European Commission

European Road Safety Observatory

Road Safety Thematic Report - Fatigue

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

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Summary

Fatigue in road traffic

Fatigue has different causes. A distinction is often made between sleep-related fatigue and task-related fatigue. Given the many causes, almost everyone is tired sometimes. Consequently, fatigued driving is fairly common. For example, in a large-scale international survey between 20 and 25% of the car drivers indicated that, during the last month, they had driven at least once while they were so sleepy that they had trouble keeping their eyes open. Fatigued driving is relatively common among (international) truck drivers, people working in (night) shifts, young men, people with untreated sleep problems/disorders. Taxi drivers are also seen as a specific risk group for fatigued driving.

People who are tired tend to be less attentive and react less quickly and less adequately (e.g., more steering movements, more variation in speed and headway distance). Fatigue also affects mood and thus behaviour: tired people tend to get irritated and frustrated more easily. It is estimated that driver fatigue is a contributing factor in 15 to 20% of serious crashes, though the results of individual studies vary widely. Shares are higher for crashes involving trucks, for fatal crashes and for motorway crashes. When driving while fatigued, the risk of a crash increases considerably. A meta-analysis of 14 studies showed an increase in crash risk of 29% for fatigued drivers compared to those who were not fatigued.

Countermeasures

Almost all drivers acknowledge the dangers of driving while fatigued. Most drivers also recognise the signs of fatigue, but often this does not effectively prevent them from driving. They do tend to take actions to counteract fatigue, but these are generally less effective actions such as opening a window or talking to a passenger. More effective responses include taking a nap or asking a passenger to drive, but these are much less common.

Since it is difficult to quantify fatigue objectively, it is not possible to set and enforce legal limits for fatigued driving. For truck and bus drivers, driving time and rest period regulations can help prevent fatigue, provided that companies and drivers comply with these rules. Company fatigue management programmes emphasise the employer's key role in setting fatigue-proof working conditions and informing employees. For non-professional drivers, education and information campaigns can help raising awareness of the problem of fatigue, but behavioural effects are likely to be limited.

In terms of infrastructure, the provision of sufficient locations and facilities allowing truck and car drivers to take a rest can help to prevent fatigued driving. Other infrastructure countermeasures can help to mitigate the consequences of fatigued driving, e.g., rumble strips to prevent running off the road. New vehicle technologies are promising, but the overall effects are still unknown. Automatic fatigue detection systems aim to warn drivers when they get tired. Advanced driving assistance systems (ADAS), e.g., lane keeping systems and forward collision warnings, aim to prevent the consequences of fatigued driving such as running off the road or colliding with a vehicle in front. The new EU Regulation on type approval requirements for motor vehicles makes a driver drowsiness and attention warning system mandatory for all vehicle categories.

1 Highlights

- Fatigued drivers tend to react less quickly and less adequately and get irritated and frustrated more easily;
- Fatigued driving is fairly common, especially among truck drivers, night shift workers, young men, people with sleeping disorders and taxi drivers.
- It is estimated that driver fatigue is a contributing factor in 15 to 20% of serious road crashes.
- Fatigue-related crashes are often serious if the driver has fallen asleep, because the impact speed is high as brakes are used too late or not at all.
- For professional drivers driving time and rest period regulations in combination with fatigue management programmes can help to combat fatigue.
- For all drivers, automatic fatigue detection and advanced driver assistance systems are promising developments, but their safety effects are still unknown.

