



Power two wheelers 2018



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1 Overview

There are two main types of power two-wheelers (PTWs):

- mopeds with 50cc and restricted top speed
- motorcycles

Use of PTW

With two wheels in line, minimal bodywork and high power to weight ratio, PTWs are an economical means of transport, offering increased mobility in traffic congestion and are therefore popular in urban commuting. In addition, riding a PTW gives a special sensation which is attractive to many riders, but, on the other hand, riding a PTW is much more dangerous than using any other motor vehicle.

The fleet of PTWs in Europe is estimated at 37 million vehicles in 2011, of which about 70% were motorcycles and 30% were mopeds (ACEM, 2013). PTWs are more popular in southern European countries. Greece has the highest ownership rate with 128 mopeds and 142 motorcycles per 1.000 inhabitants. In most countries the number of mopeds is decreasing although at different rates or has stabilised. The number of moped fatalities follows the same trend. Many European countries have a large proportion of moped fatalities among riders 25 years and older, other countries show a majority aged less than 25 years. The trends for motorcycles are quite different. Almost all European countries have experienced an increase in the number of motorcycles, again at various rates, with the increase being larger for older motorcycle riders.

Safety of PTWs

PTW rider fatalities accounted for 18% of the total number of road deaths in the EU countries in 2015 (EC, 2017). Among them, 15% come from motorcycles and 3% to mopeds fatal crashes. More specifically, in 2015, 3.952 riders (drivers and passengers) of motorcycles and 714 riders of mopeds were killed in EU countries in traffic crashes. There are 11 motorcyclist deaths per 100.000 registered motorcycles, compared to 5 car occupant deaths per 100.000 registered cars.

PTW accident characteristics and injury mechanisms

Studies of moped and motorcycle accidents find large proportions of collisions with a car driver who should have waited for the PTW, indicating problems with the perception of PTWs. These problems are both physical due to the small size of the PTW and psychological: the presence and behaviour of PTWs is not expected by car drivers and sometimes not given enough attention by them. Some PTW riders contribute to the problems by speeding and driving aggressively. A partial solution to the perceptual problems for both moped and motorcycle is the use of headlights during daytime and the wearing of fluorescent/retroreflective clothing.

Riders suffer from lack of protection which make them particularly vulnerable in case of a collision with a vehicle or a fix object in the environment. Injury mechanisms are complex; they are useful to study in order to improve protection means. Injuries to the legs are more frequent and severe with frontal collisions. Severe head injuries are more frequent with the motorcycle hitting the side of a car at a right angle.

Contributory factors in crashes

Age and experience are the main factors related to the PTW rider. Young PTW riders have much higher crash rates than older ones, even if corrected for lack of experience. The crash rates of middle aged PTW riders are still many times higher than of car drivers of the same age. Different types of experience with a PTW (years of riding, recent or frequent riding, familiarity with a specific motorcycle and familiarity with specific condition) all contribute to a lower crash rate to some extent. Riding conditions, rider motivation and riding style contribute to accidents as well.

Mopeds with their small engine and low top speed have lower fatality rates than motorcycles, but higher crash rates when less severe injuries are included. Little is known about the crash rate of 125cc motorcycles, which is unfortunate because some countries have a low minimum age limit of 16 years for these vehicles and/or allow access with only a car license. Sports motorcycles have been found to have higher crash rates than other types of motorcycle. This is possibly the consequence of the riding style of the riders who choose this type of motorcycle, a riding style which includes speeding and competing. Power to weight ratio is probably more related to crash rate than cubic capacity.

With only two wheels in line PTWs are difficult to control. Poor condition of the road surface or small objects on the road are likely to cause loss of control of a PTW.

Accident prevention and injury protection

There are a number of measures that can make riding a PTW safer. These can focus on reducing the number of crashes occurring or improving injury protection when crashes do occur. However, even if these measures were used to their full potential, the injury rates of PTW riders will still be much higher than for car drivers. A further reduction in number of PTW crashes is only possible with a very restrictive licensing system with access only at higher age limits, more extensive training and testing, lower power to weight ratios or restricted top speed and a stronger adhesion of all PTW riders to traffic rules. Some of these measures will not be popular with present user groups or the PTW industry. Framing or restricting the use of PTWs may be more acceptable if alternatives are made more attractive. Pedal bike, public transport or cars do not seem to be alternatives to the present use of PTWs. (Electric) power assisted pedal bikes and tilting three wheelers could become acceptable alternatives in the near future for some existing groups of PTW users.

PTWs provide little protection against injuries in the case of an accident. Injuries to the legs are frequent, but injuries to the head are more severe even though wearing a helmet. Accident studies show head injuries would have been much more frequent if helmets had not been worn. From the point of view of preventing injuries there is no reason to exclude any group of PTW users from compulsory wearing a helmet. Wearing protective clothing would prevent many minor injuries. Collisions between the front of the PTW and the side of a car are frequent, with many riders falling before the collision as well as many riders departing from the PTW during the collision. Devices to prevent injuries in these cases, like airbags, protective jackets and leg protectors are being developed. Braking a PTW is difficult and loss of control in an emergency situation is often found in accident studies. Some of these accidents can be prevented with ABS/CBS brake systems. They will become mandatorily fitted to new motorcycles in Europe after 2017.-Injuries from single vehicle crashes are more severe when

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hitting a fixed object like a guard rail. Devices have been designed to be retrofitted to existing guard rails to prevent injuries to motorcyclists.

Licensing requirements

Given the characteristics of a PTW and their high severe crash rate it is obvious that riders need a high level of competency. A graduated licensing system will reduce the number of motorcycle accidents because:

- Young riders are not allowed to ride a motorcycle
- Learning and gaining experience is restricted to low risk conditions
- Licensed riders are more competent (as compared with other systems)
- Some potential riders are discouraged from obtaining a motorcycle license

The European directive on licensing (2013) is not a graduated system in the strict sense: from age 18 riders have direct access to a 35kW motorcycle and from 24 years to an unrestricted motorcycle. The adverse effects of immaturity may be minimised with these age limits, but not with the age limit of 16 for 125cc motorcycles or even 14 for mopeds. In terms of accident prevention, a better licensing system has

- A minimum age limit as high as for a car license
- At least two stages of riding under low risk conditions on a low performance motorcycle with a combination of compulsory training and unsupervised practising
- Testing before and at the end of each stage
- No direct access to high performance motorcycles
- Moped riders start with compulsory training, followed by a period with a provisional license and ending with practical training/test
- But even an improved licensing system may not prevent higher crash rates caused by rider motivation and riding style. The effects of voluntary, advanced training programs will depend on the motivation of the participants. With riders who are safety minded these programs can be expected to improve their behaviour and prevent accidents. With performance oriented riders the result may be the opposite.

Enforcement

Certain types of violations by PTW riders (speeding, drinking, tampering of the engine, not wearing a helmet) contribute to accidents/injuries. Depending on the proportion of riders violating the law, increased enforcement effort may be needed.

Road design and maintenance

In road design (in particular all kinds of speed inhibitors and lane markers) and in road maintenance more attention is needed to prevent PTW accidents.

2 Use of Powered Two Wheelers

There are two main groups of PTW: mopeds with 50cc engines and restricted top speed and motorcycles. Scooters (including 3-wheeler MP3s) correspond to a shape classification (“step-through design”) and an engine with automatic transmission. They can be either “motorcycle” or “moped” type, based on engine displacement. Mopeds are generally used for shorter trips compared to motorcycles, mostly urban commuting.

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The requirements for age, training and testing have been harmonized in the EU with the 3rd Driving Licence Directive which came into force in January 2013. Mopeds have been included in the licensing system with a category license which can be obtained after passing a mandatory theory test, at least, most often accompanied with a practical training. The minimum age for riding a moped is 16 years of age whereas for motorcycles it is 18 years of age in most countries. There are however still differences between countries in the details of the respective legal requirements, e.g. in Portugal, Italy and France the minimum age for riding a moped is as low as 14 years. Most European countries recognise a separate category of light motorcycles with 125cc engines and a minimum age of 16 years. However, in Denmark, Switzerland, Belgium, Greece and the Netherlands the minimum age for this category is 18 years. In most countries motorcyclists start with motorcycles with restricted engine power and access an unrestricted motorcycle at a later age. Some of these details will be discussed in following sections.

Technical inspection of motorcycles is obligatory every 12 months (in Belgium, Ireland, Latvia, Netherlands, Austria and United Kingdom) or 24 months (in Germany, Greece, Spain, Italy and Sweden), with only a few countries (including Finland, Denmark, France and Portugal) not requiring inspections.

PTWs have a number of characteristics which are relevant to their use and their safety. Compared to cars, mopeds are an economical means of transport. For road users of younger age (less than 18 years) they provide the only means of motorised transport. Furthermore, mopeds and motorcycles are relatively small and easily manoeuvrable, which makes them attractive in areas with dense or congested traffic and absence of parking spaces.

However, their small size and their position in between (lanes of) cars make them less detectable and predictable to car drivers, causing conflicts or accidents. With two wheels in line, PTWs are unstable and require body coordination and careful control by the rider in particular at low speeds, when cornering and in emergency situations. With a smaller tyre contact patch area, PTWs are more vulnerable to wheel sliding and therefore require increased caution on poor road surfaces. Braking is further complicated because most PTWs have separate controls for front and rear wheel brakes. In the absence of much bodywork, PTWs give little protection to the rider against adverse weather conditions and against injuries in the case of an accident.

Furthermore, motorcycles have powerful engines and in combination with their low weight are capable of higher acceleration and a higher top speed than most cars. Together these characteristics make riding a PTW potentially more dangerous than other types of vehicles. At the same time riding a motorcycle gives a completely different sensation to driving a car, which is attractive to many riders.

The above considerations lead to the suggestion that the motives for riding a PTW can be different to those for driving a car and can vary between groups of PTW users. They also lead to the suggestion that riding a PTW is relatively dangerous. The level of danger again can vary between groups of PTW users. Definitive conclusions have to be based on actual accident data and empirical research and care has to be taken when applying the results of studies on one group of riders to other groups of riders in other regions or in different time periods.

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The fleet of PTWs in Europe is estimated at 37 million in 2011, of which about 70% were motorcycles and 30% were mopeds. Within the motorcycle fleet, the smallest motorizations (between 50 and 125 cm³) composed more than 60% of the total. The 125cm³ class doubled in volume in 5 years (2003-08) (ITF 2015).

In most countries the number of mopeds is decreasing although at different rates or has stabilised. The trends for numbers of motorcycles are quite different. Almost all countries experienced an increase in number of motorcycles, again at various rates. Middle European countries show an ongoing downward trend in number of motorcycles. A growing proportion of PTWs in the motorized fleet is marked in large cities.

The use of PTWs varies between countries. PTWs are more popular in southern European countries, with high rates for motorcycles and even higher for mopeds (Table 1). Greece is at the top with 122 mopeds and 153 motorcycles per 1.000 inhabitants. Figures for Portugal lie between those for southern and other countries with a rate of 31 for mopeds and 21 for motorcycles which are low even relative to western and northern European countries. At the other extreme for mopeds is Great Britain with only one moped per 1.000 inhabitants. For the other countries the rates are about 25 for mopeds (with Finland higher at 59 and Lithuania low at 4) and 40 for motorcycles (with Switzerland higher at 87 and Lithuania low at 10). There is little information for middle European countries of which Czech Republic has a relatively high rate for mopeds: 46.

