walking and cycling for transport are known to provide the largest health benefits (Mueller et al. 2015), driven by largest gains in PA (Doorley et al., 2015; Mueller et al., 2015; Rojas-Rueda et al., 2016), for public health promotion, active transport policies and the uptake walking and cycling should always be prioritized. EMM policies should be defined complementary and not as competitors to active and public transport (McQueen et al. 2021). Targeted 'push' policies that restrict and disincentivize private car and motorcycle use in the city, e.g. superblocks, low emissions zones, congestion charging, reduced on-road parking, etc., are needed to potentiate modal shifts from cars and motorcycles to, first and foremost, walking and cycling, and secondly, to EMMs, and thus, the health and environmental benefits these mode shifts can provide. To be a real competitor to car and motorcycle trips, EMMs are best nudged as first- and last-mile solutions in combination with public transport use, decreasing access time, expanding public transport reach and increasing time competitiveness in comparison to car and motorcycle trips (McQueen et al. 2021).

To fully understand health (and environmental) impacts of EMM use in Barcelona, certain operational and logistical issues, as well as risks and opportunities need to be considered. While EMMs are increasingly recognized to be viable solutions to help alleviate traffic congestion (McKinsey & Company, 2019, Söderberg et al. 2021, Glavic et al. 2021), there are key concerns targeting traffic safety and injury risk and whether current infrastructures can support the influx of EMMs (Ruhrort, 2020). For the uptake of EMMs to function well in the overall transport system of a city, clear rules and regulations on their use and parking, and awareness thereof, need to be established and enforced. These regulations should provide that each mode of transport has designated road and parking space to avoid conflicts and ensure traffic safety for everyone. Currently in Barcelona, e-scooters and e-bikes are required to use bike lanes, specific authorized paths within established speed limits (i.e. max 25 km/h), and otherwise roadways andnot sidewalks. E-mopeds are required to use roadways and dedicated parking spaces (Ajuntament de Barcelona, 2021b). Helmet use is at the moment only mandatory for e-mopeds. However, currently, incompliance of some of these rules can be observed quite frequently and enforcement of regulations needs improvement.

Nevertheless, EMMs may represent a facilitator of mobility for multiple, potentially vulnerable collectives, such as elderly people who might not have the physical strength for conventional active transport and appreciate the assistance (Castro et al., 2019; Van Cauwenberg et al., 2019), families who benefit from transporting their children in e-bike trailer combos, residents who live in the city's periphery or suburbs and through EMM use have better connectivity and accessibility (Abduljabbar et al., 2021; Milakis et al., 2020), also through enabled multimodality and first- and last-mile mobility (Holm Møller et al., 2019; Oeschger et al., 2020), and finally, groups that during the Covid-19 pandemic prefer individualized transport practising physical distancing (Li et al., 2021). Facilitating mobility for these collectives through EMMs, could benefit their health and well-being status, also through additional health pathways that we were not able to capture in our analysis, such as reduced stress, increased flexibility and autonomy. Moreover, the shared use of EMMs, if sharing systems are equitably implemented and serving all neighbourhoods, can potentially promote equity in transport choices, as it can help overcome issues related to affordability and accessibility. Once EMM use in cities is fully adopted and regulated, EMMs will most likely appeal to a broader group of people, will likely not compete with urban cycling, and will cover a different transport niche (Curl and Fitt, 2020; Gössling et al., 2019), yet to potentiate in terms of providing health and environmental benefits.

4.1 Methodological considerations

A considerable amount of METs were assigned to e-bikes (i.e. 5.8 METs), e-mopeds and e-scooters (i.e. 3.5 METs, respectively) that strongly influenced the results, e.g. a shift from public transport to e-scooter resulted in health benefits because a considerable amount of time would be spent in comparatively high energy expenditure. Here, the limited existing evidence of plausible MET values to represent EMMs needs to be acknowledged, as well as the limited generalizability of physical activity intensities overall, e.g. for e-bikes, energy expenditure varies strongly depending on the type of assistance the user chooses, and also the trip profile in terms of elevation gain or road roughness. The 3.5 METs for e-scooters and e-mopeds were based, without further validation, on the 3.5 METs assigned to the motorcycle in the Compendium of Physical Activities (Ainsworth et al. 2011), assuming that users must keep the same upright, tense body position and resist gravitation force. Further research is needed on plausible MET values for EMMs.