2 What is the problem?

2.1 Definition

Fatigue is a broad concept. The term is often used interchangeably with concepts like tiredness, drowsiness and sleepiness. There is no single definition. Phillips (2014) lists a wide variety of definitions of fatigue in traffic used in the literature, showing that fatigue has subjective components, physiological components, performance-related components and combinations of these - examples all cited by Phillips (2014):

- Subjective, e.g., “an overwhelming sense of tiredness, lack of energy and a feeling of exhaustion, associated with impaired physical and/or cognitive functioning” (Shen et al., 2006).
- Physiological, e.g.,“… a change in psychophysiological state due to sustained performance [of one or more tasks at work]” (Van der Linden et al., 2003).
- Physiological and performance, e.g., ”…. inability to function at the desired level due to incomplete recovery from demands of prior work and other waking activities. […]” (Gander et al., 2010).
- Performance, e.g., “a diminished capacity for work and possibly decrements in attention, perception, decision making and skill performance” (Cercarelli & Ryan, 1996).
- Multiple, e.g. “A psychophysiological state that occurs when a person is driving and feeling tired or drowsy, to the extent that they have reduced capacity to function, resulting in performance decrements and negative emotions and boredom as they attempt to stay awake during the task” (Craig et al., 2011).

2.2 Causes

Fatigue has different causes. A distinction is often made between sleep-related fatigue and task-related fatigue (May & Baldwin, 2009). Sleep-related fatigue is caused by:

- ongoing or once-only sleep deprivation;
- poor sleep quality due to interruptions, too much noise, being too hot etc.;
- sleep disorders such as sleep apnoea and narcolepsy; other health disorders affecting the amount or quality of sleep;
- being up and active at times when the body wants to sleep (biological clock).

Task-related fatigue is caused by

- physical or mental activity over long stretches of time (time-on-task);
- performing too many or too complicated tasks over long stretches of time (excessive workload);
- performing too few or too simple tasks over long stretches of time (too low workload).

To what degree these circumstances lead to fatigue, or to what degree fatigue manifests itself, depends on several other factors, such as physical condition, age and ambient temperature (Van Schagen, 2003).

2.3 Effects of fatigue

People who are tired are less attentive and will react less quickly and less adequately than people who are not tired (Van Schagen, 2003; Phillips, 2014). Fatigue also affects mood and thus behaviour: tired people get irritated and frustrated more easily (Brown, 1994; Phillips, 2014).

A lot of research has been done into the effect of fatigue on driver behaviour. Most of these studies have been done by means of computer tasks or driving simulators in laboratories (Gastaldi, Rossi, & Gecchele, 2014; Filtness & Bean, 2018); some of them, however, in actual traffic (for example Zhang et al., 2016). For these studies, people are kept awake for a long time to attain sleep deprivation or they have to continue driving for a long time.

The effects may thus be summarised:

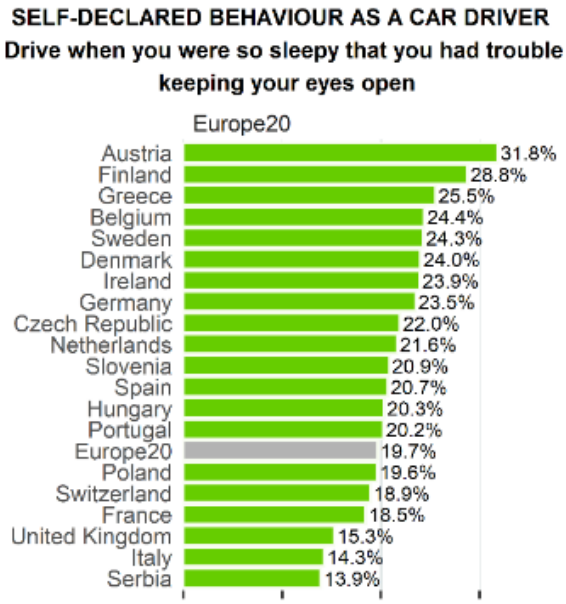
- slower reaction times;
- less accurate steering, more swerving;
- wider variations in headway distance and speed.

There are some indications that drivers try to compensate for fatigue effects by complicating the driving task through higher speeds and shorter headway distances (Hargutt et al., 2000) or, contrarily, in more severe cases of fatigue, by applying wider safety margins through lower speed and longer headway distances (Hargutt & Krüger, 2000; Van der Hulst, Meijman & Rothengatter, 2001).