Table 1: Rate of PTWs per 1000 inhabitants, 2016

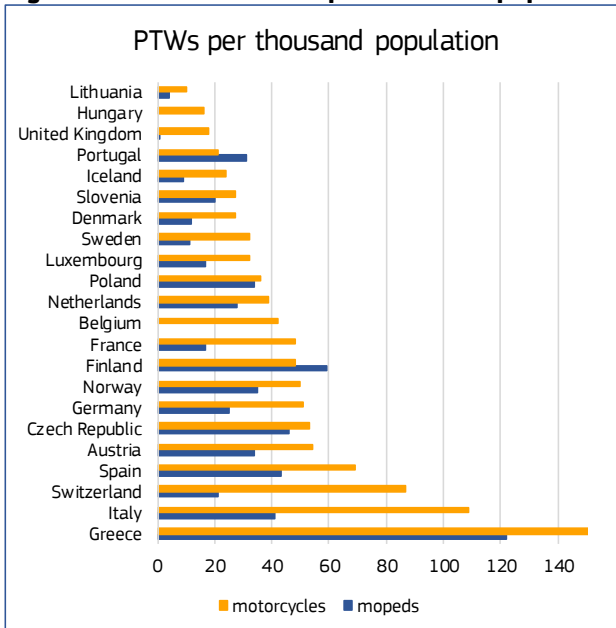
	mopeds	motorcycles
Austria (2015)	34	54
Belgium	-	42
Czech Republic	46	53
Denmark ([1] 2005)	12 [1]	27
Finland	59	48
France	17	48
Germany	25	51
Greece	122	153
Hungary	-	16
Iceland	9	24
Italy	41	109
Lithuania	4	10
Luxembourg	17	32
Netherlands	28	39
Norway (2015)	35	50
Poland	34	36
Portugal ([1] 2009; [2] 2015)	31 [1]	21 [2]
Slovenia	20	27
Spain	43	69
Sweden	11	32
Switzerland	21	87
United Kingdom	1	18

Source: OECD database, 2018

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In Figure 1 the countries are presented in order of increasing number of PTWs (mopeds and motorcycles) per 1.000 inhabitants.

Figure 1: Number of PTWs per thousand population, 2016 or latest available year



Source: OECD database, 2018

The number of PTWs per 1.000 inhabitants in Figure 1 refer to the year 2016, but there have been remarkable changes in the recent decades. In the southern countries the rate of mopeds per 1.000 inhabitants increased slowly during the last 20 years with the exception of Portugal which showed a decrease over the last 10 years. Most western and northern countries had a strong decrease between 1980 and 1995, followed by a relatively stable period. Today, the share of mopeds is declining in most European countries.

The trends for motorcycles are quite different. Almost all countries experienced an increase in motorcycle rates starting between 1990 and 1995, some with a strong increase (e.g. Austria, Germany and Greece), and some more slowly (e.g. France and Portugal). Information on ownership per age group per country is not generally available, but it is likely that the age distributions of moped and motorcycle owners is quite different between countries. There are indications that the increase in numbers of motorcycles is stronger for older riders and that the proportion of scooter type mopeds as well as motorcycles is growing in the PTW fleet.

3 Safety of PTWs

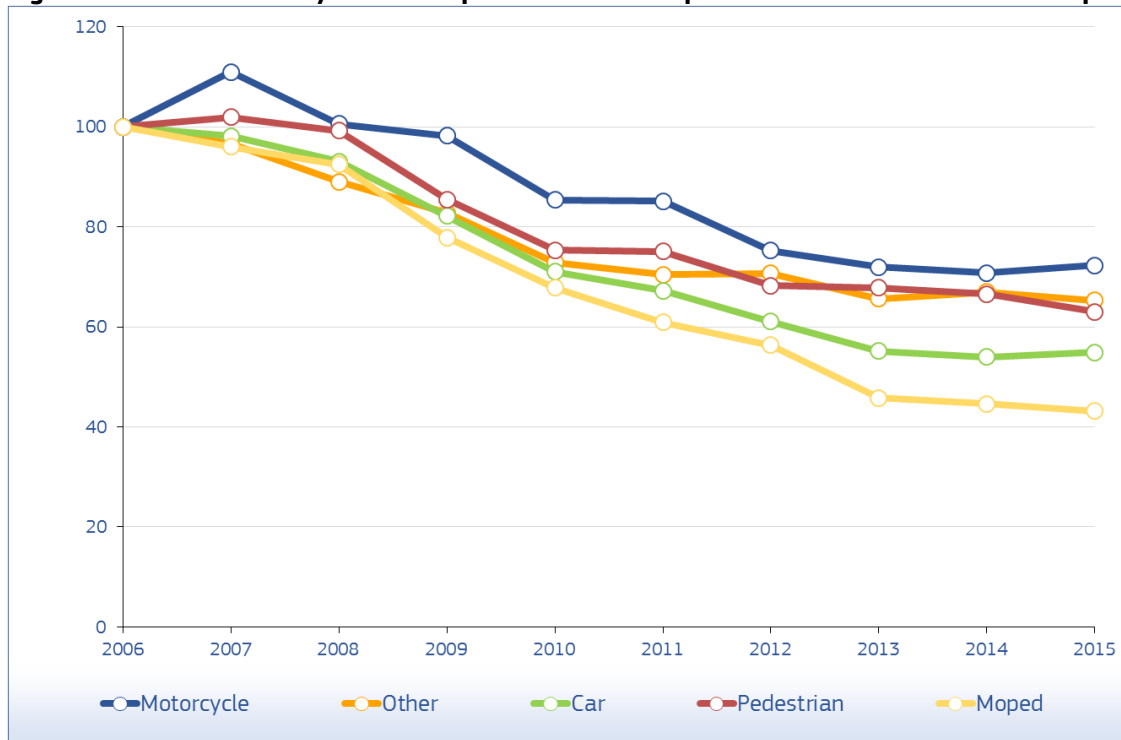
Safety, or rather the lack of safety, of PTWs is generally expressed in numbers of accidents and casualties. Since the number of accidents/casualties will depend on the amount of use (or exposure) of PTWs, these numbers should be corrected with some measure of exposure. One such measure is the number of PTWs in the traffic. This is of limited use because the amount of actual riding is likely to vary between groups of PTWs and groups of PTW riders. A better measure would be the number of kilometres on the road. It is unfortunate that many countries have no reliable and detailed data on PTWs mileages.

3.1 PTW fatalities in Europe

The total number of PTW fatalities in 2015 in Europe (EU-28 countries) was 4.666. Overall, PTW rider fatalities accounted for 18% of the total number of road deaths in the EU-28 countries in 2015. (EC, 2017). Among them, 15% come from motorcycles and 3% to mopeds fatal crashes. There are 11 motorcyclist deaths per 100.000 registered motorcycles, compared to 5 car occupant deaths per 100.000 registered cars.

Figure 2 shows the trend for motorcycle and moped rider fatalities compared to other modes of individual transport.

Figure 2: Index of motorcycle and moped fatalities compared with other modes of transport



Source: European Commission, 2017

Trends over time in numbers of moped fatalities have varied between countries. There is also much diversity in age groups of moped fatalities between countries. The most consistent finding with regard to motorcycle fatalities is the larger proportion of riders 25 years and older in 2015 as compared to 1980 when the proportion under 25 years was much higher.

Safety figures differ significantly across the EU member states both for motorcycles and mopeds, as seen in Table 2 showing the absolute numbers of fatalities in two age groups for the year 2013.

Table 2: Absolute number of PTW fatalities by age and country, 2015

	Mopeds			Motorcycles		
	<25	≥25	Total	<25	≥25+	Total
Austria	6	2	8	19	64	83
Belgium	4	15	19	13	87	100
Croatia	2	12	14	15	43	58
Cyprus	1	1	2	5	8	13
Czech Republic	0	6	6	10	81	91
Denmark	6	13	19	4	15	19
Estonia	0	0	0	0	0	0
Finland	1	1	2	5	15	20
France	95	60	155	120	494	614
Germany	10	52	62	142	497	639
Greece	7	25	32	56	180	236
Hungary	2	25	27	4	46	50
Italy	35	70	105	121	650	771
Latvia	2	4	6	1	5	6
Lithuania	2	1	3	4	9	13
Luxembourg	0	0	0	2	4	6
Netherlands	10	25	35	8	35	43
Poland	16	49	65	63	145	208
Portugal	1	41	42	7	66	73
Romania	5	29	34	13	42	55
Slovenia	0	1	1	3	22	25
Spain	15	41	56	35	294	329
United Kingdom	5	3	8	77	284	361

Source: European Commission, 2017

3.1.1 Moped fatalities

714 riders (drivers and passengers) of mopeds were killed in traffic crashes in the EU-28 countries in 2015 (EC, 2017). It corresponds to 3% of the total number of road deaths.

Most northern and western countries had strongly decreasing numbers of moped fatalities until 1990 and 1995, after which the number decreased more slowly (e.g. Germany, Switzerland and the Netherlands), remained more or less the stable (e.g. Sweden, Norway, Finland, Austria, France) or even increased somewhat (e.g. Denmark and Great Britain). Belgium is the exception with a continuous decrease since 1980.

Among the southern countries, Portugal and Italy show a continuous decline which is much stronger in Portugal than in Italy. The number of moped fatalities in Greece had a peak between 1990 and 1995 and a much lower level after that. Spain is similar with a peak in 1990. Of the central European countries Poland and Hungary have similar trends: decreasing which stopped in very recent years. On the contrary, moped fatalities in Czech Republic in recent years are lower than before. These trends in moped fatalities are roughly in correspondence with the trends in ownership.

When age groups of moped fatalities are taken into account, there is much diversity between the countries. Countries like Portugal and Hungary have a large proportion of moped fatalities

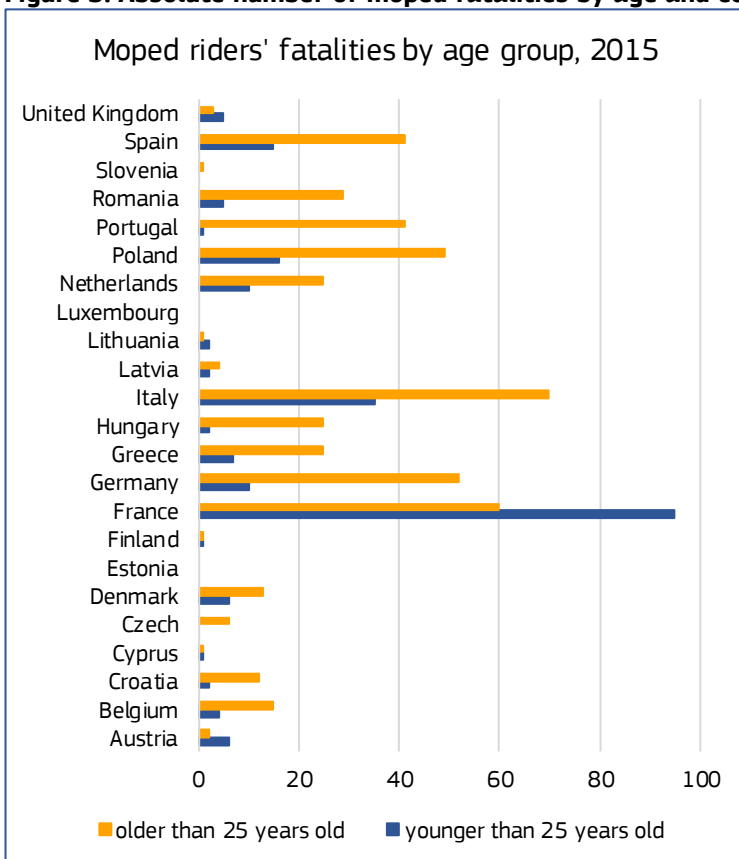
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25 years and older in 2015. This was different in 1980, when the proportion of under 25 years was larger. This indicates a strong decline of moped fatalities over the years, in particular for young moped riders. Some northern and western countries show a majority of moped fatalities under 25 years in 2015. France is one of these but used to have more fatalities 25 years old and older in 1980. Great Britain always had more young moped fatalities, but now has equal numbers of younger and older than 25 years moped fatalities.

Of the southern countries Greece, Spain and Italy have a large proportion of older moped fatalities, which for Greece and Italy has always been the case. Portugal and Spain used to have about equal numbers of young and old moped fatalities in 1980.

The central European countries always had more moped fatalities in the older age group.