The air pollution risk assessment was based exclusively on $PM_{2.5}$ exposure for the travelling person. However, long-term changes in modal share, especially if car and motorcycle traffic is reduced, are expected to produce changes in air pollution levels. This potential improvement in air quality resulting from modal shifts to EMMs and related health impacts were not considered in this analysis. Despite the air pollution health risk for the travelling person being comparatively small, further health benefits, also for the Barcelona general population, could be achieved by reducing the current annual mean $PM_{2.5}$ concentration of 17 µg/m^3 (Agència de Salut Pública de Barcelona, 2019) to the recently updated WHO health threshold of 5 µg/m^3 (WHO, 2021).

The traffic accident assessment quantified exclusively fatal traffic incidents per billion kilometers traveled, using reported data (Ajuntament de Barcelona, 2021a). We did not consider road traffic injuries because they are most likely under-reported. However, traffic injuries are believed to be considerable for EMMs because of travel at relatively high speeds, absence of protective gear requirements (except for mandatory helmet use for e-mopeds), and potentially inexperienced users, especially related to the sporadic use of shared EMMs (Glenn et al. 2020). Hence, the traffic accident health burden is probably underestimated in this analysis and most likely larger, which would also have an impact on the overall health benefit-risk tradeoff of EMM use.

4.2 Limitations and strengths

As common in HIA studies, our study was limited by the availability of data and the need to make assumptions to model the expected health impacts. The lack of data and evidence was particularly common for EMMs, as little evidence exists yet. For the modelling, multimodality was only partially considered, by including walking to and from public transport stops, bike-sharing stations and free-floating e-motorbikes. A future emphasis on multimodality and consideration that people use different modes of transport, especially in the context of EMMs offering first and last-mile solutions (Holm Møller et al., 2019), would be desirable as this would be more realistic.

Based on NewMob data (Roig-Costa et al., 2021) and also confirmed by other studies (Reck and Axhausen, 2021), we considered EMM users to be relatively young, assuming that later adopters will behave similar to innovators and early adopters, and not considering that there might be sociodemographic differences in user profiles and behaviors over time (Reck and Axhausen, 2021). Also, the NewMob survey was conducted in September 2020, right after Spain overcame the first wave of the Covid-19 pandemic. Validity and generalizability of questionnaire responses, regarding mode shifts, EMM transport behaviours and preferences need to be questioned, as the pandemic might have led to both temporary and long-term changes in mobility patterns in the city.

Further, we used mortality and disease incidence rates and risk estimates from the ERFs for the general population, as no age-specific data was available. This has likely led to an overestimation of health benefits from PA, as younger populations are at reduced risk for natural-cause mortality and degenerative disease onset. In addition, we focused on a selection of health outcomes, while a shift to EMMs would impact other health outcomes associated with PA or air pollution, such as cancer (Kyu et al., 2016; Turner et al., 2020), diabetes (Eze et al., 2015; Kyu et al., 2016), hypertension (Borjesson et al., 2016; Giorgini et al., 2015) or obesity (Wiklund, 2016). As with for the health outcomes, for the considered exposures included, there are other health pathways linked with EMM use that we did not consider in this analysis, such as noise exposure or impacts on social cohesion, interaction and life satisfaction. Moreover, there are likely more distal adverse environmental and related health impacts we did not consider. For example, the manufacturing and charging of batteries for EMMs requires energy, most likely coming from fossil fuels, that will again lead to emissions and pollution, although not in the city, that can be linked to adverse health impacts (Weiss et al. 2015). Therefore, we are providing only a limited picture of the pathways and mechanisms of EMM use affecting health and well-being outcomes in the city (and elsewhere).

