European Road Safety Observatory

Road Safety Thematic Report

Personal Mobility Devices

This document is part of a series of 20 thematic reports on road safety. The purpose is to give road safety practitioners an overview of the most important research questions and results on the topic in question. The level of detail is intermediate, with more detailed papers or reports suggested for further reading. Each report has a 1-page summary.

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Contents

Summary

Personal mobility devices in road traffic

Personal mobility devices (PMDs) have seen a market boom in recent years. These vehicles are seen as an easy way to travel around the city, and they contribute to solving the “last-mile” problem. This report focuses mainly on electric scooters (e-scooters).

Shared e-scooters are mainly used for leisure activities, during the weekend and by young men. Privately owned e-scooters are more often used for commuting. It is hypothesized that their crash risk is similar to that of cyclists. A high proportion of crashes with a PMD are usually caused by falls. The most common injuries for (shared) e-scooter users are head injuries, followed by fractures of the lower and upper limbs, soft tissue injuries, and injuries and fractures of the face and neck. Evidence suggests that injuries following e-scooter crashes are more severe than those on bicycles.

The vast majority of crashes involving an e-scooter do not involve another road user. However, most severe casualties (over 80% of e-scooter rider deaths and 50% of trauma patients’ injuries) result from crashes that do involve a heavier motor vehicle.

The proportion of e-scooter users who wear a helmet while driving is very low, even where it is compulsory. Furthermore, a large proportion of users admit that they often ride on the pavement, even when this is not allowed.

Countermeasures

To develop a safe **infrastructure** for micro-mobility, research suggests that e-scooters should be banned from pavements but alternatives are thus required. Cycle paths need to be wide enough to allow different types of vehicles to use this infrastructure together safely. Ideally, designated parking spots for e-scooters should be created.

A number of characteristics of the **vehicle** can pose a threat to road safety. PMDs would be safer with direction indicators, a sound signal, rear-view mirrors, and reflective materials. And for shared e-scooters it would be beneficial if they were able to “self-diagnose”, identifying remotely faults which require corrective action as they occur. A minimum value for the braking deceleration and two independent braking devices, at least one of which works independently of the vehicle’s electrical system, are recommended. Increasing helmet use would prevent head-injuries.

Active **enforcement** of the legal blood alcohol content, speeding, and positioning on the roadway is advisable. Speed is also a key factor whereever vulnerable road users such as e-scooter users mix with motor vehicles. National and local authorities could set a default 30 km/h limit in urban areas. It has been suggested that micro-mobility vehicles need to operate in a **regulatory framework** that defines where they can be used, at what speed, after which training, as of what age and in compliance with which safety rules.

As e-scooter users are often injured during their first ride, **training** is important. In order to oblige PMD users to drive only where they are allowed, geofencing could be used. Training motor vehicle users to be prepared to interact with PMDs is equally important.

1 Highlights

- Although data is being collected in some Member States – for example in Austria, where there is a significant increase in the number of e-scooter collisions since 2015 – there is no data available for other Member States. Therefore, not much is known about the crash risk of PMDs, although it is hypothesized that their crash risk is similar to that of cyclists.
- PMD crashes are often unilateral, which means there is only one road user involved. Crashes with another road user account for around 4% of all crashes involving an e-scooter. However, over 80% of e-scooter rider deaths result from crashes that involve a heavier motor vehicle (OECD/ITF, 2020).
- Only 4% of all e-scooter users were wearing a helmet when the crash happened. This explains the high proportion of head injuries among e-scooter victims.

2 What is the problem?

New technologies, together with the chronic congestion of urban transport networks, have led to the development of new urban mobility solutions (Kuo et al., 2019; Road Controlling Authorities Forum (NZ) Inc., 2013). **Personal Mobility Devices (PMDs)** were originally designed for pedestrians experiencing difficulties with physical mobility. Now they are a practical means to travel short distances and can therefore be a perfect solution for the last-mile-problem (the last leg of a journey within a city to the final destination) (Bruneau & Maurice, 2012). PMDs should be treated as a whole new road user category, and not as a pedestrian, cyclist, or motor vehicle (Jiménez, De La Fuente, & Hernández-Galán, 2018).

2.1 Definition

PMDs are polymorphic devices which do not have a common form. They can be classified according to their maximum speed and/or their weight, as can be seen in the figure below (OECD/ITF, 2020).

