European Commission

European Road Safety Observatory

Road Safety Thematic Report - Motorcycles

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.

The topic "Motorcycles" is also addressed in the "Facts and Figures - Motorcyclists and moped riders", presenting more detailed and up-to-date European data in addition to this qualitative analysis.

Contract	This document has been prepared in the framework of the EC Service Contract MOVE/C2/SER/2019-100/SI2.822066 with Vias institute (BE) and SWOV Institute for Road Safety Research (NL).
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Referencing	Reproduction of this document is allowed with due acknowledgement. Please refer to the document as follows: European Commission (2023) Road Safety Thematic Report – Motorcycles. European Road Safety Observatory. Brussels, European Commission, Directorate General for Transport.

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Summary

Motorcyclists in road traffic

Motorcycles play an important role in traffic in European countries. They are an economical and attractive means of transport which can offer a special sense of pleasure. A motorcycle is defined as “two- or three-wheeled vehicles with or without a sidecar”. There were an estimated 25 million motorcycles in the EU in 2018. The enormous vulnerability of motorcyclists in traffic is the downside of this flexible, nimble and "light" way of getting around.

More than 3500 motorcyclists were killed on European roads in 2019, representing 16% of all road fatalities. The number of motorcycle fatalities has decreased by 16% in the last decade. It is difficult to determine crash risk, because exposure data is often not easily available. However, evidence shows that motorcyclists are about 9 to 30 times more likely to be killed in traffic compared to a car driver. There is a pronounced seasonal variation for motorcyclists, showing a low proportion of fatalities during the winter months and a high proportion during the summer months.

Several factors play a role in motorcycle crashes. Motorcyclists are often overlooked in traffic. Some design elements (such as tyres, brakes, frame, suspension) are relevant for the safety of motorcyclists. Road environment shortcomings (such as poor road surfaces, loose material, poor road alignment, obstacles, limited line of sight, etc) have a significant influence on the risk of crashes involving motorcycles. The young age of the motorcyclist and a lack of rider training and experience also play a role in motorcycle crashes.

Countermeasures

- Safety features - also known as Advanced Rider Assist Systems (ARAS) - such as Electronic Stability Control, Forward Collision Warning - could help reduce motorcycle crashes and fatalities. ABS became mandatory on motorcycles in the EU in 2013. However, more research is needed to establish the costs and which safety systems can be realistically transferred to motorcycles
- The conspicuousness of motorcycles can be improved by the use of add-on (optional, extra) driving lights, Daytime Running Lights (DRLs) and/or reflectors, reflective colours and/or colours which contrast with the environment.
- Roads should be forgiving, and attention given to roadside safety design and road surface markings to limit the severity of trauma for motorcyclists. Specifically, crash barriers should be improved so as not to be dangerous for motorcyclists.
- Implementation of separate motorcycle lanes.
- Pre-licence training of motorcyclists should aim at teaching the necessary knowledge and skills, but also the mental attitude to ride defensively and be aware of risk exposure. Pre-licence training of car drivers to detect, notice and identify motorcycles in traffic.
- Topics for promotional campaigns are: wearing helmets, use of protective clothing, risky behaviour, paying attention to the presence of motorcycles.

1 Highlights

- Motorcycles play an important role in traffic in EU countries. They can be distinguished from other means of transport by their diversity: their dimension, motorisation, riding position, the environment in which they are ridden, the riders' motivation and their specific movement in traffic
- The fleet of motorcycles in Europe was estimated at 25 million in 2018. Data show the number has increased significantly over the last two decades.
- More than 3500 motorcyclists were killed on European roads in 2019, representing 16% of all road fatalities. The number of motorcycle fatalities has decreased by 16% in the last decade.
- Motorcyclists are about 9 to 30 times more likely to be killed in traffic compared to a car driver.
- Motorcyclists are often overlooked in traffic due to their comparative small size and the fact that they can overtake in situations where cars cannot.

2 What is the problem?

2.1 What are motorcycles?

Motorcycles play an important role in traffic in European countries. With two wheels in line, slim bodywork, and a favourable power-to-weight ratio, a motorcycle is an economical and attractive means of transport which can offer a special sense of pleasure. Motorcycles can be used for the transport of goods and people, as is the case in low and middle income countries, or as a transport means suitable for traffic congestion (Slootmans et al., 2017; Yannis et al., 2022). Motorcycles distinguish themselves from other means of transport by their diversity: their dimension, motorisation, riding position, the environment in which they are ridden (urban, outings, adventure, off-road, ...), the riders' motivation (commuting, leisure, thrill-seeking, ...) and their specific movement in traffic (use of lanes, lane filtering, position in curves, ...) (Delhaye & Vandael Schreurs, 2022).