Nevertheless, there is value in this study as it is the first study that tries to disentangle the health impacts associated with mode shifts from conventional modes of transport to EMMs, based on real-world EMM data for Barcelona. We quantified a multitude of different exposures impacted by a mode shift to EMMs, i.e. PA, air pollution and road traffic fatalities, and different physical and mental health outcomes, i.e. mortality, anxiety, depression, stroke and MI. Thereby, we contribute to the current discussion on EMM use in cities and their health (and environmental) impacts. The results can help inform local policy, raise awareness of the links between transport and health, and highlight the need for further studies to better characterize the opportunities, risks and impacts these new modes of transport mean for cities.

5. CONCLUSIONS

The growth of EMM use in cities is likely, as city dwellers need viable alternatives to current transportation options that contribute to congestion and pollution. EMM policies should be developed complementary to active transport strategies, should regulate the increasing uptake of e-bikes, e-scooters and e-mopeds in terms of use and parking, and facilitate shifts from the most passive transport modes (i.e. car, motorcycle), as these mode shifts have the potential to provide health and environmental benefits.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding source

This research paper did not receive any specific funding from agencies in the public, commercial, or not-for-profit sectors. The NewMob project, from which data was taken and analysed, is funded by the Institut de Cultura, Ajuntament de Barcelona [grant number

19S01360 -006].

Acknowledgments

The authors would like to thank Sandra Márquez for statistical support.

BIBLIOGRAPHY

Abduljabbar, R.L., Liyanage, S., Dia, H., 2021. The role of micro-mobility in shaping sustainable cities: A systematic literature review. Transp. Res. Part D Transp. Environ. 92, 102734. https://doi.org/10.1016/j.trd.2021.102734

Agència de Salut Pública de Barcelona, 2019. Qualitat de l'aire. Informe 2019.

Ainsworth, B., Haskell, W., Herrmann, S., Meckes, N., Bassett, D., Tudor-Locke, C., Greer, J., Vezina, J., Whitt-Glover, M., Leon, A., 2011. 2011 Compendium of physical activities: A second update of codes and MET values. Med. Sci. Sports Exerc. 43, 1575–1581. https://doi.org/10.1249/MSS.0b013e31821ece12

Ajuntament de Barcelona, 2021a. Personas involucradas en accidentes gestionados por la Guardia Urbana en la ciudad de Barcelona [WWW Document]. URL https://opendata-ajuntament.barcelona.cat/data/es/dataset/accidents-persones-gu-bcn (accessed 5.9.21).

Ajuntament de Barcelona, 2021b. Aparca la moto o el ciclomotor a les places habilitades [WWW Document]. URL https://www.barcelona.cat/mobilitat/sites/default/files/documentacio/flyer_motos-voreres_interactiu.pdf (accessed 6.1.21).

Ajuntament de Barcelona, 2019. New mobility in the city: environmental and social impacts of shared and private scooters, ebikes and e-motorbikes in Barcelona (NewMob). Ciència program.

Ajuntament de Barcelona, 2018. El nuevo Bicing: 24 horas, más cobertura territorial y un nuevo diseño [WWW Document]. URL https://ajuntament.barcelona.cat/noubarris/ca/noticia/el-nuevo-bicing-24-horas-mas-cobertura-territorial-y-un-nuevo-diseno-2_731730 (accessed 3.25.21).

ATM, 2019. Enquesta de mobilitat en dia feiner (EMEF). 2018 [WWW Document]. URL https://bcnroc.ajuntament.barcelona.cat/jspui/handle/11703/115924 (accessed 9.20.21).

Bartoll, X., Pérez, C., Pasarín, M., Rodríguez, M., Borrell, C., 2018. Enquesta de salut de Barcelona 2016/17. Barcelona.