Figure 3: Absolute number of moped fatalities by age and country in the EU, 2015



Source: European Commission, 2017

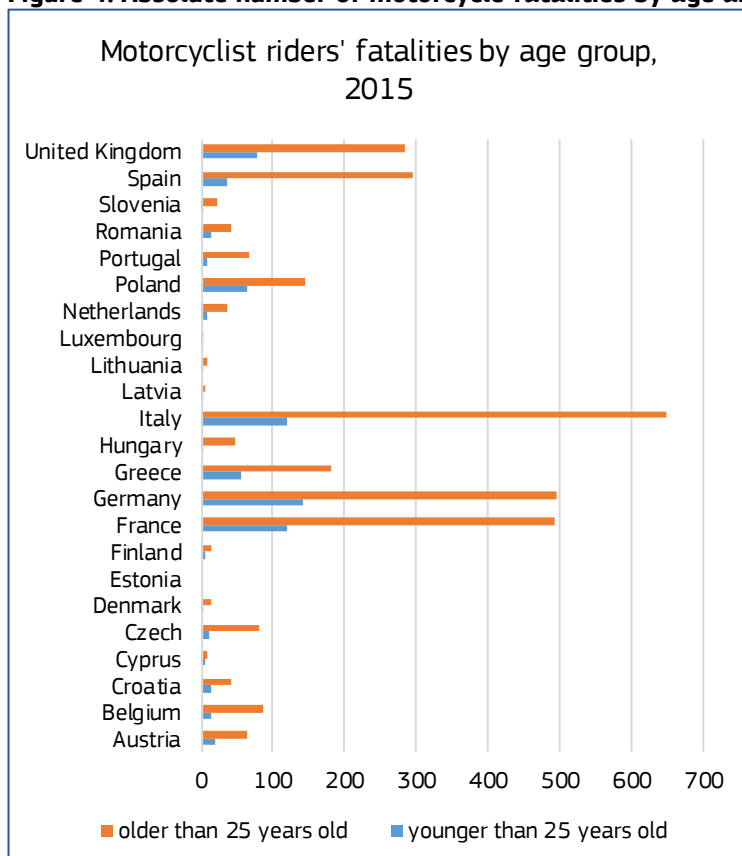
3.1.2 Motorcycle fatalities

3.952 riders (drivers and passengers) of motorcycles were killed in traffic crashes in the EU-28 countries in 2015 (EC, 2017). It corresponds to 15% of the total number of road deaths. 81% of the motorcycles riders killed in traffic were older than 25 years old.

There is a larger proportion of fatalities for riders 25 years and older in northern and western countries in 2015 as compared to 1980 when the proportion under 25 years was much higher. The trends in number of fatalities for the two age groups combined is less consistent with the northern countries showing little change and other countries (e.g. Germany, Austria, Switzerland, Great Britain) showing a decline until 1990-1995.

The southern countries are similar to the western and northern countries with many more motorcycle fatalities 25 years or older in 2015 and the younger age group higher in 1980. Of the central European countries, Czech Republic and Slovenia show a strong increase in older motorcycle fatalities in recent years and a decrease in younger fatalities, with a slowly decreasing overall number as a result. Hungary forms an exception with a rather strong fall between 1990 and 1995, which was even stronger for motorcycle fatalities 25 years and older.

Figure 4: Absolute number of motorcycle fatalities by age and country in the EU, 2015



Source: European Commission, 2017

3.2 Moped and motorcycle fatality rates

Fatality rate per inhabitant reflects both the number of vehicles per inhabitant and the fatality rate per vehicle.

All southern European countries have high **moped** fatality rates per inhabitant, but rate per vehicle is highest in Denmark and Austria. Similarly, the **motorcycle** fatality rate per inhabitant is extremely high in Greece, but mainly due to the high rate of motorcycles per inhabitant.

The fatality rates per million inhabitants give an indication for which countries the safety of riders is a matter of great concern. Table 3 gives fatality rates per million.

Table 3: Fatality rates per million inhabitants, 2013 or 2014

PTW fatality rates				
	Mopeds		Motorcycles	
	/10 ⁶ population	/10 ⁵ vehicles	/10 ⁶ population	/10 ⁵ vehicles
Austria	0,93	2,77	9,68	17,81
Belgium	1,69		8,90	21,14
Croatia	3,31		13,73	
Cyprus	2,36		15,35	
Czech Republic	0,57	1,24	8,64	16,22
Denmark	3,36		3,36	12,42
Estonia	0,00		0,00	
Finland	0,37	0,61	3,66	7,52
France	2,42	14,54	9,61	19,99
Germany	0,76	3,07	7,87	15,11
Greece	2,95	2,43	21,83	14,33
Hungary	2,74		5,07	30,86
Iceland	0,00	0,00	3,04	12,50
Ireland	0,00		0,00	
Italy	1,73	4,24	12,71	11,70
Latvia	3,02		3,52	
Lithuania	1,03	27,27	4,45	44,83
Luxembourg	0,00	0,00	10,66	31,58
Netherlands	2,07	7,32	2,54	6,58
Norway	0,19	0,56	3,87	7,75
Poland	1,71	5,03	5,47	15,34
Portugal	4,05		7,04	33,64
Romania	1,71		2,77	
Slovenia	0,48	2,38	12,12	44,64
Spain	1,21	2,82	7,08	10,25
Sweden	0,00	0,00	3,18	9,78
Switzerland	0,36	1,70	8,01	9,17

Sources: CARE database, 2017; OECD database, 2018

Among southern European countries, Portugal, Greece and Italy have high moped fatality rates. Denmark has the second highest moped fatality rate among the European countries. Based on fatality rate per 100.000 vehicles, the safety problem of mopeds is most serious in Lithuania and France and to a lesser extent in Sweden, Norway and Finland. The explanation for such high rates can only be found by detailed studies on age distributions, mileage, etc.

The rate for motorcycle fatalities per million inhabitants is extremely high for Greece and to a lesser extent for Estonia, Netherlands and Romania. Based on the fatality rate per 100.000 vehicles, Greece is no longer extreme, which is the result of the high rate of motorcycles per 1.000 inhabitants. But Lithuania, Slovenia and Portugal have high fatality rates per 100.000 vehicles. This could be an indication of a high mileage per vehicle or a high fatality rate corrected for kilometres or both. This can only be decided on the basis of more detailed studies.

4 Accident characteristics

Effective countermeasures are based on a thorough understanding of the accident causes and the circumstances under which these accidents happen. Accident reports provide valuable information in this respect, such as:

- Type of PTW (moped vs. motorcycle)
- Type of situation (built up vs. non built up and intersection vs. between intersections)
- Road users involved (single, PTW+car, other)
- Movements of PTW and car relative to situation and to each other
- Severity of damage/injuries
- A combination of these variables is needed to describe the character of PTW accidents.

Some studies include reports of both moped and motorcycle accidents while others deal with motorcycle accidents only.

Although different studies are likely to use different sampling methods or different ways to characterise the accident, three frequent accident scenarios stand out.

- Scenario 1: motorcycle/moped rider having a single vehicle accident, riding between intersections, losing control in a curve.
- Scenario 2: motorcycle/moped rider reaching an intersection, being hit by a car driver coming from a side road who did not notice the motorcycle in time.
- Scenario 3: a car driver turning left and not noticing the motorcycle coming from the opposite direction.

In the scenarios 2 and 3 a large majority of car drivers should have given right of way to the PTW, indicating problems with the perception of the PTW. In all three scenarios the motorcyclist may have been speeding.

These scenarios give a description of the situation and events before the actual crash. This is followed by a sequence of events resulting in injuries of the PTW rider.

4.1 Studies on moped and motorcycle crashes

Only a few studies are based on both moped and motorcycle accidents.

In a Dutch study (Noordzij, 1998) based on a sample of 1.054 moped accidents resulting in hospital admissions in 1993, the following observations were made:

- Twice as many accidents occurred on built-up roads.
- 20% of the accidents were single vehicle accidents, most of them in between intersections.

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- 60% of the accidents were collisions with a car, of which more than two thirds at intersections.
- At intersections about 50% of the car drivers (coming from a side road or turning left or right) should have waited for the moped rider.

A similar study (Noordzij and Vis, 1998) based on 926 motorcycle accidents resulting in hospital admissions in the Netherlands in 1993 reported the following:

- Equal numbers of accidents on built-up and non-built-up roads.
- 27% of the accidents were single vehicle accidents on non-built-up areas as compared to 17% on built-up areas.
- 60% of the accidents were collisions with a car, on non-built-up roads about equally often at intersections and road sections but on built-up roads more often at intersections.
- At intersections about 50% of the car drivers coming from a side road should have waited for the motorcyclist and another 20% turned left in front of an oncoming motorcycle
- In 80% of all collisions with a car at intersections the car driver had seen the motorcycle too late or not at all; on road sections this was the case in 60% of the collisions with a car
- On built-up roads about 40% of the motorcyclists were exceeding the speed limit before colliding with a car, in other situations this percentage was much lower.

A recent French study (ONISR, 2011) based on all PTW crashes resulting in hospital admissions collected in 2009 by police services (including 29.962 crashes, 56,1% motorcycles, 43,9% mopeds) reported the following:

For motorcycles:

- 36% of fatalities occurred in single vehicle crashes. A comparison with data from hospital services shows a strong underreporting of non-fatal single motorcycle crashes in police reports.
- 66,8% of crashes (81,0% fatalities) occurred in between intersections, 33,2% of crashes (19,0% fatalities) occurred at intersections.
- The severity of crashes increased with the engine displacement of the motorcycle involved.
- Motorcyclists were more often killed in non-built-up areas (63,1%) than in urban areas (36,9%).
- The motorcyclists were impaired by alcohol in 4,9% of injury crashes, and in 20% of fatal crashes.
- Scooters represented 25,8% of injury crashes and 6,9% of fatalities.
- 33,3% of motorcyclists were killed during the night.

For mopeds:

- 34% of fatalities occurred in single vehicle crashes.
- 61,1% of crashes (77,9% fatalities) occurred in between intersections, 38,9% of crashes (22,1% fatalities) occurred at intersections.
- Moped riders were impaired by alcohol in 7,9% of injury crashes, and in 26% of fatal crashes.
- Moped riders were more often killed in built-up areas (53,8%) than in non-urban areas (46,2%).
- 31,8% of moped riders killed were under 18.
- 52,5% of moped riders were killed during the night.

A comparison of the two populations shows that crash rates for motorcycles (11,6 for 1.000 vehicles in traffic) and mopeds (12,3 for 1.000 vehicles in traffic) are comparable, but fatality rate is higher for motorcycles (0,63) than for mopeds (0,26). More fatal crashes occurred on non-built-up roads for motorcyclists than for moped riders. Moped riders are more often killed during the night than motorcyclists. Large proportions of fatal crashes were found in between intersections for both. Alcohol is more involved in fatal than in injury crashes, both for motorcyclists and for moped riders.

4.2 Studies on motorcycle crashes only

The following studies from other European countries deal with motorcycle accidents only.

A German study based on a sample of 500 accidents in the year 2000 involving motorcycles and resulting in injuries (Kramlich, 2002) gave the following distribution of collisions between a motorcycle and a car:

- 45% at intersections with priority for the motorcyclist.
- 22% at intersections with the car turning left against an oncoming motorcyclist.
- 10% on road section with the motorcyclist passing a car which turns left.
- 6% on road section with the car making a full turn and the motorcyclist from behind or opposite direction.
- 8% on road section with car overtaking in front of an oncoming motorcyclist.

The conclusion from these results is that in nine out of ten of these collisions the car driver should have given right of way to the motorcyclist.

Broughton (2005) reports on a study based on police reports of fatal motorcycle accidents in Great Britain between 1994 and 2003. In summary:

- 60% of accidents on non-built-up roads.
- 28% single vehicle accidents.
- On built-up roads 60% at intersections, against 40% on non-built-up roads.
- 35% of accidents at bends, 20% at left hand bend (with left moving traffic), 15% at right hand bend.
- 13% of motorcyclists were overtaking.
- 72% of motorcyclists were found by the police to be principally responsible, of whom 64% were reported to have lost control, with loss of control by reason of excessive speed in 37%.
- Of drivers of other vehicle found to be responsible, 40% failed to give way.