Furthermore, motorcycles vary dramatically in design, with respect to size, weight and performance capacity. Riders can select a certain type of motorcycle based on their riding practices. Examples of types of motorcycles are: standard motorcycles, dual purpose motorcycles (i.e., adventure), touring motorcycles, cruisers, choppers, sport, sport touring, supersport, off-road motorcycle, all-terrain motorcycle, and so on (Teoh & Campbell, 2010). The best-selling motorcycle type (over 125cc engine) in Europe has for several years been the adventure motorcycle.

The enormous vulnerability of motorcyclists in traffic is the downside of this flexible and "light" way of getting around. Motorcycle riders are still relatively unprotected, even when they wear personal protective equipment such as helmets, protective suits, boots and gloves. Motorcycles have only two wheels, which makes them a self-balancing vehicle. At the same time, a motorcycle moves as fast as a car (Slootmans et al., 2017).

Motorcycles are defined as "two-wheel or three-wheel vehicles with or without a sidecar" in the Driving Licence Directive 2006/126/EC (European Union, 2006). Motor tricycles (a.k.a. trikes), which are vehicles with three symmetrically arranged wheels, are also included in the category of motorcycles. Three sub-categories of motorcycle driving licences can be distinguished:

Table 1. Motorcycle categories according to the Driving Licence Directive 2006/126/EC

Licence	Motorcycle restrictions	Early access (A1@16)	Late access (A1@18)
A1	Engine capacity: max 125 cc Motor capacity: max 11 kW Specific capacity: max 0.1 kW/kg	16	18
A2	Motor capacity: max 35 kW Unthrottled capacity: max 70 kW Specific capacity: max 0.2 kW/kg	18	20
A	No restrictions	Progressive access: 20 Direct access: 24	Progressive access: 22 Direct access: 24

Source: European Union, 2006

The Driving Licence Directive requires licences to be incremental: to move from an A1 or A2 license to the next, one needs at least 2 years of experience in the lower category. Direct access to an A licence is possible, but the age limit is put at 24 years. Member States are free to set the starting age (for an A1 licence) at 16, 17 or 18, with corresponding consequences for the entry age for the next category.

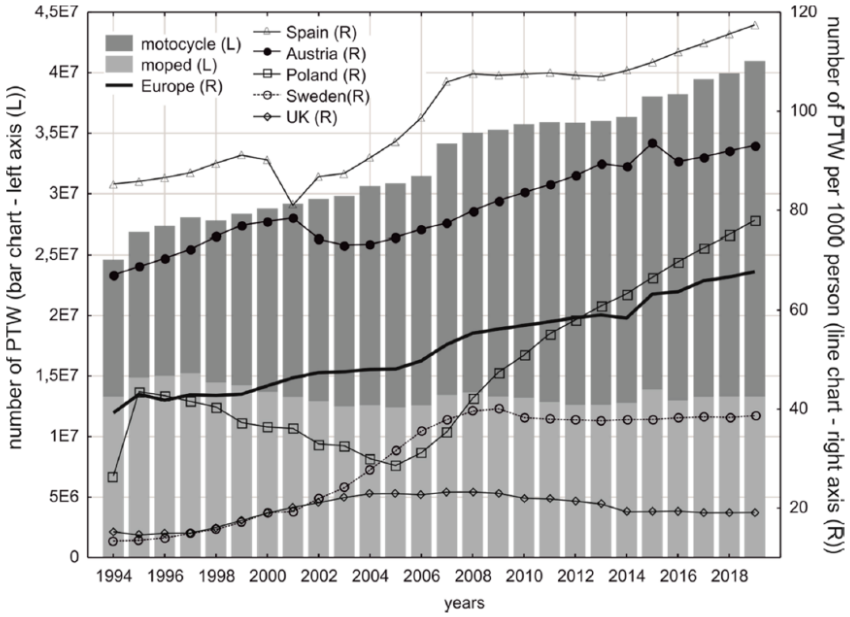
There are also detailed requirements relating to the theory test, the special manoeuvres test and the on-road test. Implementation varies from country to country. For some countries, progression from A1 to A2 or A2 to A is possible with the completion of a training module, while for some countries' progression requires a practical test, and some countries require both.