Figure 1. Classification of personal mobility devices. Source: OECD/ITF, 2020

Type A	Type B	Type C	Type D
unpowered or powered up to 25 km/h (16 mph)		powered with top speed between 25-45 km/h (16-28 mph)	
<35 kg (77 lb)	35 – 350 kg (77 – 770 lb)	<35 kg (77 lb)	35 – 350 kg (77 – 770 lb)

Type A and Type B vehicles, such as electric bikes, kick-scooters, hoverboards, unicycles, e-scooters, Segway-type scooters, skateboards, roller blades, *et cetera*, travel up to a maximum speed of 25 km/h. Type C and type D vehicles include for example speed pedelecs and mopeds (Jiménez et al., 2018; Litman & Blair, 2006; OECD/ITF, 2020). We will only consider powered type A and type B PMDs in the remainder of this thematic report. Especially popular are e-scooters, which were first introduced in the United States in September 2017 (Alwani et al., 2020).

PMDs are a relatively new type of vehicle, which means the amount of scientific studies on this mode of transport is limited. A large part of those studies concerns e-scooters. We will make a distinction between PMDs in general, and e-scooters wherever possible. When discussing e-scooters, this mainly concerns shared e-scooters rather than privately-owned e-scooters. Shared e-scooters are scooters that are made available by companies such as Lime and Bird, which can then be rented by users.

2.2 Legislation

The Forum of European Road Safety Research Institutes (FERSI) has mapped out the legal status of the e-scooter in their Member States. The table below summarises the most important findings (Kamphuis & van Schagen, 2020). Green means the measure is applicable, red means the measure is not applicable. An orange colour indicates that we do not know whether this rule is applied in the Member State.

	AT	BE	CZ	DK	DE	EL	FI	FR	HU	IT	NL	NO	PL	PT	RS	ES	SE	CH
Use of e-scooter in public spaces	Green	Green	Green	Green	Green	Red	Green	Green	Green	Green	Red	Green	Green	Green	Red	Green	Green	Green
E-scooter categorized as specific category	Green	Green	Red	Red	Green	Red	Red	Green	Orange	Red	Red	Red	Red	Red	Red	Green	Red	Red
Age restrictions for use of e-scooter	Green	Red	Orange	Green	Green	Red	Red	Green	Red	Green	Red	Red	Red	Green	Red	Red	Red	Green
E-scooter allowed on pavement	Red	Green	Red	Red	Red	Red	Green	Red	Red	Red	Red	Red	Red	Red	Red	Red	Green	Red
E-scooter allowed on bicycle path	Green	Green	Green	Green	Green	Red	Green	Green	Orange	Green	Red	Red	Green	Green	Red	Orange	Green	Green
Maximum speed limit for e-scooters	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green	Green	Green	Green	Orange	Green	Green	Green	Green
Obligatory legal liability insurance	Red	Red	Red	Red	Green	Red	Red	Green	Red	Red	Red	Red	Red	Red	Red	Red	Red	Red
Helmet obligation	Green	Red	Green	Red	Red	Red	Red	Green	Red	Red	Red	Red	Red	Red	Red	Red	Green	Red

There are currently substantial differences between European countries with respect to the legal status and related behavioural rules governing e-scooters. Only Serbia, Greece and the Netherlands do not (yet) permit the use of e-scooters in public spaces. e-scooters are categorized as a separate specific vehicle category only in Austria, Belgium, Germany, France and Spain. In other countries, they are considered as either a bicycle, a pedestrian, or a light moped. In most countries, e-scooter riders have to use the bicycle facilities. They are allowed on the pavement in only three countries: in Belgium, Sweden and Finland.

Furthermore, FERSI indicated that e-scooter riders are obliged to have legal liability insurance only in Denmark and France. A helmet is obligatory for some users (children and youngsters) in Austria, Czech Republic, France and Sweden. Age restrictions apply for the use of an e-scooter in half of the FERSI countries: the minimum age ranges from 12

(Austria and France) to 18 years old (Italy). In almost all countries, except for Hungary, there is a maximum speed limit of 20 km/h or 25 km/h.

In the context of a stakeholder discussion, the European Commission suggested that "Micro-mobility vehicles need to operate in a regulatory framework that defines where they can be used (e.g. roads, bike lanes, pavements, pedestrian areas, 30 kph areas), at what speed, after which training, as of what age and in compliance with which safety rules (e.g. protective equipment, lights, turn signals, etc.)" (European Commission, 2019).