The 64% loss of control is quite high. Loss of control is expected in single vehicle accidents. But with 28% such accidents, more than half of the lost control cases must have been collisions with another vehicle, either because of loss of control or when losing control during an emergency action.

5 Injury mechanisms

Although the prime objective is accident prevention, the second objective is injury prevention in case of an accident. To be able to design effective counter measures one has to know what parts of the body are injured and what injury mechanism is responsible for the injury. The

events before and during an accident can be very complex. The rider of the PTW may take action to avoid the accident. This may change the trajectory and speed of the PTW and its rider. A collision with a car or other object will again change these and eventually parts of the body of the rider may hit some parts of his own PTW, of another vehicle or of another object. The nature and severity of the injuries depend on how these parts hit each other (which speed and angle).

The standard accident reports contain little information on injuries. Detailed information on the events before and during the accident can only come from in-depth studies at the scene of the accident and from inspection of vehicles and objects involved in the accident as well as from medical examination of the casualties. As a consequence the sample of an in-depth study is usually small, includes few severe injury cases and is regional rather than national; relatively few such studies exist.

In-depth studies show that injuries to the legs are frequent, but injuries to the head are more severe even though wearing a helmet. Head injuries would have been much more frequent if helmets had not been worn. Collisions between the front of the PTW and the side of a car are frequent, with many riders falling before the collision as well as many riders departing from the PTW during the collision. Injuries from single vehicle accidents are more severe when hitting a fixed object.

Special attention is paid to the injuries as a result of a rider colliding with a guard rail. The injuries as a result of a collision with a guard rail are influenced by the design of the guard rail. More injuries result from hitting the rail post than from impact with the rail itself. Little is known about differences in injury mechanisms between types of PTW, between different traffic conditions or about accidents with more severe injuries.

5.1 In depth studies

There is a recent in-depth study with samples from mostly urban areas in five European countries: France, Germany, the Netherlands, Spain and Italy (MAIDS, 2004). The accident sample for 1999-2000 contained 398 moped and 523 motorcycle accidents. About 70% of the PTW riders took action to avoid the accident, mostly by braking. However, about half of these (i.e. one third of all 921 riders) lost control doing this.

The parts of the PTW that were hit first:

- 63% at the front (29% centre front)
- 26% at either side

The other vehicles were first hit:

- 32% at the front (7% centre front)
- 40% at either side

The report contains lots of information e.g. on the angle at which the vehicles hit each other, on the speed of both vehicles before and at the time of collision. However there is no combination of these elements or separate figures for motorcycles and mopeds in the report.

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A report of a German study (Otte, 1998) provides a combination of elements. The sample contains 1029 accidents with injured motorcyclists (excluding scooter types) from 1985-1995. Many riders suffered multiple injuries to different parts of the body. The parts of the body that were injured:

- 20% of the riders had injuries to the head
- 21% of the riders had injuries to the upper torso
- 21% of the riders had injuries to the lower torso
- 44% of the riders had injuries to the arms
- 71% of the riders had injuries to the legs

The part of the motorcycle and the part of a car that were hit first, together with the angle are combined as types of collision:

- 36% no car involved
- 13% both frontal
- 7% front of car against side of motorcycle
- 27% front of motorcycle against side of car (5% at right angle)
- 4% front of car against rear of motorcycle

Injuries to the leg were more frequent and more severe with frontal collisions. Severe injuries to the head were more frequent with the motorcycle against the side of the car at a right angle.

Otte (1998) also examined the trajectory of the motorcycle rider during the accident:

- 8% thrown from motorcycle without hitting car
- 20% fell from motorcycle before hitting car/object
- 18% remained on motorcycle and hit car
- 50% departed from motorcycle and hit car (6% after being thrown)

More and more severe head injuries as well as leg injuries resulted from being thrown and landing on the car. Injuries to the upper torso were more frequent and severe when the rider fell before hitting car/object.

22% of the accidents were single vehicle accidents. In most of these cases (75%) the rider was injured by hitting the road surface. However, injuries from hitting fixed objects were more severe.

Otte (1998) also presented results of a sample of 89 accidents with scooters most of which were mopeds. The results showed more single vehicle accidents than with motorcycles (33% against 22%) and some differences in injury patterns. Since on the average the speed of scooters was lower it is not possible to decide if the two PTW designs result in different injury patterns.

5.2 Guard rails

A French study (Brailly, 1998) was concerned with collisions with guard rails. In 1993-1995 there were 63 fatal collisions of motorcyclists with a guard rail in France per year. This is 8%

of all motorcycle fatalities. Records of injury accidents were used to reconstruct the accidents, which was only possible with 157 out of 239 records:

- In 21 cases the motorcycle hit the rail but the rail had nothing to do with the injuries of the rider
- In 43 cases the motorcycle hit the rail and the rider was thrown away and injured (42 of them without hitting the rail)
- In 50 cases the motorcycle and rider hit the rail (in 29 cases with the rail post)
- In 43 cases the rider fell and slid under the rail

The number of such cases is dependent on both the frequency of motorcycles leaving the road by accident and the presence of guard rails at such places. What would be the outcome of these accidents if the guard rail had not been there is difficult to decide since the guard rail was there to prevent collisions with other objects. On the basis of the records Brailly suggests that in about half of these cases the injuries would have been less severe with a different design of the rail.

6 Contributory factors

Contributing factors are traditionally categorized in three groups.

- Factors related to road users. In the case of PTW accidents it is useful to distinguish between factors related to the PTW rider (such as age and experience) and factors related to other road users in particular their perceptual problems.
- Factors related to the vehicle. Examples of such factors are engine performance and type of PTW, etc.
- Factors related to the road. Examples of such factors are quality of road surface and obstacles.

6.1 Factors related to road users

Riders or rider groups who ride more kilometres are more exposed to the dangers of road traffic and will usually have more accidents. Therefore, when studying other factors that may contribute to accidents, the accident figures have to be corrected for kilometres travelled. Such a study can be based on national statistics. However, reliable and detailed data on kilometres are scarce. Other designs to study rider factors that may contribute to accidents are case control and questionnaires.

There is a problem when the results of all these studies are compared: the more information on rider characteristics in the study, the more accidents with no or less severe injury.

In all studies the age of the rider has been found to be important. Young riders have much higher accident rates, even if corrected for (lack of) experience. This has to be explained as a result of age related psychological factors. Unfortunately, there is no information on accident rates for the very young ages at which mopeds or motorcycles are allowed in some countries. Trends in risk by age have been different for different modes over the last 20 years.

Experience as a rider is also found to be related to accident rates of motorcycle riders, although not in all studies. There are different types of experience: years of riding, recent or frequent riding, familiarity with a specific motorcycle and familiarity with specific conditions.

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All types of experience contribute to a lower accident rate to some extent. Riding experience may not be sufficient to overcome the extra problems created by adverse weather conditions during winter.

Several studies emphasise the high accident rate of riders of a sports motorcycle. Some studies indicated a higher accident rate for recreational riding which may have to do with a combination of different conditions and a different riding style. Other groups of riders with a relatively high accident rate were only found in single studies: winter riders in Great Britain, urban riders in New Zealand, inexperienced riders of custom bikes in the Netherlands.

Other factors influencing PTW safety are psychological factors, influencing rider motivation and riding style, and the increasing numbers of older motorcyclists.

There are several violations of the law which are common to PTW riders and may contribute to accidents such as speeding, drinking, riding without a valid licence, tampering of the engine. The proportions of riders with such violations vary from country to country.

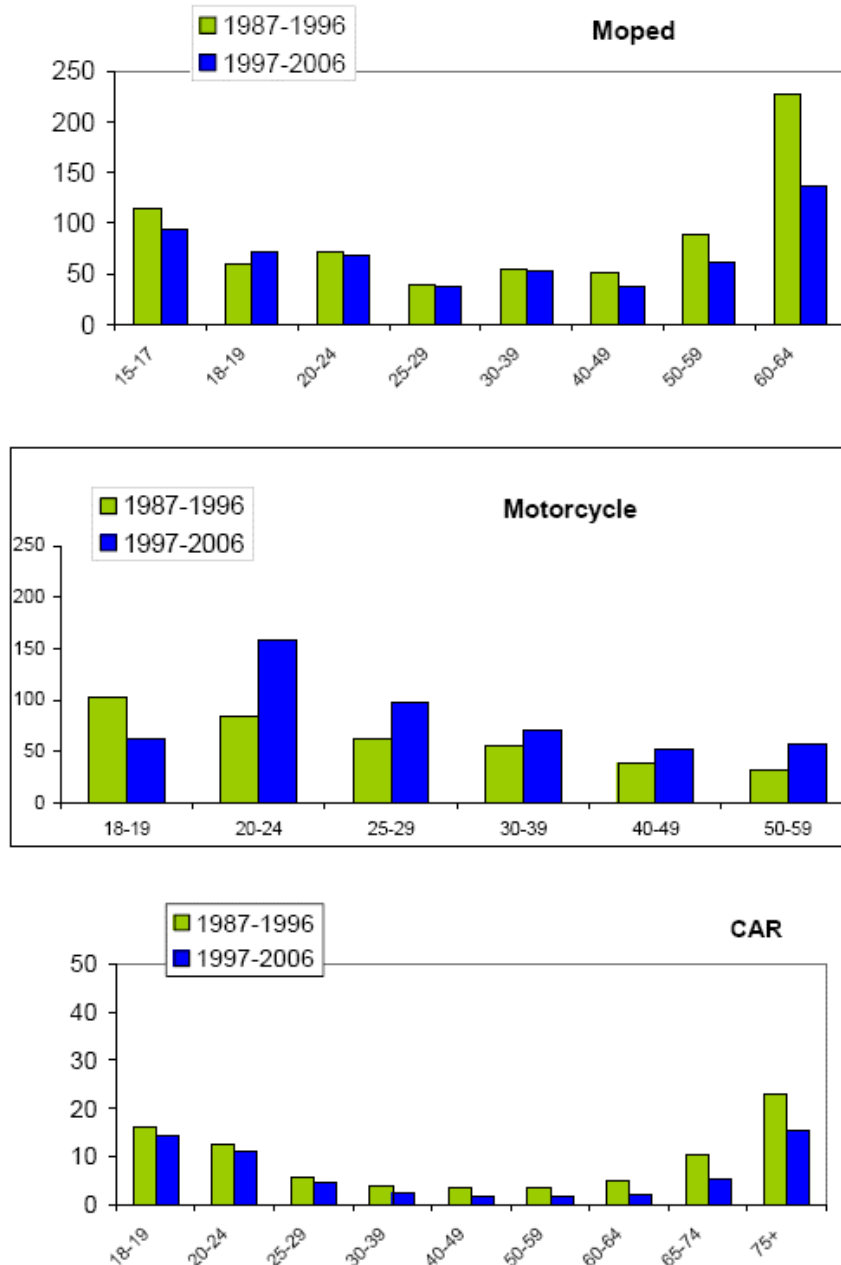
Rider safety is also influenced by the perceptions of other road users. Other road users appear often to fail to perceive PTW riders and to some extent this lack of perception is made worse by the behaviour of the PTW riders.

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6.1.1 Age, comparing transport modes

As an example of using national statistics Figure 5 shows accident rates per billion kilometres per vehicle type and per age group for two 10 year periods. The accident figures are actually vehicle occupants fatalities (i.e. riders/drivers as well as passengers) in the Netherlands. Kilometre data are from an ongoing national travel survey. There are several interesting observations to be made.

Figure 5 Fatalities per 10⁹ kilometres for different modes of transport by age of driver or rider for two periods in the Netherlands



Source: SWOV

For the most recent 10-year period, car occupants of all ages have a much lower fatality rate than moped or motorcycle occupants. E.g. between 40 and 50 years of age (which is the age group with the lowest rates for all three vehicle types) the rate is 2 for car occupants and 37

and 52 respectively for moped and motorcycles. There is a strong relation between these fatality rates and age.