2.2 How do motorcycle riders participate in traffic?

The fleet of motorcycles in Europe is estimated at 25 million in 2018. According to the European Association of Motorcycle Manufacturers (ACEM), the markets for motorcycles in Italy, France, Germany, Spain and UK account for about 80% of new motorcycle registrations in the EU/UK block.

Overall, the number of powered two-wheelers (PTWs) per 1,000 inhabitants increased from 39.3 in 1994 to 67.8 in 2019. PTWs are most common in southern European countries (Vanpée et al., 2022).

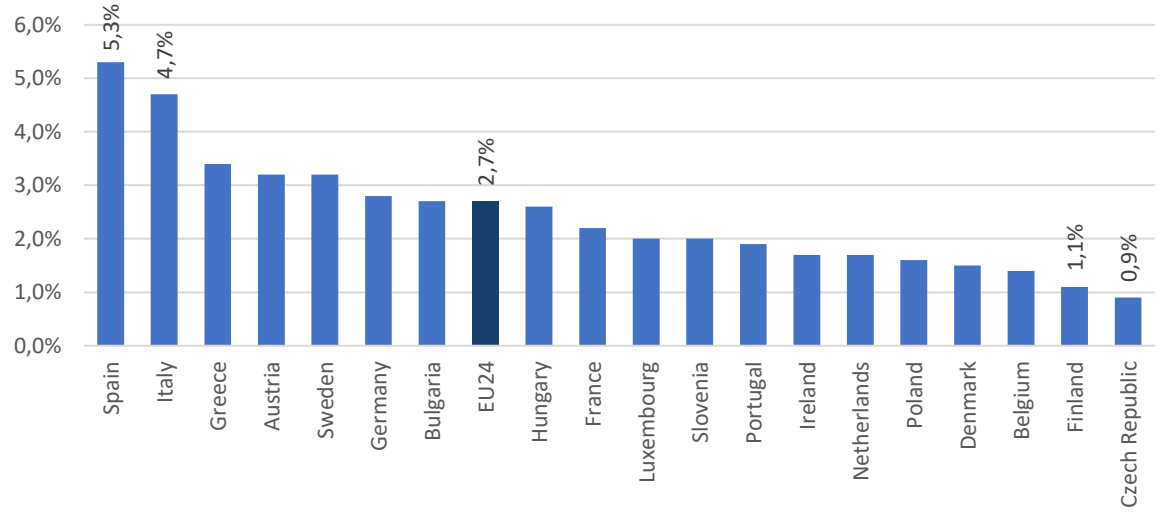
Figure 1. PTW fleet and PTW per 1,000 inhabitants in selected European countries, 1994-2019



Source: Dorocki & Wantuch-Matla, 2021

There is relatively little data on motorcycle mileage. However, the number of passenger kms for powered-two-wheelers is estimated at s 144 billion kms in 2019 (European Union, 2021). Furthermore, according to the E-Survey of Road Users' Attitudes (ESRA) survey, on average 2.4% of EU respondents ride a motorcycle 1 to 3 days a week. The proportion of respondents who ride a motorcycle regularly is highest in Spain and Italy and lowest in the Czech Republic and Finland. This proportion is below the EU average for France and similar to the EU average for Germany, even though the motorcycle markets in these countries are among the biggest in Europe (Yannis et al., 2022).

Figure 2. Percentage of respondents claiming to ride a motorcycle 1 to 3 days a week



Source: Yannis et al., 2022

The Riderscan project showed that almost half of all respondents claim to use a PTW primarily for leisure. One third of the respondents use their PTW mainly for commuting,

while almost two out of 10 respondents use their vehicle for long distance travelling (Delhaye & Marot, 2016).

3 Motorcycles and road safety

3.1 Crash risk or relative risk

Exposure data is needed in order to determine risks. The number of kilometres travelled by motorcycles gives a good proxy of their exposure to risk. Other indicators to measure exposure, such as the number of motorcycles in circulation or total travel time, are not collected on a regular basis. It is therefore difficult to determine crash risk (OECD/ITF, 2015).

Evidence has shown that motorcycle riders experience a greater risk of being severely injured compared to other road users, while at the same time they do not pose much risk for other road users. The OECD estimates that motorcyclists are about 9 to 30 times more likely to be killed in traffic compared to a car driver (OECD/ITF, 2015). Motorcyclists have a higher risk of crashes resulting in serious injury or death compared to other road users (Möller et al., 2020). However, motorcycles prior to and after 2015 are significantly different from a safety point of view, e.g., ABS became mandatory on motorcycles in the EU in 2013[1]. An update of the crash risk for motorcycles would therefore be appropriate.