2.3 Advantages and disadvantages

One of the potential advantages of PMDs is that they can contribute to solving the "last-mile-problem". The last mile is the last leg of people's journeys within a city — after they park their car, come off a bus or metro, or simply do a quick trip to the corner shop, etc., — which is considered too long to walk (Allem & Majmundar, 2019). Some of the other benefits often mentioned are: low cost, accessibility, and avoiding traffic jams by using cycle paths and pavements (Alwani et al., 2020; Nisson, Ley, & Chu, 2020). The reduced physical effort makes them easier to use than, for example, a bicycle. E-scooter users do not sweat while riding, so they can easily ride in office clothing (Tuncer & Brown, 2020). It is also a more environmentally friendly mode of transport compared with motor vehicles (Gössling, 2020; Sikka, Vila, Stratton, Ghassemi, & Pourmand, 2019). The OECD has looked at cities across the world and concludes that the shift in transport mode from car/taxi to e-scooter is somewhere between 8% (France) and 50% (Santa Monica, United States). The lowest figures were observed in Europe and New Zealand, the highest figures in the United States. The authors say: "This most likely reflects the varying levels of car use across the world. In a city with very low car use, it is only natural that a very small fraction of e-scooter trips replace car trips." (OECD/ITF, 2020, page 31).

Although many are convinced of the advantages of this mode of transport, questions also arise about the disadvantages and dangers of PMDs. These vehicles are also seen as a road safety challenge and a danger to other road users (Gössling, 2020; King et al., 2020; Kolaković-Bojović & Paraušić, 2020). Siman-Tov et al. (2013) speak of "the paradox of the green vehicle": E-scooters were introduced to reduce traffic density, but several studies show that they lead to an increase in the number of injuries (Bresler et al., 2019; King et al., 2020; Kobayashi et al., 2019; Trivedi et al., 2019). PMDs share the same space as pedestrians, cyclists, and motorised traffic. They have a higher mass than pedestrians and move at higher speeds. This means that there are consequences for pedestrians if they share the road with them. PMDs are also very quiet vehicles, and they do not have the same powerful lighting as cars and motorbikes. This makes them particularly difficult for pedestrians to anticipate, especially for seniors and the hearing impaired (Bruneau & Maurice, 2012; Nisson et al., 2020; Siman-Tov, Radomislenskya, & Pelega, 2013). On the other hand, when sharing the road with motorised vehicles, it is the PMD user that is at particular risk given the large difference in mass and speed. Furthermore, critics argue that PMDs will make people walk less. Some countries have not yet regulated the use of such vehicles, which does not help develop safe vehicles and safe behaviours (Jiménez et al., 2018).

Looking at e-scooters in particular, it must be noted that they do not have parking docks, which means that there is no specific space provided for parking. Users can simply leave their e-scooter on the pavement, blocking the way for pedestrians (Bruneau & Maurice, 2012; Gössling, 2020; Jiao & Bai, 2020; Jiménez et al., 2018). Moreover, irresponsible behaviour (speeding, using the pavement, random parking, etc.) and vandalism (damage caused, for example, by throwing down the e-scooter) are also factors that often gain media attention (Gössling, 2020).

Finally, there are also drawbacks in the actual design of the e-scooter. These are vehicles with small wheels that are very sensitive to road bumps, which means it is easy to lose balance. There are no minimum standards for wheel diameter, tyre width, ground clearance, or stability (Road Controlling Authorities Forum (NZ) Inc., 2013; Störmann et al., 2020). A study by Belgian consumer association Testaankoop failed to lead to a recommended best buy. Their report, based on specially designed laboratory tests as well as an on-road test route, found numerous problems with the devices. One particular problem was battery failure or braking problems in wet conditions (ETSC, 2020). KFV also reports on problems with braking distance. Five commercially available e-scooter models were tested and compared to a commercially available bike. Only one of the five e-scooter models delivered better values than the minimum braking deceleration required by law for bicycles.

2.4 Usage of PMDs

Degele et al. (2018) have studied the length of shared e-scooter trips in Germany. They calculated that 5% of journeys with a shared e-scooter were up to 1 km long, 25% between 1 and 3 km and 33% between 4 and 6 km. In another third of the journeys, the shared e-scooter was used for a distance greater than 6 km. They conclude that the shared e-scooter is not just a 'last mile' mode of transport. Commuters who need to get from A to B on time find it difficult to rely on shared vehicles haphazardly scattered throughout the city. Logically therefore it is more likely that shared e-scooters will mainly be used by tourists and casual users (Tuncer & Brown, 2020).