Mopeds

The moped fatality rates show a U-shaped curve, with equally high rates for young (15-17) and old (60-65) occupants and the lowest rate between 25 and 50 years of age. The fatality rates for car occupants show a U-shape too, with the highest rate for young car occupants (18-19) and the very old (75+) and the lowest level between 40 and 60 years of age.

Motorcyclists

The trend with age for motorcyclists is different with fatality rates falling from age 20-25 and a lower rate for 18-19 years than for the next youngest group. The higher fatality rates for young riders/drivers as compared to middle aged ones has to do with both inexperience as a rider/driver and a difference in age related (psychological) factors. The higher rates for old riders/drivers are influenced by their poorer physical condition, resulting in more serious injuries from accidents.

Disregarding the age differences gives accident rates of 4 for car occupants, 68 for moped and 73 for motorcycle. However, the strong relation of these fatality rates with age means that a comparison of vehicle types over all age groups is less meaningful since for instance moped fatalities are mostly young and old, motorcycle fatalities mostly in the middle ages and car fatalities mostly middle age and older.

6.1.2 Trend in risk by age over the last 20 years

Mopeds

A comparison between the two 10-year periods shows that for moped and car occupants the fatality rates are lower for the most recent years, but only for older age groups. For moped occupants the lower rates start from age 40 and car occupants already have lower rates at 30 years. A partial explanation for the difference in trend for young and old rider/drivers could be that older riders/drivers in the recent 10-year period are on average more experienced than riders/drivers of the same age in the earlier period; younger riders/drivers are relatively inexperienced in both periods.

Motorcyclist

There is a striking difference in fatality rates between the two periods for motorcycle occupants. For the early 10-year period there was a continuously falling rate with age, starting with the youngest age group. For this age group only the fatality rate has decreased. But from age 20 there was a substantial increase in fatality rates from the first period to the most recent 10 years. There are two possible explanations. Firstly, many riders of the older age groups in the recent period are starting riders and thus are less experienced than riders of the same age in the earlier 10-year period. In addition, the motorcycles they ride tend to be heavier and more powerful. Secondly, the Netherlands have introduced a graduated licensing system in 1996. From then on riders of 18-20 years could only ride motorcycles with restricted engine power. A more definitive explanation would require more detailed information which is not available.

Severity of accidents

The rates in figure 4 are for fatalities only. Including accidents with less serious injuries would change some of the observations. Based on fatalities plus hospital admissions, the rates for moped occupants for all age groups are much higher than for motorcycle occupants. This is because moped occupants are more likely to become involved in an accident (corrected for kilometres travelled) but with less serious injuries than motorcycle occupants. This finding illustrates the importance of the method of sampling accidents in a study on the safety of PTWs. A sample with less severe injuries can lead to different conclusions than a sample with fatalities only.

6.1.3 Age and experience

Although the accident statistics show a clear effect of age, the question whether this effect is a result of the actual age of the rider, rather than his level of experience remains unanswered. To tease out the effects of the two factors, extra information is needed about actual driving experience, or by comparing accident involved riders with accident-free riders (case-control studies).

Additional accident information

In figure 4 the effects of age and experience are combined in the fatality rates per age group. To separate these effects information is needed on experience of riders involved in accidents and of riders not involved. This requires a special study design to obtain this information.

Noordzij & Vis (1998) obtained extra information on 926 motorcyclists involved in accidents resulting in hospital admission in the Netherlands in 1993 as well as from a special national survey of 3000 motorcyclists. Motorcyclists were divided in young (under 25 years of age) and inexperienced (less than five years riding a motorcycle), old and inexperienced and old with (five or more years) experience. The extra information also included type of motorcycle as touring, sports or custom. The rates of accidents per million kilometres show:

- Accident rate for young motorcyclists is one and a half times higher than for older riders with equally limited experience
- For older motorcyclists the accident rate is lower with more experience
- The rates for sports motorcycles is approximately double that of touring motorcycles and the rate for custom motorcycles is also higher than for touring motorcycles but only for inexperienced riders.

Case control studies

A slightly different study design to study the effects of contributory factors is the case-control study. With this design, accident facts are recorded in detail as soon as possible after the accident took place. As a consequence of this method the sample of accident cases is usually small, includes few severe injury cases and is regional rather than national. The sample of riders serving as controls is more or less similar to the accident sample in terms of times and places of sampling and in any way consists of riders not involved in an accident at the time of sampling. By a comparison of accident and control samples it is possible to calculate relative accident rates i.e. the accident rate corrected for exposure of a subgroup of riders relative to that of all other groups of riders (or one specific other group).

Such studies have been done in Australia and New Zealand. In the New Zealand study 463 accident cases in 1993-1995 were compared to 1.233 control cases. The results show a strong

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relation between relative accident rate and age as well as with familiarity with the specific motorcycle. There was no evidence of an effect of experience in terms of years riding a motorcycle after adjusting for age (Langley et al., 2000). The same data were used in a study on the effect of engine size on accident rate (Langley et al., 2000) and another study on motorcycle conspicuity (Wells et al., 2004).

The Australian study had 205 accident cases and 1.225 controls (Haworth & Smith, 1998). Relative accident rate was again found to be strongly related to age and this time a weak relation with years of riding was found. The results also indicated a higher relative accident rate for infrequent riding (less than three days a week) and for non-work related riding. A sub group of riders without valid license had a high relative accident rate.

Questionnaire studies

Another Australian study was designed as a survey in which both accident data and exposure data are obtained from 790 questionnaires completed by motorcyclists (Harrison & Christie, 2005). The weakness of such a design is the response rate which usually is around 40%. This implies that the results found in the study do not necessarily apply to the whole group of PTW riders at which the study was originally aimed. Another point of concern is that accidents reported by the respondents are without injury or slight injury only. The advantage of such a study is that many questions can be asked on riding habits and psychological variables that seem to be relevant for accident involvement.

Among the results of this study is a relation between accident rate corrected for kilometres and kilometres per year, with lower rates for more kilometres per year. Three groups of riders were found with a high accident rate, all three with a pattern of recreational riding, either as off-road riding or as long distance riding on a sports motorcycle, or weekend riding in urban areas with low kilometres per year.

A large scale study was done in Great Britain in 2002 (Sexton et al., 2004) based on 11.265 questionnaires from registered motorcyclists. These riders reported 1.495 accidents of which over half occurred during commuting or work related riding. A statistical model was used to calculate the expected number of accidents per rider based on kilometres per year and other factors. This model showed that the age of the rider is the most important predictor, closely followed by kilometres per year. The experience of the rider was next most important, followed by riding conditions. The relation with kilometres per year was such that riders with more kilometres per year had lower accident rates corrected for kilometres per year. The effect of riding conditions was such that those who ride on a regular basis during the year irrespective of weather have the highest accident rate corrected for kilometres, age and experience.

Riding experience may not be sufficient to overcome the extra problems created by adverse weather conditions during winter. Engine capacity was related with accident rate in the way that riders of motorcycles with an engine of more than 125cc had a 15% lower rate (corrected for other factors) than riders of 125cc motorcycles. The authors found no evidence that riders who returned to riding after a long break had higher accident rates compared to other riders of the same age.

6.1.4 Psychological factors

The questionnaire in the Sexton study included a part on rider behaviour and a part on rider motivation. The latter part was based on several studies in Germany by Schulz and partners. Schulz et al. (1991) distinguished twelve different aspects of motorcycle rider motivation which were found to be closely related to age of the rider and type of motorcycle. In later work Schulz (1998) used a questionnaire aimed at riding style. Analyses of the Great Britain questionnaire showed:

- Three aspects to describe motivation: pleasure from riding, liking for speed, economic aspects
- Three aspects to describe riding style: careful vs. careless, tolerant vs. intolerant and slow vs. fast
- Five aspects describing behaviour: traffic errors, speeding, stunting, use of safety equipment, control errors

Rider motivation and riding style were found to be related to rider errors and violations, which were related to accidents. To be more precise: a part of the self-reported accidents were the result of behaviour such as speeding, traffic errors and control errors, which were the result of riding style such as confident, fast and careless and/or the result of rider motivation such as a liking for speed. These authors conclude that an important part of the motorcycle safety problems stems from the motivations for choosing to ride motorcycles.

It might be expected that PTW riders differ from car drivers or the general population with regard to some psychological factors. There has not been much recent interest from researchers in this subject. A study with an interesting design compared motorcyclists and car drivers in Great Britain (Horswill & Helman, 2003). Three groups of subjects were tested in a simulator with traffic situations and completed a questionnaire on behaviour and some psychological variables including social motives and sensation seeking. A first group of 47 motorcyclists had to react as a motorcycle rider but a second group of 47 riders were asked to react as if driving their car. The third group was 48 car drivers. The three groups were carefully matched with regard to age, sex and experience. The results of the car drivers and of the motorcyclists acting as car drivers were very similar except that the motorcyclists were better at detecting potentially dangerous situations. The group of motorcyclists reacting as riders travelled faster, pulled out into smaller gaps, overtook more often, but did not follow closer to a vehicle in front. These results do not necessarily apply to all motorcycle riders.

The samples were not representative since the subjects volunteered themselves and all motorcyclists also held a car driving license. But it is clear that at least a group of motorcyclist is equally (or even more) competent and careful as a group of car drivers with similar demographics, except for the fact that the riders choose to ride a motorcycle in order to profit from the properties of the motorcycle such as being small and powerful.

6.1.5 Older Motorcyclists (aged 30+)

With increasing numbers of older motorcyclists in many countries there is a need for information on the safety aspects of this group. A rather detailed questionnaire study was made in Australia (Haworth et al., 2002). Riders aged over 30 were divided in continuing riders (384), returned riders (240) and new riders (275, with a licence for only seven years or less). All three groups named touring as the most common reason for using their motorcycle but were different in other respects. Continuing riders were more likely to ride all year round and

appeared to ride the most but in circumstances that are less likely to result in serious injuries. Returned riders rode less and new riders did more riding in urban areas on smaller motorcycles. The authors state that the accident rate corrected for kilometres for new and returned riders is probably higher than for continuing riders but there are no exact figures in the report.

6.1.6 Violations

Apart from speeding there are other examples of PTW rider behaviour in violation of the law, which may contribute to PTW accidents. Broughton (2005) found that 12% of the motorcyclist fatalities died in a drink/drive accident in 1994-2001, compared with 22% for car drivers. The situation in Great Britain seems to be different from that in France. Filou et al. (2005) report 23% of motorcyclists and 32% of moped riders in a fatal accident as positive for alcohol, compared to 19% for drivers of a passenger car. Filou et al. (2005) also mention that 18% of the riders of a light motorcycle and 8% of the riders of heavier motorcycles who died in an accident did not have a valid rider license.

Tampering with a moped or 125cc motorcycle engine to make it go faster seems to be a problem in Germany. Raithel (1998) obtained questionnaires from 137 young riders of PTWs, half of whom admitted tampering. It is very likely that tampering is related to a higher accident rate. The "Handbook of road safety measures" (Elvik & Vaa, 2004) refers to a Norwegian study in which the relative rate for injury accidents was found to be about 50% higher for tampered mopeds.

The most extreme example of violations is from Greece in 1994, where only 15% of the injured motorcyclists had been wearing a helmet when this was compulsory (Petridou et al., 1998). In more recent years the Greek wearing rates seem to be higher. In other countries where helmet wearing is compulsory the wearing rates of helmets by moped and motorcycle riders is usually reported as between 90 and 100%.

6.1.7 Perception by other road users

Accident studies show that the perception of PTWs is problematic and a contributory factor to collisions with cars. Wulf et al. (1989) present a review of studies on these problems and discuss several explanations for them. The first explanation has to do with the physical properties of the PTW: the small size of the PTW compared to cars makes it less conspicuous and judging of distance and speed with a small frontal area or with only one headlight is difficult. Other explanations are of a psychological nature. Because of the small number of PTWs in traffic, car drivers do not expect to meet a PTW and are therefore less prepared to notice or recognise a PTW. PTWs seem to lack relevance to most car drivers. Wulf even suggests that a car driver is inclined to ignore the presence of a PTW since the impact of a collision with a PTW is less threatening than with a car.