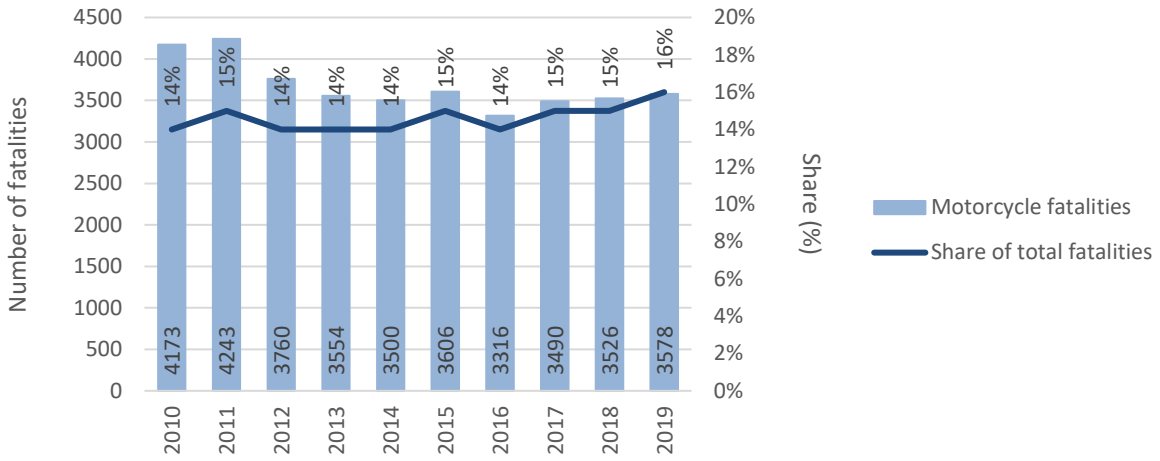
3.2 General trend in the number of fatalities

The proportion of motorcycle fatalities within the total number of road fatalities in the EU in 2019 was 16%. Although the number of motorcycle fatalities decreased by 14% between 2010 and 2019, the total number of all road fatalities decreased even more (-23%). As a result, the relative proportion of motorcycle fatalities within the total number of fatalities has slightly increased (European Commission, 2021). The relatively small decrease in motorcycle fatalities contrasts with the -45% decrease for moped fatalities. Possible explanations are the decrease in the number of registered mopeds while the number of registered motorcycles has increased, but also the fact that mopeds are very popular in cities (in contrast to motorcycles which are used in more rural areas). The difference in speed could also be part of the explanation.

The EU Member States with the highest number of motorcycle fatalities are (highest to lowest numbers) Italy, France, Germany, Spain, and Poland. This is not surprising, since four of these countries also have the largest motorcycle markets (European Commission, 2021).

[1] Regulation (EU) No 168/2013 made it mandatory for all motorcycles in the L3e-A1 subcategory to be fitted with an advanced braking system consisting of either an ABS or a combined braking system (CBS) or both at the discretion of the manufacturer.

Figure 3. Annual number of motorcycle fatalities, and their share in the total number of fatalities in the EU27 (2010-2019)



Source: European Commission (2021)

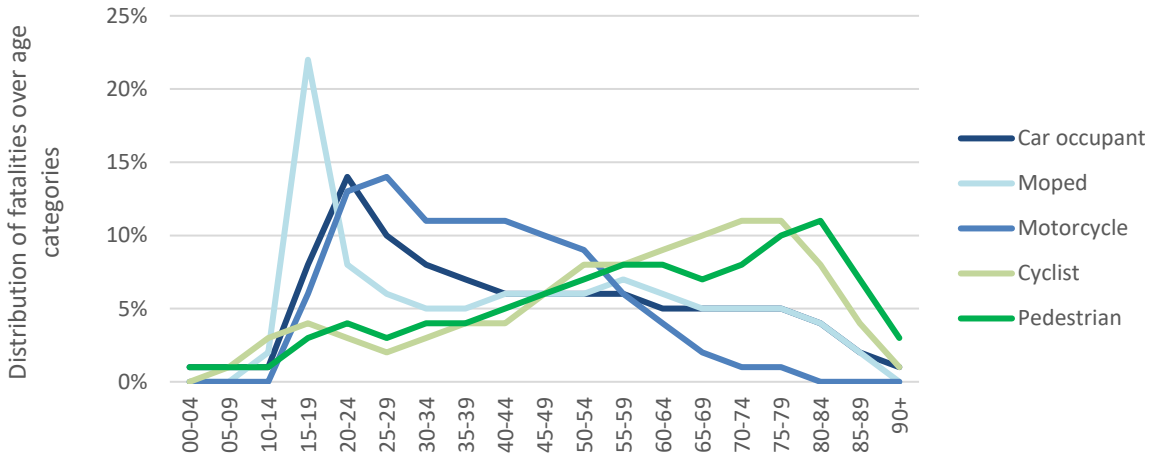
The mortality rate and proportion of fatalities (within the total number of fatalities) for motorcycle riders is highest in the south of the EU. The popularity of these transport modes in these countries needs to be taken into account when interpreting these figures (European Commission,2021).