Shared e-scooters can be an alternative to the less environmentally friendly use of a car. However, research in New Zealand (Fitt & Curl, 2019) shows that 52% of the 591 people surveyed would have walked if they had not used the shared e-scooter for their most recent trip, 11% would not have made the journey at all, and 6% would have used a bicycle or skateboard. So, for 69% of trips, the shared e-scooter does not appear to have replaced the car. Respondents who had used a shared e-scooter more than once were more likely to have replaced a car trip with a shared e-scooter trip. Research from the United States shows similar trends: about a third of shared e-scooter users would have used the car if there had not been an e-scooter, but about half of them would have walked or cycled instead (Zagorskas & Burinskiene, 2020). E-scooters and other PMDs are not just replacing the car but public transport, walking and cycling as well. (Beck, Barker, Chan, & Stanbridge, 2020; Fitt & Curl, 2019; Gössling, 2020; Zagorskas & Burinskiene, 2020).

There are considerable differences in usage between owners of private scooters and users of sharing schemes. Riders who own their own vehicle use the e-scooter more often compared to riders who rent an e-scooter. Furthermore, e-scooter renters are mostly replacing walking trips, while e-scooter owners are showing a considerable mode-shift away from private car trips (Laa & Leth, 2020).

3 What part do PMDs play in traffic generally?

Surveys of e-scooter users and analysis of user data show that e-scooters are mainly used by young, employed men. There is also a significant proportion of users between 45 and 50 years old. This age-group covers longer distances in a single ride. Usage tails off after 45-50 years of age (Degele et al., 2018; Fitt & Curl, 2019; Jiao & Bai, 2020).

Based on a German study on shared e-scooter users (Degele et al., 2018), we can distinguish three groups of users

1. One-off users: only used an e-scooter once, but covered a longer average distance than users in other groups.
2. Casual users: the e-scooter is used for leisure activities. Renting an e-scooter is irregular, and usually happens during the weekend.
3. Power users: a small but very active group of users; they mostly use the e-scooter on weekdays suggesting that they use them mainly for commuting.

Shared e-scooters are mainly used (a) to ride through the city for leisure activities, and (b) when there is little time pressure, but less so for commuting (Tuncer & Brown, 2020). According to Tuncer & Brown (2020), the pleasure of riding an e-scooter, but also the feeling of freedom and continuous movement and the minimum amount of effort involved, are important motivations for using a shared e-scooter, as is optimising travel time. First-time users usually rent an e-scooter for fun, and while later use is probably still motivated by pleasure, regular users also notice the practical advantages such as how much faster it is to travel with an e-scooter compared to other means of transport (Fitt & Curl, 2019).

Analysis of usage data in the United States shows that there is a peak in the renting of e-scooters during the weekend, mainly on Saturdays. On weekend days, the average distance covered in one trip is greater than the average distance on weekdays, but the speed is lower on weekend days. On weekdays, there is a peak in the use of the e-scooter at 1 pm and at 5 pm. On weekend days the peak is different: most users start their trip after 11 am and use remains high until late in the afternoon (Almannaa et al., 2020; Espinoza, Howard, Lane, & Van Hentenryck, 2019; Jiao & Bai, 2020; Noland, 2019).

4 PMDs and road safety

In general it is not possible to obtain an overall picture of the number of crashes with powered PMD involvement, since in many countries this vehicle category is not yet or only very recently identifiable in official police records (Kamphuis & van Schagen, 2020). Some countries have started to record crashes with PMD's, such as France (Observatoire national interministériel de la sécurité routière, 2020) and Germany (Destatis, 2020). If they are identifiable, this type of crash is likely to be under-reported as is the case with all crashes without involvement of a motor vehicle. In addition, there is little to no information on the number of kilometres travelled on PMDs or on the number of hours for which users drive this type of vehicle. Consequently, it is very difficult to calculate crash risks (King et al., 2020; Nisson et al., 2020; Störmann et al., 2020; Yang et al., 2020).