Berge, S.H., 2019. Kickstarting Micromobility – a Pilot Study on e-Scooters. TØI Rep. 68p.

Berntsen, S., Malnes, L., Langåker, A., Bere, E., 2017. Physical activity when riding an electric assisted bicycle. Int. J. Behav. Nutr. Phys. Act. https://doi.org/10.1186/s12966-017-0513-z

Bicing, 2021. Bicing - Personal communication.

Borjesson, M., Onerup, A., Lundqvist, S., Dahlof, B., 2016. Physical activity and exercise lower blood pressure in individuals with hypertension: Narrative review of 27 RCTs. Br. J. Sports Med. https://doi.org/10.1136/bjsports-2015-095786

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. Int. J. Behav. Nutr. Phys. Act. https://doi.org/10.1186/s12966-018-0751-8

Bowe, B., Xie, Y., Yan, Y.Y., Al-Aly, Z., 2019. Burden of Cause-Specific Mortality Associated with PM2.5 Air Pollution in the United States. JAMA Netw. Open 2, 1–16. https://doi.org/10.1001/jamanetworkopen.2019.15834

Buekers, J., Dons, E., Elen, B., Int Panis, L., 2015. Health impact model for modal shift from car use to cycling or walking in Flanders: Application to two bicycle highways. J. Transp. Heal. 2, 549–562. https://doi.org/10.1016/j.jth.2015.08.003

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. Transp. Res. Interdiscip. Perspect. 1, 100017. https://doi.org/10.1016/j.trip.2019.100017

Cesaroni, G., Forastiere, F., Stafoggia, M., Andersen, Z.J., Badaloni, C., Beelen, R., Caracciolo, B., De Faire, U., Erbel, R., Eriksen, K.T., Fratiglioni, L., Galassi, C., Hampel, R., Heier, M., Hennig, F., Hilding, A., Hoffmann, B., Houthuijs, D., Jöckel, K.H., Korek, M., Lanki, T., Leander, K., Magnusson, P.K.E., Migliore, E., Ostenson, C.G., Overvad, K., Pedersen, N.L., Pekkanen, J.J., Penell, J., Pershagen, G., Pyko, A., Raaschou-Nielsen, O., Ranzi, A., Ricceri, F., Sacerdote, C., Salomaa, V., Swart, W., Turunen, A.W., Vineis, P., Weinmayr, G., Wolf, K., De Hoogh, K., Hoek, G., Brunekreef, B., Peters, A., 2014. Long term exposure to ambient air pollution and incidence of acute coronary events: Prospective cohort study and meta-analysis in 11 european cohorts from the escape project. BMJ 348, 1–16. https://doi.org/10.1136/bmj.f7412

Chen, J., Hoek, G., 2020. Long-term exposure to PM and all-cause and cause-specific mortality: A systematic review and meta-analysis. Environ. Int. 143, 105974. https://doi.org/10.1016/j.envint.2020.105974

Curl, A., Fitt, H., 2020. Same same, but different? Cycling and e-scootering in a rapidly changing urban transport landscape. N. Z. Geog. 76, 194–206. https://doi.org/10.1111/nzg.12271

de Bortoli, A., 2021. Environmental performance of shared micromobility and personal alternatives using integrated modal LCA. Transp. Res. Part D Transp. Environ. 93. https://doi.org/10.1016/j.trd.2021.102743

de Hartog, J., Boogaard, H., Nijland, H., Hoek, G., 2010. Do the health benefits of cycling outweigh the risks? Environ. Health Perspect. 118, 1109–16. https://doi.org/10.1289/ehp.0901747

de Nazelle, A., Bode, O., Orjuela, J.P., 2017. Comparison of air pollution exposures in active vs. passive travel modes in European cities: A quantitative review. Environ. Int. 99, 151–160. https://doi.org/10.1016/j.envint.2016.12.023