3.3 Crash characteristics

The proportion of male fatalities for motorcycle riders is high: 95% (compared to 77% of male fatalities overall). There are few differences between Member States (European Commission, 2021).

The Figure below provides a more detailed picture of the distribution of motorcyclist fatalities by age. A peak is reached for people in their twenties. After that, the number of fatalities decreases, but in a gradual way. The distribution of fatalities among motorcycle riders is very different from the distribution among pedestrians and cyclists (European Commission, 2021).

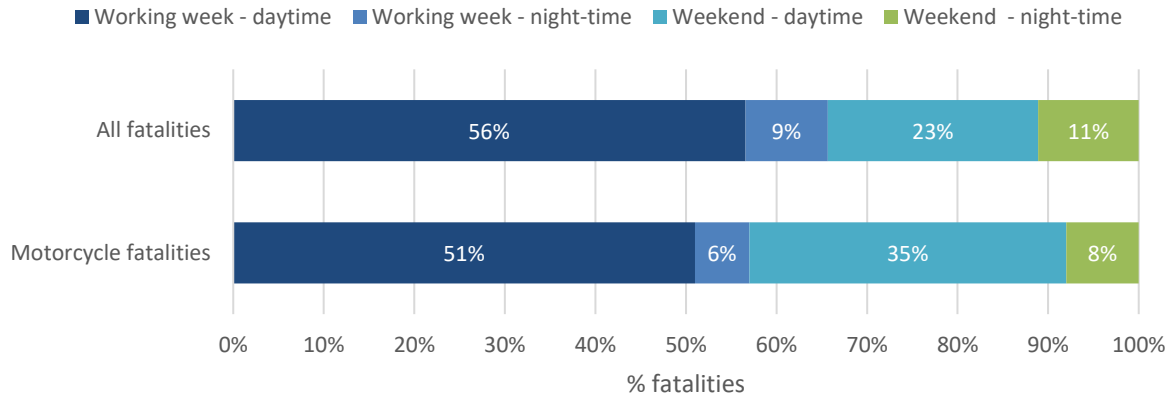
Figure 4. Distribution of fatalities over 5-year age categories, by transport mode, in the EU27 (2010-2019)



Source: European Commission (2021)

Motorcycle fatalities are proportionately higher during day-time at the weekend, compared to all fatalities. This difference can probably be explained by differences in utilisation of modes of transport (European Commission, 2021). Furthermore, car drivers have difficulty detecting and identifying motorcyclists at night, but also in the daytime (Abdul Khalid et al., 2021a).

Figure 5. Distribution of fatalities among motorcycle riders ad all fatalities, according to period of the week in the EU27 (2019)