However, several retrospective hospital studies have been carried out, where the authors looked at the reports of patients who were involved in a crash with, in particular, an e-scooter and had registered with the emergency department. The safety information in this section is mainly based on studies of this type. (Aizpuru et al., 2019; Alwani et al., 2020; Badeau et al., 2019; Bauer et al., 2020; Beck et al., 2020; Bekhit, Le Fevre, & Bergin, 2020; Bresler et al., 2019; Cassel, E. & Clapperton, 2006; Dhillon et al., 2020; King et al., 2020; Kobayashi et al., 2019; Liew, Wee, & Pek, 2020; Nellamattathil & Amber, 2020; OECD/ITF, 2020; Störmann et al., 2020; Trivedi et al., 2019; Yarmohammadi et al., 2020).

4.1 Crash risk

Like pedestrians, PMD users tend to have higher per-mile crash casualty rates than motorised vehicles, but not necessarily per trip. This is because a typical pedestrian or PMD trip is much shorter than, e.g., a car trip (Bruneau & Maurice, 2012). These researchers also looked at the risk pedestrians and different types of PMDs pose to others. They concluded that the risk of pedestrians injuring others is low, while the risk of powered e-scooters injuring others is medium, as is the risk to others of skaters, people with a skateboard, and push-scooters.

The OECD (OECD/ITF, 2020) has assessed risks for trips with an e-scooter. Based on the limited available data, it has been calculated that there are between 78 and 100 fatalities per billion trips. They conclude:

- There is no difference in the risk of rider fatality per trip between e-scooters and bicycles.
- The risk of rider fatality per trip on a motorcycle or moped is 5 times higher than with e-scooters.
- The risk for hospitalisation appears significantly higher with e-scooter riders than with cyclists.
- The risk of a visit to the emergency department is the same for e-scooter riders and cyclists.

4.2 Types of crash

The few studies on crashes involving PMDs in general show that many of these crashes are self-caused, probably at least partly due to unskilled driving and that the proportion of crashes with a pedestrian or cyclist is low (King et al., 2020; Lee, Kim, & Kim, 2017). There are somewhat more studies on crashes with an e-scooter. These crashes are often unilateral, where only one road user is involved. These crashes rarely involve a collision with another road user (OECD/ITF, 2020). According to the OECD (page 24), “Between 2% and 23% of emergency department (ED) patients involved in e-scooter crashes declare that a motor vehicle was involved. Among e-scooter trauma patients, however, half declare that a motor vehicle was involved”. However, when looking at e-scooter rider fatalities, over 80% resulted from crashes involving a heavier motor vehicle (OECD/ITF, 2020). When pedestrians are involved, it is usually because an e-scooter crashes into them, but some pedestrians also trip over a parked e-scooter or injure themselves when trying to lift an e-scooter (Alwani et al., 2020; Bekhit, Le Fevre, & Bergin, 2020; Liew, Wee, & Pek, 2020; OECD/ITF, 2020; Störmann et al., 2020; Trivedi et al., 2019; Vias institute, 2020). Most crashes involve occasional users or users using an e-scooter for the first time, and inexperience with the vehicle most likely plays a role here (Störmann et al., 2020; Vias institute, 2020). However, it must be noted that in cities where e-scooters were only recently introduced, it is mathematically inevitable that most people are injured during their first few rides (OECD/ITF, 2020).

4.3 Types of injury

Types of injury have been mapped out in various hospital studies. King et al. (2020) studied crashes involving a PMD in an emergency department in Singapore. Most patients were injured in a crash involving an e-scooter, but they also encountered crashes with skateboards and powered bicycles. A large proportion of those patients arrived at the emergency department on their own and stayed for a couple of hours. Minor injuries were most common: external injuries, but also injuries to the upper and lower limbs. Most patients had been injured as a result of a fall.

The number of deaths resulting from an e-scooter crash is very low, but a significant proportion of patients require surgery or even end up in the intensive care unit (Dhillon et al., 2020; Liew et al., 2020).

Head injuries are by far the most common injury sustained in crashes with an e-scooter (Aizpuru et al., 2019; Badeau et al., 2019; Bauer et al., 2020; Beck, Barker, Chan, & Stanbridge, 2020; Bresler et al., 2019; Kobayashi et al., 2019; Störmann et al., 2020; Vias institute, 2020) but records also often indicate fractures of the lower and upper limbs (Aizpuru et al., 2019; Kobayashi et al., 2019; Liew et al., 2020; Störmann et al., 2020), soft tissue injuries (such as abrasions and bruises) (Alwani et al., 2020; Badeau et al., 2019; Beck et al., 2020; Bekhit et al., 2020; Liew et al., 2020); and injuries and fractures of the face and neck (Bauer et al., 2020; Yarmohammadi et al., 2020).