3 What is the prevalence of fatigue in traffic?

Almost everyone is tired sometimes, due to a short or poor night's sleep for instance. Consequently, fatigued driving is common. A large-scale international survey (the E-Survey of Road users' Attitudes – ESRA) asked car drivers about driving while fatigued. In Europe, on average, around 20% of the car drivers reported that during the last month they had driven at least once while they were so sleepy that they had trouble keeping their eyes open (Goldenbeld & Nikolaou, 2019 – see graph below). This survey also indicated that fatigued driving is most common among male drivers and young drivers (18- to 34-year olds). Countries show substantial differences in self-reported prevalence.

Figure 1. Self-reported fatigued driving. Source: ESRA survey, Goldenbeld & Nikolaou, 2019.



A questionnaire study among Dutch drivers (Goldenbeld et al., 2011) showed that 4% had fallen asleep behind the wheel in the previous year. Compared to car drivers, truck drivers more often appear to be very tired or to (almost) fall asleep while driving . Results from various surveys show that over 50% of long-haul drivers had fallen asleep at the wheel at some time (ETSC, 2001).

Information about the prevalence of fatigue is generally based on questionnaire studies and therefore on self-reported data. Objective and large-scale measuring of fatigue while driving is practically impossible.

4 How dangerous is fatigue?

4.1 Share of fatigue-related crashes

It is estimated that, overall, driver fatigue is a contributing factor in 15 to 20% of crashes (SWOV, 2019). This range concerns more serious crashes. In general, shares are higher

for crashes involving trucks (ETSC, 2001; McKernon, 2008; Goldenbeld et al., 2011) and for fatal and motorway crashes (Moradi, Nazari & Rahmani, 2018).

The estimates in individual studies vary widely - from as low as 5% to up to 50%, mainly due to differences in definitions and research methodology used to determine whether a crash involved driver fatigue (Dawson et al., 2018).

The lowest shares originate from analyses of **police-registered** crash circumstances. Police seem to hardly ever register fatigue as a specific accident factor, probably because it is hard to ascertain objectively. Should a driver have been tired, then this fatigue will mostly be masked in the aftermath of a crash. Neither is it likely that the driver involved will voluntarily admit having been very tired or having fallen asleep.

The highest shares of fatigue-related crashes generally originate from studies that examine whether a crash was related to fatigued driving based on **crash characteristics**. A fatigue-related crash has a number of specific characteristics (no skid marks for instance – see Section 4.3 *Typical fatigue-related crashes*). If some of the specific characteristics apply to a crash, it will be qualified as (probably) caused by fatigue. Countries often use different criteria for determining if a crash is related to fatigue (Dawson et al., 2018).

The involvement of fatigue in crashes is also studied by means of **questionnaires** in which crash-involved drivers are asked whether fatigue contributed to the crash. These questionnaires are usually anonymous, meaning that there is probably no strong bias due to socially acceptable answering. If based on this type of study, the estimated shares of fatigue-related crashes are somewhere in between the estimates based on police reports and crash characteristics.

4.2 Crash risk

In general, the risk of a crash increases considerably when the driver is tired. Again, methodologies to determine the risk, and thus the individual study results, vary widely (Talbot & Filtness, 2017). A 2018 meta-analysis of 14 studies (Moradi, Nazari & Rahmani, 2018) found an odds ratio (OR) of 1.29, meaning that the crash risk when driving while fatigued is 1.29 times the crash risk when driving while not fatigued. This is a best estimate: with 95% certainty the OR is between 1.24 and 1.34). A Naturalistic Driving study (Dingus et al., 2016), not included in the meta-analysis, reported a substantially higher risk: an OR of 3.4 with a 95% confidence interval between 2.3 and 5.1. In this study, more than 3,500 drivers were monitored during everyday trips in different parts of the USA.

Some groups of road users have a higher chance of being fatigued in traffic and, hence, of being involved in a fatigue-related crash. This relates to the circumstances of their traffic participation, to physical aspects, lifestyle and combinations of these factors. Groups that are relatively often involved in a fatigue-related crash are (SWOV, 2019):

- (international) truck drivers;
- people working in (night) shifts;
- young men;
- people with untreated sleep problems/disorders;

- taxi drivers.