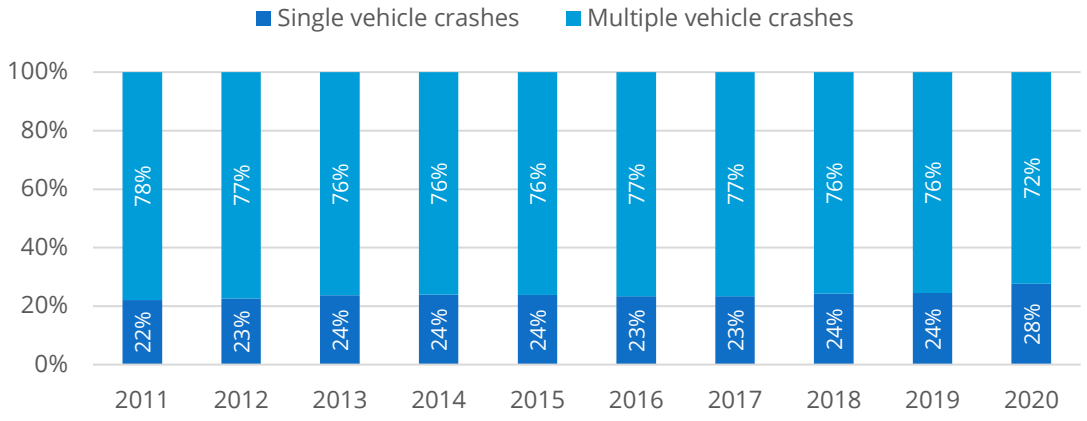


Source: European Commission (2021)

Furthermore, there is a pronounced seasonal variation for motorcyclists, showing a low proportion of fatalities during the winter months (November to March) and a high proportion from June to September. In each of these last four months there are nearly 6 times more motorcycle fatalities than in January. This difference may naturally reflect the fact that during the winter months there are far fewer motorcyclists in traffic than in the summer (holiday) months (European Commission, 2021).

Almost three out of 10 crashes involving a motorcycle are single vehicle crashes, meaning that only the motorcycle is involved. In 7 out 10 crashes, another road user is involved.

Figure 6. Distribution of single vehicle crashes and multiple vehicle crashes for motorcyclists in the EU27 (2011-2020)



Source: CARE

3.4 Causation factors

3.4.1 Factors related to road users

Collisions between motorcyclists and passenger cars usually happen because the motorcyclist has been overlooked. The important issue, therefore, as far as the other road user is concerned, is that of perception (ACEM, 2009; SWOV, 2017). The approaching speed and distance of the motorcyclist are also often underestimated (ACEM, 2009, Huertas-Leyva et al., 2021). Because motorcyclists can overtake in situations where cars cannot, other road users may not look for them in places where they do not look for cars (European Commission, 2018; IRAP, 2022a). Being less conspicuous, motorcycles themselves also contribute to being overlooked (Huertas-Leyva et al., 2021). Some motorcyclists' own low expectation of problems can lead to speeding and risk-taking which can play a role in crashes. In the MAIDS study, speed was identified as a causal factor in 21% of cases (ACEM, 2009).

Young age in motorcyclists and lack of rider training and experience also play a role in motorcycle crashes (Möller et al. 2020). Young males especially have a strong propensity for risky behaviour, which increases the risk of crashes (Vlahogianni, Yannis & Golias, 2012). There are different types of experience: years of riding, familiarity with a specific motorcycle or with specific conditions. Every type of experience will impact the crash rate to some extent (European Commission, 2018). Sexton et al. (2004) surveyed more than 11,000 (British) motorcyclists, and concluded that both age and experience play a significant role. For example, the crash risk of a 17-year-old novice is 40% higher than that of 26-year-old novice and 60% higher than that of 40-year-old novice.

3.4.2 Factors related to the vehicle

Some design elements, such as frame, suspension, wheels, brakes, and tyres, are relevant for motorcycle safety (European Commission, 2018). Certain manoeuvres carry a higher risk for motorcycle riders than car drivers. For example: riding a motorcycle involves body movement and counter steering and is therefore less stable, meaning riders are more likely to lose control of their vehicle while cornering (IRAP, 2022a).

Braking is difficult for several reasons. Because a motorcycle has only two wheels in line, it is easy to lose friction between tyres and road surface, resulting in a fall, most often while braking in a curve. If the front wheel locks during braking, the stabilizing effect of the spinning wheel disappears and the motorcyclist can fall or start skidding (European Commission, 2018; SWOV, 2017). The Anti-Lock Braking System (ABS) on motorcycles – which prevents the wheels locking while braking hard - has been an improvement for motorcycle safety, reducing the number of motorcycle crashes by 34% to 43% and consequently the number of motorcycle rider fatalities and injuries. (SWOV, 2017).

Other factors that can contribute to a loss of control are: wet or oily roads, loose material on the ground, and sudden avoidance manoeuvres (European Commission, 2018).

The relationship between type of motorcycle, engine size, and behaviour of the motorcycle rider is less clear. However, studies suggest that riders of the "sporty" motorcycle type

have a significantly increased risk of serious crashes and, in particular, fatal crashes (ACEM, 2009; Martensen & Roynard, 2013, Dubois et al., 2020).