4.4 Risky behaviours

From a road safety point of view there is considerable concern about the behaviour of PMD users. However, there is a dearth of data describing their actual behaviour. Where information is available, it relates only to e-scooter users, not other PMD users.

Hospital studies show that **drink-driving** is a problem among e-scooter users, just as it is among other road users. The magnitude of the problem is unclear, but the percentage of e-scooter users in hospital who were under the influence of alcohol is higher compared to car drivers in the hospital (Badeau et al., 2019; Blomberg, Rosenkrantz, Lippert, & Collatz Christensen, 2019; Dhillon et al., 2020; Puzio et al., 2020; Störmann et al., 2020; Trivedi et al., 2019; Yarmohammadi et al., 2020).

With regard to **helmet wearing**, the conclusions of various observational and hospital studies are unanimous: virtually no-one who uses a shared e-scooter wears a helmet (Alwani et al., 2020; Badeau et al., 2019; Blomberg et al., 2019; Dhillon et al., 2020; Fessler, Sparks, & Zinsser, 2019; Kobayashi et al., 2019; Lefrancq, 2019; Liew et al., 2020; Trivedi et al., 2019). The official Instagram account of Bird, the market leader in shared e-scooters with more than 66,000 followers, rarely shows e-scooter users with protective clothing. This sends a signal to Bird's followers that the company approves of customers riding without a helmet (Allem & Majmundar, 2019). The OECD (OECD/ITF, 2020) indicates that only 4% of all e-scooter users had been wearing a helmet at the time of a crash. FERSI reported the following about Austria, where wearing a helmet is compulsory: “In Austria it was found that 3% of the e-scooter riders use a helmet while riding. In Denmark 27% of the e-scooter riders riding a privately-owned e-scooter wore a helmet and 2% of the riders riding a rented e-scooter.” (Kamphuis & van Schagen, 2020, page 17). Users of private e-scooters wear a helmet substantially more often than users of shared e-scooters (KFV, 2019). According to Tuncer & Brown (2020) e-scooter users consider riding without a helmet to be the norm and find it absurd to take a helmet with them.

Che et al (2020) found that pedestrians and cyclists feel safest when e-scooter users ride at a **maximum speed** of only 15 km/h. A virtual reality study showed that pedestrians feel safer when the e-scooter user overtakes at a maximum speed of 10 km/h. However, this was considered too slow by the participants driving an e-scooter (Che, Lum, & Wong, 2020). The risk of instability is much higher at a speed of 10 km/h (Arellano & Fang, 2019; Che et al., 2020). KFV (the Austrian Road Safety Board) has observed that e-scooter users in Austria travel at an average speed of 15,1 km/h, with the highest speed measured being 31 km/h (KFV, 2019).

Several studies show that e-scooter users do not always drive in the right **place on the roadway**. According to e-scooter users, motor vehicles drive too fast and are unpredictable, making them feel unsafe, and this is why they often drive on the pavement (Tuncer & Brown, 2020). However, according to another study (Fitt & Curl, 2019), only half of the e-scooter riders feel that the pavement is a suitable environment for driving an e-scooter. Most of them think that cycle paths and quiet streets are more suitable. They think the e-scooter is too fast to use near pedestrians, but on the other hand users also find it dangerous to drive on roads used by fast and heavy vehicles.

Finally, **parking** an e-scooter is not always carried out correctly. They must be parked so as not to obstruct other road users, especially pedestrians. An observational study assessed just over 600 parked e-scooters: 16% were parked incorrectly, and 6% of the e-scooters blocked the pavement (James, Swiderski, Hicks, Teoman, & Buehler, 2019).

5 Countermeasures

Since a large part of the literature deals with e-scooters, most of the measures suggested apply to this type of vehicle. Wherever possible, we try to include measures aimed at all PMDs.

5.1 Infrastructure

Developing a safe infrastructure network for micro-mobility will have a positive impact on the safety of all road users. In most cities there is space for PMDs, but this space is often already occupied by motor vehicles and other road users (OECD/ITF, 2020).