To a certain extent these problems are made worse by the behaviour of the PTW riders such as overtaking in situations where cars cannot do this and high speeds. Other road users may not look for PTWs in places where they do not look for cars and they do not anticipate higher speeds and shorter approach times than for cars.

More fundamental research on the perception of objects has shown that attention may be drawn through physical properties and or through the relevance these objects have for the

observer. The lack of relevance of PTWs for car drivers has not been studied directly, but is illustrated in a study by Magazzu et al. (2006). The results of the MAIDS case control study were used to obtain 740 cases of a collision between a car and a PTW, together with an expert judgement if the rider or car driver was at fault. After correction for other factors such as age and experience of the car driver it was found that car drivers who also held a motorcycle licence were less likely to be at fault than car drivers without this licence. The possession of a motorcycle licence is an indication of interest in and experience with riding a motorcycle, which may have helped in the detection of an oncoming PTW and the prediction of its manoeuvre.

6.2 Factors related to the vehicle

The effect of engine performance on safety is not fully understood; the relation between engine power and accident rate is not a simple one. And engine cubic capacity is not a very good indication of motorcycle performance and its associated accident rate. In practice the relation is further complicated since different groups of PTWs are used by different groups of riders with different accident rates.

- Accident rates differ between different types of PTW.
- Mopeds with their small engine and restricted top speed have accidents with less severe injuries than motorcycles, which results in lower fatality rates. Including less severe injuries results in rates that are not much different from or even higher than for motorcycles.
- There is little known about the accident rate of 125cc motorcycles.
- Sports motorcycles have been found to have higher accident rates than other types of motorcycle. Power to weight ratio is probably a better indication of performance and more strongly related to the accident rate of sports motorcycles than cubic capacity. A higher accident rate for these motorcycles, even if corrected for age and experience of the rider, does not automatically mean that the type of motorcycle is more difficult to control and therefore less safe. It is quite possible that they are used by riders with a different style of riding. There is no knowledge on the accident rate of scooters either as moped or as motorcycle. This is unfortunate because their number on European roads is increasing.
- Braking on a PTW is difficult and loss of control in emergency situations often occurs.

6.2.1 Engine performance

At first sight the engine power seems to be the most important of all PTW properties in relation to safety. There are several studies on this subject with mixed results. The idea is that a heavy and powerful PTW is difficult to control even at low speeds and may invite riders to test the potential acceleration and/or top speed, which brings them in situations which are difficult to control. This means that it is not necessarily the character of the PTW itself, but the experience and motivation of the rider which determine the safety of the rider-PTW combination. In addition, heavy or powerful PTWs may be used more in conditions which differ from smaller PTWs and these conditions themselves may be related to the safety of PTW use.

Cubic capacity

A study with accident data from 1984-1986 in Great Britain (Broughton, 1988) covers the whole range of engine (cubic) capacity. The kilometre data came from a travel survey of 372 riders. Accident rates per million kilometres were found to be related to the age of the rider and traffic conditions as well as to engine capacity. Riders of 16-18 years had fatality rates

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which were about four times higher than for riders of 30 years and older, after correction for conditions (built-up or non-built-up) and engine size. The age difference was even stronger for less severe injuries. The fatality rate for non-built-up roads was about one third higher but the rate for less severe injury about half that for built-up roads. This is an indication of more accidents on built up roads (corrected for kilometres) but with much less severe injuries. After correction for age of the rider and traffic conditions, the fatality rate for the 50cc PTW was lowest and highest for PTWs with engines of more than 250cc, with the fatality rate for 125cc in between. Including injuries resulting in hospital admission produced a rate which is a little higher for 125cc machines with little or no difference between the other engine capacities, i.e. both 50cc and over 125cc. It must be remembered that in this study most riders of 125cc PTWs had a provisional license. Problems with the interpretation of these results are the small sample of the travel survey and the absence of information on the experience of the PTW riders. The study is rather dated and today's motorcycles in general have bigger and more powerful engines.

The "Handbook of road safety measures" (Elvik & Vaa, 2004) refers to a Norwegian study by Ingebrigtsen (1990) which corrects for age, experience and other factors, including a measure to take risk. The study found no substantial increase in accident rate with increasing cubic capacity.

A more recent New Zealand study used 463 accident cases from 1993-1995 and 1233 controls in a case control design (Langley et al., 2000). The relative accident rate was corrected for age and experience of the rider and other factors and was found to be somewhat lower for motorcycles under 250cc, with no clear relation between cubic capacity and relative accident rate for motorcycles over 250cc. The authors conclude that if cubic capacity is used as basis to restrict motorcycles of novice riders the limit should be substantially lower than 250cc and power to weight ratio or motorcycle type may be a better basis.

Power to weight ratio

The cubic capacity of the engine may not be the best indication of the potential acceleration and top speed. An Australian study (Rogerson et al., 1992) used power to (laden) weight ratio for the motorcycle and focussed on novice riders. There were 2.247 novice riders involved in casualty accidents in 1987-1990 (learners: 1.356 and first year license holders: 891). The age limit to obtain a license was 18 years. The sample of motorcycles was compared with registered motorcycles. The accident rate (corrected for estimated kilometres) shows a strong relation with power to weight ratio, with four times higher rates for the most powerful motorcycles compared to the least powerful. The study did not correct for age of the rider, but many of the novices must have been young. It has to be remembered that learner riders were restricted to motorcycles with engines up to 260cc.

6.2.2 Type of PTW

There is a study with a case control design with samples from mostly urban areas in five European countries: France, Germany, the Netherlands, Spain and Italy (MAIDS, 2004). The accident sample for 1999-2000 contained 398 mopeds and 523 motorcycles, which were compared with 923 control cases. The report states that there is no difference between the accident and control cases with regard to age of the PTW rider, moped versus motorcycle and scooter versus other PTW. Young moped riders and scooters with mostly young riders are

compared with mostly older motorcycle riders. Unfortunately, this does not allow conclusions to be drawn for these factors separately.

Mopeds

Mopeds with their small engine and restricted top speed can be expected to have a lower accident rate than motorcycles. But this is not evident from the actual figures. They have accidents with less severe injuries than motorcycles, which results in lower fatality rates. Including less severe injuries results in rates that are not much different from or even higher than for motorcycles. There are some remarkable differences between countries. A report comparing the traffic safety in the United Kingdom, Sweden and the Netherlands discusses the difference in moped accident rates (Sunflower). This rate (over all ages) for the Netherlands is almost double that for the other two countries. In the United Kingdom the moped is much less popular than in the Netherlands but the average kilometres per moped per year in the United Kingdom is about double that in the Netherlands. Therefore, the use of the moped must be quite different. In the United Kingdom the moped is mainly used for commuting, in the Netherlands more for social or recreational purposes and in Sweden the moped is mainly used in the summer. In Great Britain moped riders have to obtain a license after taking a basic training course and passing a test (car drivers only have to take the training course and motorcyclists are already qualified). There is also a difference in traffic conditions, which are much less dense in Sweden. All these differences may affect the overall moped accident rates. In addition, the majority of mopeds in Sweden are light mopeds with a lower maximum speed. The Netherlands have the same type of moped, but without helmet. According to Noordzij (1998) the accident rate per million kilometres (and corrected for age) for the light moped without helmet is about the same as for the faster moped.

125 cc

There is little known about the accident rate of 125cc motorcycles. At least in Great Britain they were shown to have a slightly higher rate than other motorcycles. This does not necessarily mean that this also holds for other countries. A German study presents fatality rates per 100.000 motorcycles for 1994-1999 (Assing, 2002). For all age classes these rates are lower for 125cc vehicles only than for all motorcycles. For 125cc motorcycles the age 16-19 has a fatality rate five to ten times higher than riders 25 years and older. There is no information on kilometres and the pattern of accident rates corrected for kilometres may be quite different. It is unfortunate that these rates are not known especially for the age group 16-18 and for the older drivers who are allowed to ride these motorcycles with only a car license since there are differences in legislation between countries for these groups.

Sports motorcycles

The type of motorcycle has been studied in surveys in Germany (Schulz, 1995), (Schulz, 1998). The samples were attendants of motorcycle shows. The questionnaires included questions on riding style and type of motorcycle. Only for sports motorcycles and only for riders with a sporting style the number of self-reported single vehicle accidents was higher for very powerful engines. There was no such relation for collisions with other road users.

With a different type of study design Noordzij & Vis (1998) calculated accident rates per million kilometres for three groups of riders and three types of motorcycle. 926 motorcycles involved in accidents resulting in hospital admission in the Netherlands in 1993 were combined with kilometre data from a national travel survey with 3.000 motorcyclists. The accident rate

per million kilometres for sports motorcycles was about double that for touring motorcycles regardless of age and experience of the rider. Custom motorcycles also had higher accident rates than touring motorcycles, but only for inexperienced riders. This last finding is surprising because this has not been found in other studies.

Other design elements

Other design elements of PTWs are relevant for their safety such as frame, suspension, wheels, brakes, tyres. But with today's PTWs their contribution to accidents is low. The MAIDS study found 5% accidents with vehicle failure as a contributing factor, mostly tyre or wheel problems.

6.2.3 Braking

Braking on a PTW is difficult for several reasons. With only two wheels in line the PTW may easily lose friction between tyres and road surface resulting in a fall. This is more likely during braking or cornering and even more likely during braking in a curve. The rider has to carefully apply braking force taking account of the quality of the road surface and the leaning angle of the PTW. Modern high performance motorcycles have high performance braking systems with which locking of the wheels is easy. In addition, the PTW rider has to divide the braking capacity between front and rear wheel. Most PTWs have separate controls for the front and rear wheel brakes. As a result, the total braking capacity will seldom be fully used or, when braking suddenly, the rider may lose control.

Loss of control in an emergency situation is often found in accident studies (Broughton, 2005). In a special study on the role of braking in accidents, Sporer (2002) used a sample of 502 injury accidents in 2001-2002 in Germany. 279 of the motorcyclists took action to avoid the accident, of which 54 lost control.

6.3 Factors relating to the road

In an Australian in depth study with 205 accident cases as reported by Haworth et al. (2005) 15% of the cases were found in which the road surface had contributed to the accident. In more than half of all cases some site factor (of various kinds, including lack of vision) was involved. The role of road design and maintenance in PTW accidents may vary from country to country.

The MAIDS study (2004) with 921 PTW accidents reports roadway defects in 30% of all cases. This does not necessarily mean that the defect contributed to the accidents. In a report by the European Motorcycle Industry (2006) some more results are presented. In 25 of all 921 cases a roadway maintenance defect was judged to have contributed to the accident. The total number of cases in which the road environment contributed was 72, including road design defects as well as temporary obstacles.

Both studies were based on officially reported accidents. It could well be that the role of poor road surface is more prominent in accidents that are not reported because no other road user was involved or the damage and/or injuries were minor.