Departament de Salut, 2018. Resultats de l'enquesta de salut de Catalunya (ESCA). [WWW Document]. URL https://salutweb.gencat.cat/ca/el_departament/estadistiques_sanitaries/enquestes/esca/resultats_enquesta_salut_catalunya/

Doorley, R., Pakrashi, V., Ghosh, B., 2015. Quantifying the Health Impacts of Active Travel: Assessment of Methodologies. http://dx.doi.org/10.1080/01441647.2015.1037378 35, 559–582. https://doi.org/10.1080/01441647.2015.1037378

Eze, I.C., Hemkens, L.G., Bucher, H.C., Hoffmann, B., Schindler, C., Künzli, N., Schikowski, T., Probst-Hensch, N.M., 2015. Association between ambient air pollution and diabetes mellitus in Europe and North America: Systematic review and meta-analysis. Environ. Health Perspect. https://doi.org/10.1289/ehp.1307823

Ezzati, M., Lopez, A.D., Rodgers, A., Murray, C.J.L., 2004. Comparative Quantification of Health Risks.

Fan, S.J., Heinrich, J., Bloom, M.S., Zhao, T.Y., Shi, T.X., Feng, W.R., Sun, Y., Shen, J.C., Yang, Z.C., Yang, B.Y., Dong, G.H., 2020. Ambient air pollution and depression: A systematic review with meta-analysis up to 2019. Sci. Total Environ. 701. https://doi.org/10.1016/j.scitotenv.2019.134721

Fu, P., Guo, X., Cheung, F.M.H., Yung, K.K.L., 2019. The association between PM 2.5 exposure and neurological disorders: A systematic review and meta-analysis. Sci. Total Environ. 655, 1240–1248. https://doi.org/10.1016/j.scitotenv.2018.11.218

Giorgini, P., Di Giosia, P., Grassi, D., Rubenfire, M., D. Brook, R., Ferri, C., 2015. Air Pollution Exposure and Blood Pressure: An Updated Review of the Literature. Curr. Pharm. Des. 22, 28–51. https://doi.org/10.2174/1381612822666151109111712

Gojanovic, B., Welker, J., Iglesias, K., Daucourt, C., Gremion, G., 2011. Electric bicycles as a new active transportation modality to promote health. Med. Sci. Sports Exerc. 43, 2204–2210. https://doi.org/10.1249/MSS.0b013e31821cbdc8

Gössling, S., 2020. Integrating e-scooters in urban transportation: Problems, policies, and the prospect of system change. Transp. Res. Part D Transp. Environ. 79, 102230. https://doi.org/10.1016/j.trd.2020.102230

Gössling, S., Choi, A., Dekker, K., Metzler, D., 2019. The Social Cost of Automobility, Cycling and Walking in the European Union. Ecol. Econ. 158, 65–74. https://doi.org/10.1016/j.ecolecon.2018.12.016

Holm Møller, T., Simlett, J., Mugnier, E., 2019. Micromobility: moving cities into a sustainable future.

Kyu, H.H., Bachman, V.F., Alexander, L.T., Mumford, J.E., Afshin, A., Estep, K., Veerman, J.L., Delwiche, K., Iannarone, M.L., Moyer, M.L., Cercy, K., Vos, T., Murray, C.J.L., Forouzanfar, M.H., 2016. Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: Systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013. BMJ 354, 1–10. https://doi.org/10.1136/bmj.i3857

Li, A., Zhao, P., Haitao, H., Mansourian, A., Axhausen, K.W., 2021. How did micro-mobility change in response to COVID-19 pandemic? A case study based on spatial-temporal-semantic analytics. Comput. Environ. Urban Syst. 90, 101703. https://doi.org/10.1016/J.COMPENVURBSYS.2021.101703

Marquet, O., Miralles-Guasch, C., 2016. City of Motorcycles. On how objective and subjective factors are behind the rise of two-wheeled mobility in Barcelona. Transp. Policy 52, 37–45. https://doi.org/10.1016/J.TRANPOL.2016.07.002

McKinsey & Company, 2020. The future of micromobility: Ridership and revenue after a crisis [WWW Document]. URL https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-micromobility-ridership-and-revenue-after-a-crisis (accessed 3.25.21).