Sleep disorders notably include obstructive sleep apnoea (temporary respiratory arrest while sleeping) and narcolepsy (tendency to suddenly fall asleep, also by day). If these disorders are not treated, they will lead to excessive daytime sleepiness (EDS) even after sufficient nighttime sleep and thus to an increased risk of a fatigue-related crash (Smolensky et al., 2011). A review by Talbot and Filtness (2016) suggests that drivers with untreated sleep apnoea are two to three times more likely to be involved in a crash with the risk of truck drivers with apnoea being potentially higher still. The prevalence of sleep apnoea is estimated to be between 3% to 7% of the general adult population (Talbot & Filtness, 2016). If sleep apnoea is treated successfully, crash risk can be reduced substantially (Tregear et al., 2010).

Sleep apnoea often goes hand in hand with being overweight. Obesity, and thus sleep apnoea, is relatively common among truck drivers (Sieber et al., 2014; Wiegand, Hanowski & McDonald, 2009) and taxi drivers (Lim & Chia, 2015).

Proof of over-representation of **taxi drivers** is circumstantial. An Australian study (Fletcher & Mitchell, 2011) shows that this group has a higher crash risk. The researchers suspect that fatigue is an important factor because of the nature of their work (long shifts, also after midnight). A Chinese study (Meng et al., 2015) reaches similar conclusions based on questionnaire outcomes.

4.3 Typical fatigue-related crashes

In general, a fatigue-related crash has some of the following characteristics (Horne & Reyner, 2001; Dawson et al., 2018):

- The vehicle ran off the road or bumped into a (stationary) car in front/object.
- The crash occurred on a high-speed road.
- The crash occurred between midnight and dawn.
- There were no skid marks.
- The driver had a clear view of the road.
- There were no passengers in the vehicle.
- There were no other plausible explanations (such as alcohol use or indisposition).

In general, the outcome of asleep-behind-the-wheel crashes is serious, because the impact speed is high as brakes are used too late or not at all.

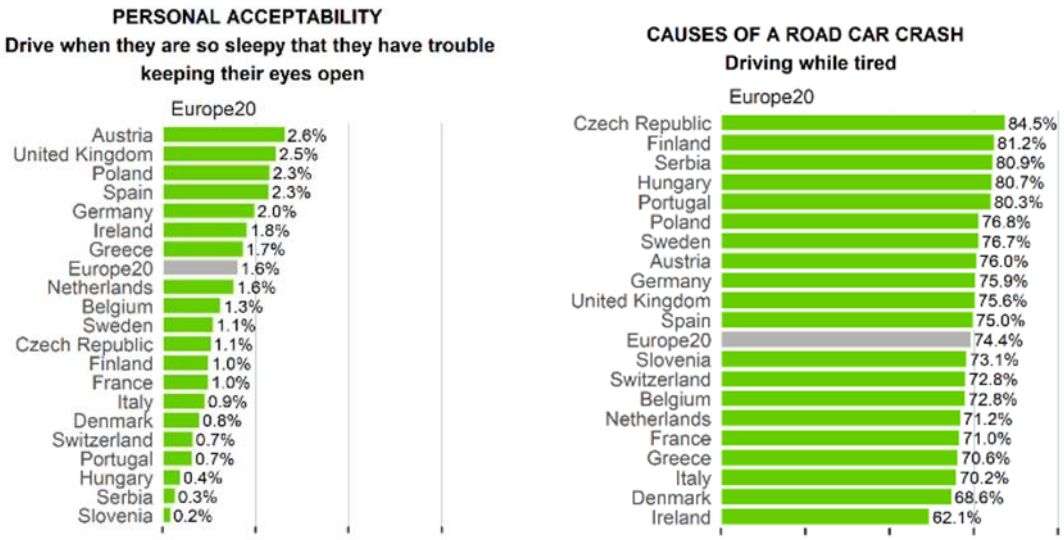
5 Why do road users drive while fatigued?