Brendicke et al. (1995) present an overview of the problems of PTW riders with different road surfaces. They show the considerable, adverse consequences of poor road surface on skid resistance and thus on braking and cornering of PTWs

7 Prevention of injuries

PTWs provide little protection against injuries in the case of an accident. Injuries to the legs are frequent, but injuries to the head are more severe even though wearing a helmet. Based on knowledge of injury mechanisms there are several ways to prevent injuries:

- Helmets and clothing are devices worn by the PTW rider to provide protection in case of a collision with an object, be it the own PTW, other vehicle, road surface or fixed object. The main purpose of the helmet is to absorb energy from a direct collision of the head, whereas clothing cannot be expected to absorb much energy, but prevents direct contact of body parts.
- Studies show that head injuries would have been much more frequent if helmets had not been worn. From the point of view of preventing injuries there is no reason to exclude any group of PTW users from compulsory wearing a helmet. Wearing protective clothing would prevent many minor injuries.
- Other devices such as neck and knee braces or back protectors are specially designed for riders on a race track or off road.
- Other devices may be integrated into the design of the PTW. Accident studies show that collisions between the front of the PTW and the side of a car are frequent, with many riders falling before the collision as well as many riders departing from the PTW during the collision. Most attention to devices to prevent injuries in these cases has been given to leg protection and air bags. The purpose of such devices may be quite different: from preventing direct contact with collision objects to controlling speed and trajectory of the rider when departing the PTW during a collision. These devices are still experimental.
- Another way to prevent injuries is to equip the collision objects with energy absorbing devices or smoothing their surface. Accident studies have shown that injuries from single vehicle accidents are more severe when hitting a fixed object like a guard rail. Devices have been designed to be retrofitted to existing guard rails to prevent injuries to motorcyclists. So far the design of cars has had little attention in respect to reducing injuries of PTW riders.

7.1 Helmets

It is well known that helmets are very effective in preventing or reducing the severity of injuries to the head. A review of all (53) available studies on helmets (Liu et al., 2004) concludes that helmets are effective in reducing head injuries to motorcyclists who crash by 72%. To study this effect requires a sample of accidents with large numbers of riders with and without helmets. A recent study is from Greece where helmet wearing rates are still low (Petridou et al., 1998). This sample consisted of 143 motorcycle riders with helmet and 1764 without killed or injured in accidents. The fatality rate of riders with helmet was 44% lower than for riders without a helmet.

The main purpose of helmets is to reduce the peak and duration of acceleration of the head by absorbing energy in case of a collision. There are two types of helmet: open face and full face.

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The full face helmet provides better protection to the face and chin area but is usually a little heavier. On the basis of research, it is not possible to decide which type is better.

Tests at TRL with different energy absorbing liners and shells have shown that standard helmets have liners that are too stiff and shells that are too stiff and resilient (Hopes & Chinn, 1989). A more recent study showed that this may be correct when helmets are tested with existing standard tests. Tested with a more demanding test (which is recommended in that report) required an even stiffer shell. Anyway, this means that the design of helmets for PTW riders can be much improved. Eventually the motorcycle helmet may have a different design from a moped helmet. So far helmets for motorcycle riders and moped riders are the same and the standards for (testing) helmets make no difference between the two. From the point of view of preventing injuries there is no reason why any group of PTW users should be exempted from compulsory wearing of a helmet.

7.2 Protective clothing

Proper clothing should protect all body parts against injuries when sliding over a surface. Other requirements depending on the climate and weather conditions are protection against cold, wet or heat. Clothing should not restrict the movements of the rider. On the basis of four studies, Elvik & Vaa (2004) estimated the effectiveness of protective clothing in reducing injuries. They concluded that the use of protective clothing reduces the probability of minor injury in an accident by 33-50%. This applies to the use of gloves, boots and clothing.

7.3 Leg protection and air bags

Leg protection in the form of crash bars may only prevent injuries from direct contact in collisions of the side of the PTW with a car/object. Other forms of leg protection have been studied to prevent injuries in frontal collisions by absorbing energy and directing the trajectory of the legs. Unfortunately, these devices may change the directory of the rider in such a way that the upper parts of the body are more likely to be injured.

Experiments with air bags show that the speed of the PTW rider who departs from the PTW during a frontal collision can be considerably reduced. Such devices are tested in full scale collision tests in which a moving PTW with a dummy rider collides with a moving or stationary car. The accelerations and loads on parts of the dummy are recorded and translated into injury patterns. The resulting injuries will depend on the speed of the PTW, the type of PTW, the seating position of the rider, the angle and point of collision with the car and the type of car. Only a limited number of these variables have been included in such tests. For this reason, it is difficult to decide how effective devices such as airbags or leg protectors are in practice. It seems that a combination of such devices will be needed to prevent injuries in a number of types of collision and to avoid that devices are beneficial in one type of collision but have adverse effects in others, or are effective in preventing one type of injury but introduce others. These devices are not likely to have much effect on loss of control accidents.

Most tests have been done with a motorcycle at a speed of about 60 km/h. It would be interesting to know the results of tests with scooter or step through types of moped.

The experiments with air bags are based on the idea that reducing the speed and controlling the trajectory of the PTW rider during a collision is preferable to fixing the rider to the PTW. A departure from this idea is made in the design of one particular type of PTW (Kompass et al., 1998). In this case the PTW is designed as a safety cell which largely protects the rider from direct contact with collision objects among other things by means of a roof frame and seat belts. Tests showed positive effects with several types of collision.

7.4 Guard rails

Guard rails have been designed to prevent cars from colliding with obstacles behind the rail. They absorb energy and control the trajectory of the vehicle in collision with the rail. Existing rails have not been designed for collisions by PTWs and may cause severe injuries to their riders.

The first studies on collisions of PTWs with guard rails have concentrated on the design of the rail post as a short term, low cost solution. A recent German study tested several guard rail designs intended to reduce injuries to motorcycle riders (Gärtner et al., 2006). The full scale collision tests showed two problems: a motorcycle sliding against the rail with the rider hitting the rail post and/or sliding under the rail and an upright motorcycle with the rider hitting or being trapped by the upper part of the rail. The experimental devices were designed to be retrofitted to existing rail designs. The test results showed the devices to be effective in preventing injuries to the rider and in controlling the trajectory of the motorcycle. They have not been tested yet in collisions by a car.

The costs of fitting these devices can be reduced by selecting road sections where collisions by motorcycles is more frequent, i.e. in tight curves in rural areas (Domhan, 1987).

8 Prevention of accidents

Measures to prevent PTW accidents are based on knowledge of the accident characteristics and of factors contributing to accidents. Measures to prevent accidents are directly or indirectly aimed at the riders, the vehicles, other road users, the road environment or a combination of these.

Licensing, testing and training are related measures directed at the riders as well as defining access to categories of PTW. Little evidence exists of the effect of current licensing systems in improving safety. One future option is to introduce a more graduated system.

Braking on a PTW is difficult and loss of control in an emergency situation is often found in accident studies. Some of these can be prevented with ABS/CBS brake systems on motorcycles but they are still too expensive to be fitted to all PTWs and depend on their effective use by riders.

Conspicuity devices are worn by riders or are part of the vehicle. Most research has focused on the potential role of daylight running lights.

Enforcement and promotional campaigns may be directed at PTW riders as well as at other road users.

Measures aimed at the road environment may directly prevent accidents or act through their influence on the behaviour of road users. Variations in road surface can cause particular problems for PTW riders.

Work on E-safety systems has mainly been directed at cars and Lorries but the potential to improve motorcycle safety through ITS is now being explored.

8.1 Learning, testing and licensing

Learning, testing and licensing of PTW riders are related subjects. Together they form a system to make sure that all riders have an acceptable level of competency. This competency requires sufficient mental maturity and has to be learned by training and experience. Given the characteristics of a PTW and their high accident rate, it is obvious that riders need a high level of competence both in terms of vehicle control and in terms of safe interaction with other road users.

During training and practising riders have to learn where and when to take action to avoid a situation in which there is little or no time left to avoid an accident. In most situations riders will react in time with a gradual change in speed and/or direction, but sometimes more extreme changes are needed and in an emergency situation only a change at the limit of losing control is needed to prevent an accident.

During learning riders will improve their control of the PTW when accelerating, braking, changing direction at different speeds and on different sorts of road surface. As a result, situations that are close to resulting in an accident at an early stage of learning may not be so later on. The aim of training programs is to improve the competency of riders in order to reduce their accident rate. But a program may have adverse effects depending on the motivation of the applicants. More experienced riders may willingly start actions (like overtaking, cornering at high speed) which are close to their limit of losing control.

There is a recent review on licensing and training of motorcycle riders from Australia (Haworth & Mulvihill, 2005). The review emphasises that there is no convincing evidence of the effect of licensing systems and very little of elements of such systems. The review presents an optimal motorcycle licensing and training model. The model is based on the concept of gaining experience in low risk situations before graduating to higher risk situations. According to the review this requires that potential riders should gain experience driving a car before they start learning to ride a motorcycle. The model specifies a learner stage, a provisional stage and a full license stage with both a minimum and maximum period for a learner license and a minimum period for holding a provisional license. Off road training and testing is needed to obtain a learner license aimed at acquiring skills for unsupervised riding. On road training and testing is needed for a provisional license aimed at improving ability to detect and respond to physical hazards as well as hazards associated with other road users. Both stages also have restrictions on power to weight ratio of the motorcycle, on carrying of passengers and a zero alcohol level. Fully licensed riders are retested on road each ten years.

Such a system of graduated licensing is expected to reduce the number of motorcycle accidents because:

- Young riders are not allowed to ride a motorcycle
- Learning and gaining experience is restricted to low risk conditions
- Licensed riders are more competent (as compared with other systems)
- Some potential riders are discouraged to obtain a motorcycle license

The Australian review does not address the licensing of moped riders or the voluntary advanced training of fully licensed riders.

There are current proposals to change the European Directive on licensing. This increases the age access for some types of PTW but generally does not apply graduated licensing principles, and includes some aspects which may increase the likelihood of motorcycle accidents.

The potential to introduce hazard perception as part of the motorcycle test is also the subject of recent research. Such training might also be achieved through voluntary advanced training programmes. Specific training programmes for moped riders might also be considered.

8.1.1 European directive on licensing

Most European countries are subject to the EU Driving Licence Directive, and will follow the requirements for licensing and testing according to Directive 2006/126/EC which was implemented in 2013, although with some variations according to the subsidiary principle. This European Directive on licensing increases the age access for some types of PTW but generally does not strictly apply graduated licensing principles dealing with progressive access to more powerful motorcycles.

The Directive has detailed requirements relating to the theoretical test, special manoeuvres test and the on-road testing for the following categories:

- Category AM: Moped with design speed of max. 45km/h, minimum age of 16 years (countries may vary between 14 and 18), compulsory theoretical test or motorcycle/car license instead (countries may require practical test or motorcycle license instead).
- Category A1: 125cc motorcycle, with max. 11kW and 0.1kW/kg, minimum age 16 years (countries may vary to 18 years), compulsory theory and practical testing or other motorcycle license instead.
- Category A2: 35kW motorcycle, with max. 0.2kW/kg, age limit two years more than for 125cc (i.e. at least 18), compulsory theory and practical test or two years 125cc license plus practical training/test instead.
- Category A: Unrestricted motorcycle, with age limit of 24 years and compulsory theoretical and practical test, or two years 35kW license plus practical training/test instead.

The most striking differences with the optimal training and licencing model proposed by Haworth & Mulvihill (2005) are: no car license required, low age limit for a 125cc license, absence of unsupervised and restricted riding to gain experience, possibility of direct access to 35kW and to unrestricted motorcycle. The requirement of a car license has several effects on accidents. Experience in real traffic is gained in a car which is safer than on a motorcycle and motorcycle riding is delayed or possibly given up. There is no question that a higher age limit will result in less accidents and in this respect an age limit for moped riders of 18 is much better than 16 or 14 and an age limit of 18 years for 125cc motorcycles is better than 16. The

European system is not a graduated system in the strict sense. It may be hoped that potential riders will start riding on a moped or 125cc motorcycle but from 18 years they have direct access to a 35kW motorcycle and from age 24 to an unrestricted motorcycle. The adverse effects of immaturity may be minimised with these age limits. But a system with direct access to high powered motorcycles is more likely to produce accidents during the first years of riding than a truly graduated system unless the quality of training for direct access is at an exceptionally high level.

In western European countries it is common to allow on-road training only if supervised by a qualified instructor. Great Britain differs with compulsory training at 17 years, followed by maximum period of two years of unsupervised riding on a 125 cc motorcycle with a "L" plate and no pillion passenger allowed. After passing a theoretical and practical test the rider is then licensed to ride a 25 kW motorcycle and after two more years to ride an unrestricted motorcycle. Again this system is not strictly graduated since it also has the option of direct access from age 21.