McKinsey & Company, 2019. Micromobility's 15,000-mile checkup [WWW Document].

McQueen, M., Abou-Zeid, G., MacArthur, J., Clifton, K., 2021. Transportation Transformation: Is Micromobility Making a Macro Impact on Sustainability? J. Plan. Lit. 36, 46–61. https://doi.org/10.1177/0885412220972696

Milakis, D., Gedhardt, L., Ehebrecht, D., Lenz, B., 2020. Is micro-mobility sustainable? An overview of implications for accessibility, air pollution, safety, physical activity and subjective wellbeing. Handb. Sustain. Transp. 180–189. https://doi.org/10.4337/9781789900477.00030

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., 2017a. Urban and Transport Planning Related Exposures and Mortality: A Health Impact Assessment for Cities. Environ. Health Perspect. 125, 89–96. https://doi.org/10.1289/EHP220

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., 2017b. Health impacts related to urban and transport planning: A burden of disease assessment. Environ. Int. 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. Prev. Med. (Baltim). https://doi.org/10.1016/j.ypmed.2015.04.010

Mueller, N., Rojas-Rueda, D., Khreis, H., Cirach, M., Andrés, D., Ballester, J., Bartoll, X., Daher, C., Deluca, A., Echave, C., Milà, C., Márquez, S., Palou, J., Pérez, K., Tonne, C., Stevenson, M., Rueda, S., Nieuwenhuijsen, M., 2020. Changing the urban design of cities for health: The superblock model. Environ. Int. 134. https://doi.org/10.1016/j.envint.2019.105132

Mueller, N., Rojas-Rueda, D., Salmon, M., Martinez, D., Ambros, A., Brand, C., de Nazelle, A., Dons, E., Gaupp-Berghausen, M., Gerike, R., Götschi, T., Iacorossi, F., Int Panis, L., Kahlmeier, S., Raser, E., Nieuwenhuijsen, M., 2018. Health impact assessment of cycling network expansions in European cities. Prev. Med. (Baltim). 109, 62–70. https://doi.org/10.1016/j.ypmed.2017.12.011

Nieuwenhuijsen, M.J., Khreis, H., 2016. Car free cities: Pathway to healthy urban living. Environ. Int. 94, 251–262. https://doi.org/10.1016/j.envint.2016.05.032

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. Environ. Int. https://doi.org/10.1016/j.envint.2017.03.022

Nieuwenhuijsen, M.J., Khreis, H., Verlinghieri, E., Rojas-Rueda, D., 2016. Transport And Health: A Marriage Of Convenience Or An Absolute Necessity. Environ. Int. https://doi.org/10.1016/j.envint.2015.12.030

Oeschger, G., Carroll, P., Caulfield, B., 2020. Micromobility and public transport integration: The current state of knowledge. Transp. Res. Part D Transp. Environ. 89, 102628. https://doi.org/10.1016/J.TRD.2020.102628

Peterman, J.E., Morris, K.L., Kram, R., Byrnes, W.C., 2016. Pedelecs as a physically active transportation mode. Eur. J. Appl. Physiol. 116, 1565–1573. https://doi.org/10.1007/s00421-016-3408-9

Pietrzak, K., Pietrzak, O., 2020. Environmental effects of electromobility in a sustainable urban public transport. Sustain. 12. https://doi.org/10.3390/su12031052

Power, M.C., Kioumourtzoglou, M.A., Hart, J.E., Okereke, O.I., Laden, F., Weisskopf, M.G., 2015. The relation between past exposure to fine particulate air pollution and prevalent anxiety: Observational cohort study. BMJ 350. https://doi.org/10.1136/bmj.h1111

Reck, D.J., Axhausen, K.W., 2021. Who uses shared micro-mobility services? Empirical evidence from Zurich, Switzerland. Transp. Res. Part D Transp. Environ. 94, 102803. https://doi.org/10.1016/j.trd.2021.102803

Roig-Costa, O., Gómez-Varo, I., Cubells, J., Marquet, O., 2021. La movilidad post-pandemia: perfiles y uso de la micromovilidad en Barcelona (under review). Rev. Transp. y Territ.