A higher crash rate for heavy or powerful motorcycles does not necessarily mean that they are more difficult to control or are less safe vehicles. It is possible that they are used by riders with a different style of riding. Therefore, it is possibly not the character of the motorcycle but the character, experience and motivation of the rider which determines the safety of the motorcycle (European Commission, 2018).

The effect of alcohol on car drivers is well known: drink-driving increases the likelihood of engaging in risk-taking behaviour, which leads to a higher crash risk for the alcohol-impaired driver. However, research on the impact of alcohol on motorcyclists is lacking. The few studies that have been conducted show that increased blood alcohol levels lead to increased driving errors, especially "running off the road", significant changes in vehicle controlling skills, lengthening of brake reaction time, and an increase in the standard deviation from lateral position (Vu et al., 2020).

3.4.3 Factors related to the road environment

Road environment affects motorcyclists because riders can fall or slip, and often the road environment is 'unforgiving', leading to serious or even fatal injuries. Infrastructure also influences human behavior: it helps riders control their vehicle, prevents loss of control, and influences interaction with other road users. The following shortcomings in the road environment have a significant influence on the risk of crashes involving PTWs (Delhaye & Marot, 2016; IRAP, 2022a):

- Road surface defects, such as unevenness and potholes
- Water, oil or moisture on the road
- Poor road alignment
- Presence of obstacles, roadside hazards and safety barriers
- Interaction with larger vehicles
- Excessive or thick (high) lane markings, use of raised pavement markers, in general all road markings or bituminous road surface fixes with insufficient skid resistance.

Obstacles (such as poles, walls, trees, …) can add to the severity of a crash. The severity of a crash might have been lower if the obstacles had not been there or if they had been shielded (Delhaye & Marot, 2016).

The most contentious area of debate are crash barriers (IRAP, 2022a). They are typically not tested for their impact on motorcyclists (IRAP, 2022a) and are designed to prevent cars from colliding with obstacles behind the rail, but they do not take into account collisions with motorcycles. A motorcyclist colliding with an unprotected crash barrier can cause severe injuries (SWOV, 2017; European Commission, 2018).

4 Countermeasures

4.1 Safer road users

4.1.1 Licensing and training

Pre-licence training should aim at teaching the necessary knowledge and skills, but also the mental attitude to ride defensively and be aware of risk exposure. Training in ABS operation and knowledge of ABS are also important. New simulation techniques offer new opportunities for training programs for motorcyclists (Delhaye & Marot, 2016). Because the effects and efficiency of pre-license training have not yet been ascertained, any new programmes in this area should be evaluated.

In the European Initial Rider Training Project, a 3-part curriculum was compiled in collaboration with the European motorcycle associations. The theoretical module should cover traffic rules and road signs, the mechanical and dynamic aspects of a motorcycle, the perception of dangerous situations, wearing protective clothing, social responsibility (e.g. avoiding noise pollution), and the role of alcohol, drugs, and fatigue. The necessity of a defensive driving style, in which the rider also anticipates possible errors of other road users, is also important. The second module is dedicated to motorcycle control, in which the students have to familiarise themselves with the machine, try out first movements, shifting, braking and changing direction, practice manoeuvres at low speed, and also practise manoeuvres in certain emergency situations. The third module is about participating in traffic, in which proper positioning, correct distance and appropriate speed in various situations are practised: turns, intersections, overtaking, motorways. Here also the emphasis should be placed on anticipation (European Union, 2011).

Attention should also be paid to training car drivers during their driving licence training to detect, notice and identify approaching motorcycles when crossing a road (Slootmans et al., 2017).

4.1.2 Promotional campaigns

There is a link between the type of motorcycle and the motive of the rider, the experience they seek and their concept of riding. Persuasive communication, tailored to the requirements of the average ride of a motorcycle type, could be provided when buying a motorcycle so as to encourage safe riding behaviour (Delhaye & Marot, 2016).

4.1.3 Helmets and protective clothing

Protective clothing protects the rider against abrasion and reduces the risk of burns from contact with hot metal. It even reduces the severity of fractures and the risk of infection from road dirt in the case of open wounds (IRAP, 2022b). In low and middle income countries, the proportion of motorcyclists wearing protective clothing is low because of high cost and perceptions about discomfort (in a local, warm, climate).