The question whether PMDs should be allowed on pavements is controversial, and there is no one-size-fits-all answer. In an ideal world, there would be special (bicycle) paths which separate PMDs from both pedestrians and motorised traffic (Fitt & Curl, 2019; King et al., 2020; Nisson et al., 2020; OECD/ITF, 2020). One possibility is to allow PMDs to use cycle paths. PMD users themselves express a clear preference for cycle paths, but for safety reasons the design standards would have to be upgraded. Cycle paths should be wide enough so that different types of vehicles can use this infrastructure together in complete safety. It is important that the road surface is smooth and well maintained. Damage to the road surface must therefore be repaired as quickly as possible (Bruneau & Maurice, 2012; OECD/ITF, 2020).

There is also a lot of discussion about the parking of e-scooters on the pavement. It is clear that parking zones need to be set up to prevent users from leaving their e-scooter wherever they like, thereby creating an obstacle for pedestrians and other road users. In some cities, parking zones for e-scooters are being created near pedestrian crossings, since cars are not allowed to park there in order to safeguard the visibility of pedestrians. In other cities, parking e-scooters on the footpath is discouraged as much as possible by creating micromobility parking spots off the pavement. This reinforces the idea that the pavement is only intended for pedestrians. Moreover, parking an e-scooter on the pavement inevitably leads to driving on the pavement in order to access and exit the parking space (Gössling, 2020; OECD/ITF, 2020).

5.2 Road users

Studies show that many e-scooters users are injured during their first ride. The main reason mentioned is that they are surprised by the speed of the vehicle (Basky, 2020; Nisson et al., 2020; Vias institute, 2020). Training before the first ride can help, preferably combined with practice in a closed area under the supervision of authorized trainers (Vias, 2020). Users of shared e-scooters and other shared PMDs rely on smartphones to locate and unlock vehicles. This means that smartphones could become an effective solution for providing rider training, an opportunity that Swedish e-scooter company VOI explored through an app-based traffic school (OECD/ITF, 2020). In this context, traffic training for children at secondary school could also be expanded, with all types of personal mobility devices being addressed (OECD/ITF, 2020).

The safety of micromobility does not just depend on training PMD users: driver training for motor vehicle users is equally important, especially since most e-scooter fatalities are a result of a crash with a motorised vehicle (see Section 4.2) (OECD/ITF, 2020).

Head injuries are very common in PMD crashes and helmet wearing rates are currently low among PMD users (see Section 4.4). However, it has been argued that making helmet wearing compulsory for PMDs could make these vehicles less attractive in comparison to far more dangerous vehicles such as mopeds and motorcycles. An alternative might be to increase awareness for the need for a helmet, through both policy-makers and the micro-mobility companies themselves. "Nudging” can offer a way forward. For example, e-scooter users who share a photo of themselves with a helmet on could be rewarded by the company providing the e-scooter (Choron & Sakran, 2019; OECD/ITF, 2020). Yet another option is to create new helmet designs with better portability. After all, a survey of e-scooter users showed that they found it difficult to carry the helmet with them. One example is folding helmets, which could be distributed by the companies renting e-scooters (Fessler et al., 2019; Nisson et al., 2020).

We have reported that users of e-scooters also often suffer fractures of the upper limbs when they are involved in a crash. Wrist guards, which have been shown to reduce the severity of fractures in roller skaters, should be recommended for users of e-scooters (Aizpuru et al., 2019; Liew et al., 2020).

5.3 Legislation and enforcement

As far as legislation is concerned, several studies point out that traffic rules specifically for PMDs are inadequate. In most European countries, traffic rules designed for cyclists are invoked without taking into account the specific characteristics of PMDs and their users (Gössling, 2020; Zagorskas & Burinskiene, 2020). Some ask for a driving license to be made compulsory for PMD riders, because they are involved in (sometimes dense) motorised traffic, often without sufficient knowledge of traffic rules. However, one reason why a driving license is not required in order to ride a bicycle or PMD in most countries is the belief that administrative measures should remain proportionate to the risks of a vehicle for third parties. An alternative solution would be to make it compulsory to undertake training, similar to that required of learner moped riders in some European countries (Bruneau & Maurice, 2012; Lee et al., 2017; OECD/ITF, 2020).

Since alcohol seems to play a substantial role in e-scooter crashes (see Section 4.4), communication and active enforcement of the legal blood alcohol content should also include users of PMDs/e-scooters alongside other road users. Another option is for e-scooter sharing companies to install motion sensors on their vehicles to detect excessive wobbly motion and reduce the vehicle speed in situations where the rider is impaired by alcohol, drugs, a pillion rider or for any other reason (OECD/ITF, 2020).