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, 1–14. https://doi.org/10.1371/journal.pone.0149990

Rojas-Rueda, D., de Nazelle, A., Teixidó, O., Nieuwenhuijsen, M.J., 2012. Replacing car trips by increasing bike and public transport in the greater Barcelona metropolitan area: A health impact assessment study. Environ. Int. 49, 100–109. https://doi.org/10.1016/j.envint.2012.08.009

Rojas-Rueda, David, De Nazelle, A., Teixidó, O., Nieuwenhuijsen, M.J., 2012. Appendix. Replacing car trips by increasing bike and public transport in the greater Barcelona metropolitan area: A Health Impact Assessment Study 1–23.

Ruhrort, L., 2020. Reassessing the role of shared mobility services in a transport transition: Can they contribute the rise of an alternative socio-technical regime of mobility? Sustain. 12. https://doi.org/10.3390/su12198253

Simons, M., Van Es, E., Hendriksen, I., 2009. Electrically assisted cycling: A new mode for meeting physical activity guidelines? Med. Sci. Sports Exerc. 41, 2097–2102. https://doi.org/10.1249/MSS.0b013e3181a6aaa4

Sperlich, B., Zinner, C., Hebert-Losier, K., Born, D.P., Holmberg, H.C., 2012. Biomechanical, cardiorespiratory, metabolic and perceived responses to electrically assisted cycling. Eur. J. Appl. Physiol. 112, 4015–4025. https://doi.org/10.1007/s00421-012-2382-0

Turner, M.C., Andersen, Z.J., Baccarelli, A., Diver, W.R., Gapstur, S.M., Pope, C.A., Prada, D., Samet, J., Thurston, G., Cohen, A., 2020. Outdoor air pollution and cancer: An overview of the current evidence and public health recommendations. CA. Cancer J. Clin. 70, 460–479. https://doi.org/10.3322/caac.21632

United Nations, 2018. Revision of World Urbanization Prospects [WWW Document]. URL https://www.un.org/development/desa/publications/2018-revision-of-world-urbanizatio n-prospects.html (accessed 2.1.21).

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 (Amst). 46, 2151–2172. https://doi.org/10.1007/S11116-018-9919-Y

Van den Brenk, I., 2018. The use of Health Impact Assessment tools in European Cities [WWW Document]. URL https://ec.europa.eu/futurium/en/urban-agenda. (accessed 4.29.21).

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. Transp. Res. Part D Transp. Environ. 41, 348–366. https://doi.org/10.1016/j.trd.2015.09.007

Wen, Y., Bassett Jr, D., Zhang, S., Brakewood, C., Cherry, C., Thorsen, T., JT, W., Morse, J., 2019. Evaluating the Physical Activity Impacts of Riding Electric Kick Scooters.

WHO, 2021. WHO global air quality guidelines.

Wiklund, P., 2016. The role of physical activity and exercise in obesity and weight management: Time for critical appraisal. J. Sport Heal. Sci. https://doi.org/10.1016/j.jshs.2016.04.001

Winslott Hiselius, L., Svensson, Å., 2017. E-bike use in Sweden – CO2 effects due to modal change and municipal promotion strategies. J. Clean. Prod. 141, 818–824. https://doi.org/10.1016/j.jclepro.2016.09.141

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. Int. J. Epidemiol. 40, 121–138. https://doi.org/10.1093/ije/dyq104

Zagorskas, J., Burinskiene, M., 2020. Challenges caused by increased use of E-powered personal mobility vehicles in European cities. Sustain. 12. https://doi.org/10.3390/su12010273