In these countries, it is best to focus on helmet-wearing rates, legislating for compulsory helmet-wearing (including enforcement) for all riders and to promote improvements in

the quality of helmets. In countries with high helmet-wearing rates, it is better to invest in public education campaigns about protective motorcycle clothing. In these campaigns, the protective value of such clothing should be highlighted, and good quality clothing should be clearly described (IRAP, 2022b).

4.2 Safer vehicles

4.2.1 Conspicuousness of motorcyclists

An important reason for motorcyclists' poor perceptibility is the comparatively small size of their motorbikes. Moreover, some drivers who only see the headlight of the motorcycle do not see that they are dealing with a motorcyclist and underestimate the time remaining to perform a manoeuver (Slootmans at al., 2017). Reflectors, bright clothing, and helmets are used by motorcyclists in an attempt to make them more conspicuous (Gershon & Shinar, 2013). Some other solutions can help increase the visibility of motorcyclists:

- front lighting that emphasizes the contours of the motorcycle (for example, additional lights at the ends of the handlebars, or an illuminated fork) (Slootmans at al., 2017).
- an Alternating Blinking Light System that is placed at the top of the helmet, which blinks in an alternating manner. This creates an illusion of movement (Gershon & Shinar, 2013).
- Daytime Running Lights (DRL) have been studied many times, and are found to effectively contribute to better motorcycle visibility and detection. However, this effect is hampered when other vehicles also adopt DRL. One solution is to change the DRL colour for motorcycles, so they can be recognized more easily (Adbul Khalid, 2021a).
- several front light configurations and their effect on conspicuousness have also been studied. Motorcycles with a T-shaped light configuration are more quickly identified in traffic (Rößger et al., 2012).

Research suggests that that motorcyclists using alternative light systems were more rapidly recognized as such, but that this effect disappears over time (Rößger et al., 2012; Gershon & Shinar, 2013).

4.2.2 Advanced Rider Assist Systems

Tests have shown that the Advanced Cruise Control systems of cars are not able to detect motorcycles correctly. Enhancements in the safety characteristics and functional capabilities of modern cars' ADAS systems could help better identify motorcycles in traffic (Westerband, 2018). The new EU General Safety Regulation 2019/2144 which has introduced as of July 2022 state-of-the-art safety technologies as standard vehicle equipment should help improve the safety of vulnerable road users including moped riders. For example:

- Advanced emergency braking systems capable of detecting motor vehicles and vulnerable road users in front of them
- Enlarged head-impact protection zones capable of mitigating injuries in collisions with vulnerable road users.

- Cars and vans must be constructed in such a way that will help to reduce blind spots in front of and to the side of the driver.

Compared to passenger cars, the introduction of safety features for motorcycles is lagging behind. Some motorcycle Advanced Rider Assist Systems (ARAS) could help reduce motorcycle crashes and fatalities, such as Electronic Stability Control, Forward Collision Warning, Lane Departure Warning, etc. (Abdul Khalid, 2021b; IRAP, 2022c). Currently, some ARAS systems are already in use or under development (such as Adaptive Cruise Control), but more research is needed to establish the approximate costs and which safety systems can be realistically transferred to motorcycles.

4.2.3 Safer roads

Motorcycles are an important mode of transport, and their requirements should be reflected in road design (IRAP, 2022a). Improving the road environment for motorcyclists requires a better understanding of motorcycling riding activity and the actual needs and constraints of motorcyclist riders (Delhaye & Marot, 2016).

Roads should be forgiving: errors are inevitable in the road transport system and should be ameliorated by better design. In the first place, road design should allow adequate room for rectification of any errors (IRAP, 2022d).

Roadside safety design can limit the severity of trauma for motorcyclists by providing clear zones of soft ground surface and by removing, relocating or modifying roadside hazards. Parapets of appropriate design, height and layout are needed for bridges and along other drops (IRAP, 2022d). Crash barriers should also be improved: secondary rails (such as BikeGuard, BASYC or Moto Tub systems) which protect riders from posts and present a continuous surface should be implemented (IRAP, 2022d).

A more far-reaching solution would be the implementation of separate motorcycle lanes. These can be inclusive – located outside of the main carriageway for each direction of traffic flow – or exclusive – requiring a carriageway completely separate from the one used by other vehicles. These separate motorcycle lanes could reduce vehicle to motorcycle crashes by limiting the interaction with heavier vehicles and can improve traffic flow (IRAP, 2022e). However, they would have little effect on single vehicle accidents at intersections. Further research is needed to determine their effect on the crash risk of motorcyclists.

5 Further reading

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