As for alcohol, better communication and enforcement of current legislation regarding speeds and positioning on roads are recommended. With respect to exceeding speed limits, this is likely to be exacerbated by the pay-per-minute method used when renting an e-scooter. This payment method is also an incentive to carry out dangerous manoeuvres, such as driving through a red light or not giving way to pedestrians. The time-dependent nature of the pricing system should be reduced: it could be complemented or replaced with a price-per-kilometre travelled, a price per journey, or even a monthly subscription (OECD/ITF, 2020; Polis, 2019). However, speeding by drivers of motorised vehicles should also be targeted. The average car speed is below 25 km/h in dense cities at peak hour. It would be logical to adopt and enforce 30 km/h speed limits (if not lower) for all vehicles in areas where vulnerable road users mix with motor vehicles (OECD/ITF, 2020).

With respect to positioning on roads, a technology called 'geofencing' can be used to oblige e-scooters to drive and park only where they are legally allowed. Speed could also be regulated using geofences. A geofence is a set of lines, defined by geographical coordinates, that demarcate an area where special regulations apply. Within these areas, speed can then be regulated, but access to the area or parking within the area can also be prohibited. However, geofences only apply to shared e-scooters, and it is therefore impossible to regulate privately owned e-scooters in this way (and other PMDs) (Basky, 2020; Gössling, 2020; OECD/ITF, 2020).

5.4 Vehicles

E-scooter users are usually injured in the event of a fall. The stability of the vehicle is therefore a design priority. Replacing narrow, hard wheels with wider and softer wheels would reduce the likelihood of users falling when there are bumps on the road. A wider platform also provides greater stability. In addition, improvements to shock absorbers are needed to avoid falls caused by potholes or other road bumps (Aizpuru et al., 2019; Alwani et al., 2020; Nisson et al., 2020; OECD/ITF, 2020).

E-scooter riders have to keep both hands on the wheel in order not to fall, which prevents them from sticking out their arm in order to show which direction they want to go. Equipping e-scooters with a direction indicator can remedy this problem (Fitt & Curl, 2019; OECD/ITF, 2020). The addition of a bell or other sound signal to warn other road users is also recommended. E-scooters can easily be equipped with a bell, but it is conceivable that they will be damaged quickly as a result of frequent and rough handling of shared e-scooters. A bell should therefore be designed to withstand vandalism and lack of care during the lifetime of a shared scooter, such as a bell integrated into the handlebar or an electronic sound activated by pushing a button (Nisson et al., 2020; OECD/ITF, 2020). The same recommendations apply to PMDs in general: they must be equipped with a sound signal and direction indicators. The addition of rear-view mirrors is also a consideration for PMDs. Moreover, they should be subject to safety tests and standards for the windshield, braking system, weight, dimensions *et cetera*.

Reflectors and easily identifiable colours can add to easier detection of PMDs by other road users (Bruneau & Maurice, 2012; Jiménez et al., 2018; Lee et al., 2017). In some countries, road users are required to wear fluorescent clothing when using an e-scooter. However, they often ignore this rule, and enforcing it seems difficult because of its low acceptance. It would therefore be more effective to impose the use of reflective material on vehicle manufacturers (OECD/ITF, 2020).

KFV, which carried out braking test for commercially available e-scooters, recommends setting a minimum value for the braking deceleration at 4 m/s2. They also recommend two independent braking devices, at least one of which works independently of the vehicle's electrical system (ETSC, 2020).

Driving aid systems can also improve the safety of PMDs. E-scooter users regularly drive on the pavement, where they can come into conflict with pedestrians. Companies Lime, Jump and Bird are already working on solutions to detect and prevent driving on the footpath by using vehicle sensors. If an e-scooter rider is riding on the footpath, the company can send a real-time warning to the user (Jump, 2019; OECD/ITF, 2020).

However, GPS positioning is not accurate enough at the moment. Electronic stability control enhances steering resistance at higher speeds and applies a corrective steering input when there is a risk of a fall. This could also facilitate the use of hand signals while driving an e-scooter (OECD/ITF, 2020).

Shared e-scooters are exposed to severe weather conditions and vandalism. Remote diagnosis of faulty equipment and the protection of brake cables are important steps towards safer vehicles. In addition, maintenance is a challenge given their intensive use in the open air. Vehicles should be able to "self-diagnose", identifying faults when they occur and remotely calling for corrective action (OECD/ITF, 2020).

6 Further reading

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