There is no evidence or indication which of the presently existing systems is better, supervised training by a qualified instructor or unsupervised practising on a low performance PTW. There is little doubt, however, that a better system in terms of accident prevention is a graduated system with:

- High minimum age limit (at least as high as for a car license)
- At least two stages of riding under low risk conditions on a low performance motorcycle with a combination of compulsory training and unsupervised practising
- Testing before and at the end of each stage
- No option of direct access

8.1.2 Hazard perception and responding

According to the Australian review the present tests and training programs do not adequately address rider motivation and riding style or hazard perception and responding. A traffic hazard is an element of a traffic situation with the potential of initiating an accident and therefore requiring special attention. It may be related to the road (a change in road surface, a curve) or related to the presence and behaviour of other road users. Hazard perception and responding is the behaviour in between normal and timely actions (to avoid a situation with little or no time to avoid an accident) and emergency actions (with little or no time left).

Hazard perception has been the subject of recent research, mostly in relation to car driving. Studies have shown that hazard perception can be improved by training but as yet there is no proof that this will result in safer behaviour or a lower accident rate.

Great Britain has introduced a hazard perception test as part of the compulsory testing for a license. The test consists of video presentations of traffic situations containing an indication that a risky situation might result. There is no separate test for motorcycle riders. Haworth et. al. (2005) argue that hazard perception in relation to motorcycling is different because motorcyclists have to deal with additional hazards which are road based as well as related to the behaviour of other road users in the presence of a motorcycle. Responding to a hazard is also more crucial because other road users may not respond to the motorcyclist and controlling the motorcycle trying to avoid the risky situation is difficult. The subject of hazard perception and responding is complicated because whether the situation becomes risky also

depends on the behaviour of the rider. Motorcyclists may start actions like overtaking and accepting small gaps in situations where car drivers would not do so.

8.1.3 Voluntary, advanced training programs

Many private organisations offer voluntary, advanced training programs. Their aim may differ, e.g. improving the detection and avoidance of (potential) emergency situations or improving vehicle control in difficult situations. The effects will depend on the motivation of the participants. With riders who are safety minded these programs can be expected to improve their behaviour and prevent accidents. With performance-oriented riders the result may be the opposite.

8.1.4 Moped riders

There is very little research on the licensing of moped riders. In the Netherlands the effect of an experimental practical training program has been studied (Goldenbeld, 2004). Participants had just passed the compulsory theoretical test at age 16 and were randomly assigned to the training program and to a control group. The program consisted of 16 hours off and on road training over a period of four weeks. During a 30-minute standard test ride in real traffic the riders were scored by a qualified (motorcycle) examiner who did not know which riders were trained. The training group scored better in the test ride two weeks after training. After 11 months the control group had improved as well to about the same level of competency, but the trained riders had slightly lower scores then before. Based on the results of this study a licensing system for moped riders could start with a compulsory training programme, followed by a period with a provisional license and ending with a practical training programme/test.

8.2 Braking a PTW

In a special study on the role of braking in accidents, Sporer (2002) used a sample of 502 injury accidents in 2001-2002 in Germany. 279 of the motorcyclists took action to avoid the accident, of which 54 lost control. Based on the accident records an estimate was made of cases that might have been prevented if the rider had been able to use an anti-locking brake system (ABS). 10-15 accidents would have been avoided and another 30 would have had less severe consequences since the system would have prevented loss of control and would have reduced the collision speed.

Today ABS is available for many large motorcycles and scooters, and the European Commission in 2012 decided that fitment with ABS for all new motorcycles above 125cc will be mandatory from 1 January 2016. There are various systems with ABS on front wheel only or on both wheels with separate or combined control of both wheels. A combined braking system (CBS) automatically distributes the braking force between front and rear wheel. These systems are also available without ABS, but these will not prevent locking of the wheels when braking too hard.

Even ABS is no guarantee for successful braking in an emergency. Braking in a curve produces forces on the steering system which have to be corrected by the rider. For this reason, the full potential of ABS cannot be used at the same time. Also riders have to learn to use the full potential of ABS when riding in a straight line.

8.3 Conspicuity devices

Research has mainly focussed on the potential benefit of daytime running lights. Although it is clear that the perception of a PTW is much improved by the use of a PTW headlight during the daytime this is only a partial solution; many accidents still occur where the driver had not seen the motorcycle in spite of the headlight being on.

Research studies show that the use of daytime running lights by cars has no adverse effect on the benefits of headlight use by PTWs in most situations.

8.3.1 Daytime running lights for PTWs

Several experiments have been done on potential solutions to the problems of perception of PTWs by other road users. The effect of headlights during daytime and of clothing have been studied by Hole et al. (1996) using slide pictures and by Langham (1995) using video presentations in a similar study. At short viewing distance it did not matter whether the motorcycle headlight was on or against which sort of background the motorcycle was shown. At longer viewing distance the motorcycle was noticed better with headlight on against a complex background. The effect of bright clothing also depended on the type of background. In another experiment Hole & Tyrrell (1995) found that the more pictures were shown in which other motorcycles had headlights on, the less likely a motorcycle without headlight was to be noticed.

These experiments will never fully reproduce the natural behaviour of car drivers in real traffic i.e. their strategy to scan the road for other road users who may be relevant to them. But the assumption is made that if one condition (e.g. headlight on) is found to be better than another (e.g. dark clothing) this will be the same in real traffic.

The effects of headlights and clothing in practise have been studied in a case control study in New Zealand (Wells et al., 2004) with 463 accident cases from 1993-1995 and 1233 controls. The relative accident rate was corrected for other factors such as age and experience of the rider and found to be 27% lower for motorcycles with headlight on during daytime and 37% lower for riders with reflective or fluorescent clothing.

Bijleveld (1997) used accident statistics from Austria and calculated a saving of 35% of collisions between car and motorcycle during daylight after the introduction of compulsory use of headlights by motorcyclists (compared to a situation with 0% use). Elvik and Vaa (2004) included 12 studies primarily from the United States in a meta-analysis on the effects of a mandatory use of running lights. This meta-analysis showed a reduction of around 7% (+/- 3%) in the number of multiparty accidents in daylight.

Although it is clear that the perception of a PTW is much improved by the use of a headlight during daytime it is only a partial solution. Noordzij & Vis (1998) still found many accidents in which the car driver had not seen the motorcycle in time in spite of its headlight being on.

8.3.2 Daytime running lights for cars

The benefits of motorcycle headlights may be less if cars also have their headlights on. There are some experimental studies on this subject. Brendicke et al. (1994) showed pictures of traffic situations and observers had to report which vehicles they had seen. The pictures

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contained motorcycles with headlights and cars with or without headlights on urban as well as rural intersections and road sections. A closer examination of their results shows that on rural intersections motorcycles were less often noticed than cars and even less so in combination with cars with headlights.

In an experiment by Brouwer et al. (2004) observers had to report if and which other road user was present. The slides always showed a car with or without headlight. The experiment also varied the distance between car and other road user, the background, the proportion of slides with a car with headlight on and the proportion of slides with another road user. It took more time to detect a pedestrian than a pedal cyclist or motorcyclist and the detection of a motorcycle with headlight was even faster than without headlight. However, the headlight of the car had no negative effect in all situations studied.

In a field experiment (Cobb, 1992) observers in a moving car had to report which road user they had seen at an intersection. There was always a car alone or together with a pedal cyclist or a motorcycle with headlight on. Observers always noticed the pedal cyclist and motorcycle except when the car had very bright headlights on.

The conclusion from these experiments is that the use of headlights during daytime by cars has no adverse effect on the benefits of headlight use by PTWs in most situations, except when the car headlights cause glare. This conclusion is confirmed by Koornstra et al. (1997) with accident statistics from Norway and Denmark where compulsory use of headlights was introduced for cars some years later than for motorcycles. An increase in collisions between car and motorcycles during daylight was insignificant.

All studies were concerned with motorcycles rather than mopeds, but the perceptual problems are likely to be the same and the use of headlights during daytime by mopeds and the wearing of fluorescent/reflective clothing is a partial solution to them as well.

Another contribution to solve the problems of perception of PTWs may be found in more attention to these problems in the training of car drivers.

8.4 Enforcement of legislation

A license system needs enforcement to prevent the use of PTWs by unlicensed riders. Haworth & Smith (1998) found a group of Australian riders without valid license with a relatively high accident rate. Other subjects that may need enforcement are speed limits, drinking, tampering of the engine and helmet wearing.

The actual need for enforcement programs will depend on the proportion of riders in violation of the law. This may vary between countries.

8.5 Promotional campaigns

Several subjects are eligible for promotional campaigns to prevent PTW accidents and injuries:

- Wearing helmets and protective clothing
- Headlights on and wearing fluorescent/retroreflective clothing

- Avoiding risky behaviour and situations
- Attention from car drivers to the presence and behaviour of PTW riders

8.6 Road environment

The quality of the road surface is much more important for the safety of PTWs than for cars. Poor condition of the road surface or small objects on the road are likely to cause loss of control of a two wheeled vehicle.

The European Motorcycle Industry has prepared “Guidelines for PTW safe road design in Europe” (ACEM, 2006). This is an inventory of aspects that are relevant for (the safety of) PTWs with attention to road design, road maintenance, traffic engineering and traffic management.

Particular problems in view of PTW safety are:

- All kinds of speed inhibitors in urban areas with different types of road surface, speed humps, lane narrowing's etc.
- Use of raised lane markings and lane dividers
- Poor maintenance and temporary road repairs

8.7 E- safety

Technical developments have sparked off a complete new field of potential countermeasures, which aim to assist the rider, to control the vehicles, to regulate the access to vehicles, and to monitor behaviour. These so-called ITS systems are mainly developed for implementation in passenger cars and lorries. Bayly et al. (2006) reviewed the literature on the availability and effects of ITS systems on motor cycle safety. They concluded that almost no systems are available for motorcyclists, and that very little evaluative studies exist.

To fill this gap in knowledge, several major projects, funded by the European Commission, have focused on the capacity to enhance vehicle safety with electronic devices. The PISa project (2008) aimed to develop and implement "reliable and fail-safe" integrated safety systems for a range of PTWs, to improve the performance and primary safety (handling and stability) and that can link to secondary safety devices. The SAFERIDER (2008) project aimed at studying the potential of integration of advanced information and assistance systems on motorcycles and at developing rider-friendly interfaces. The ROSA project (2011) developed a Handbook on Good Practices in Safety for Motorcycles, with a specific volume dedicated to the vehicles. The recent RIDERSCAN project (2015) presents the existing knowledge on PTW safety, including ITS. These projects give indications on the potential to be gained by developing and implementing intelligent transport systems, and also on some of the challenges when considering the specificity of PTWs (e.g. the question of Human-Machine Interface, the risk of interference with riders' actions, the problem of stability, etc.). More information can be found on the respective websites of these projects.

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Notes

1. Country abbreviations

	Belgium	BE		Italy	IT		Romania	RO
	Bulgaria	BG		Cyprus	CY		Slovenia	SI
	Czech Republic	CZ		Latvia	LV		Slovakia	SK
	Denmark	DK		Lithuania	LT		Finland	FI
	Germany	DE		Luxembourg	LU		Sweden	SE
	Estonia	EE		Hungary	HU		United Kingdom	UK
	Ireland	IE		Malta	MT			
	Greece	EL		Netherlands	NL		Iceland	IS
	Spain	ES		Austria	AT		Liechtenstein	LI
	France	FR		Poland	PL		Norway	NO
	Croatia	HR		Portugal	PT		Switzerland	CH

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3. All Traffic Safety Syntheses of the European Road Safety Observatory have been peer reviewed by the Scientific Editorial Board composed by: George Yannis, NTUA (chair), Robert Bauer, KFV, Christophe Nicodème, ERF, Klaus Machata, KFV, Eleonora Papadimitriou, NTUA, Pete Thomas, Un.Loughborough.

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