The vast majority of drivers acknowledge the dangers of driving while fatigued. According to the outcomes of fatigue-related questions in the international ESRA survey (Goldenbeld & Nikolaou, 2018 – see graphs below), only a very small share of the car drivers (generally, 1% to 2%) consider fatigued driving acceptable and around 70 to 80% consider ‘driving while tired’ to (very) often be the cause of a road crash. In general,

young drivers and male drivers are somewhat less worried about fatigued driving than older drivers and female drivers, although the differences are small.

Drivers are well able to recognise the signs of being fatigued (Williamson et al., 2014). Nevertheless, often this does not effectively prevent them from starting or continuing to drive. This is shown, for example, by questionnaire studies in Norway (Nordbakke & Sagberg, 2007) and in the Netherlands (Goldenbeld et al., 2011). Car drivers take yawning, loss of concentration, and not being able to keep their eyes open as the most important indications of fatigue (mentioned by respectively 70%, 43% and 38% of the nearly 2,000 respondents in the Dutch study). Yet, in practice, not all car drivers take adequate actions. In the Dutch study, approximately 20% indicated having started or kept driving while being too tired in their own eyes. For truck drivers the percentage was 37%.

Figure 2. Driver opinions about fatigued driving. Source: ESRA survey, Goldenbeld & Nikolaou, 2019.



Taking a nap and asking a passenger to take the wheel are among the effective strategies to prevent driving while being tired, both according to drivers themselves (Goldenbeld et al., 2011) and according to research (Anund et al., 2015). They are, however, not the most common responses. Car drivers report opting for fresh air in the car (opening a window or turning on the air conditioning), talking to a passenger, stopping to eat or move around, or turning up the music (Anund et al., 2008). However, these responses are less effective (Schwartz et al., 2012). Anund et al. (2008) report that some drivers are more inclined to stop for a nap when they were fatigued than others, notably:

- drivers who have been involved in fatigue-related crashes,
- drivers who have experience with driving while severely fatigued,
- professional drivers,
- males, and
- drivers aged 46-64 years.

6 Which rules and legislation exist to combat fatigue?

Fatigue is hard to identify and measure objectively. Hence, it is impossible to set a legal limit to the degree of fatigue permissible for traffic participation, as is common practice for alcohol use. This means that there are no specific rules or regulations related to fatigued driving that apply to all road users.

For professional drivers, there is the European driving time and rest period regulation: *Regulation (EC) No 561/2006 of the European Parliament and of the Council of 15 March 2006 on the harmonisation of certain social legislation relating to road transport*[1]. This regulation applies to passenger transport and road haulage operations, both international and national, long and short distance, for employees and for self-employed drivers. It is meant to "harmonise the conditions of competition [...], and to improve working conditions and road safety."

The main rules are[2]:

- Daily driving period shall not exceed 9 hours, with an exemption of twice a week when it can be extended to 10 hours.
- Total weekly driving time may not exceed 56 hours and the total fortnightly driving time may not exceed 90 hours.
- Daily rest period shall be at least 11 hours, with an exception of going down to 9 hours maximum three times a week. Daily rest can be split into 3 hours rest followed by 9 hours rest to make a total of 12 hours daily rest.
- Weekly rest is 45 continuous hours, which can be reduced every second week to 24 hours. Compensation arrangements apply for reduced weekly rest period. Weekly rest is to be taken after six days of working, except for coach drivers engaged in a single occasional service of international transport of passengers who may postpone their weekly rest period after 12 days in order to facilitate coach holidays.
- Breaks of at least 45 minutes (separable into 15 minutes followed by 30 minutes) should be taken after 4 ½ hours at the latest.

Individual Member States have to adopt and enforce these rules as a minimum requirement.

1. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32006R0561

2. From: https://ec.europa.eu/transport/modes/road/social_provisions/driving_time_en

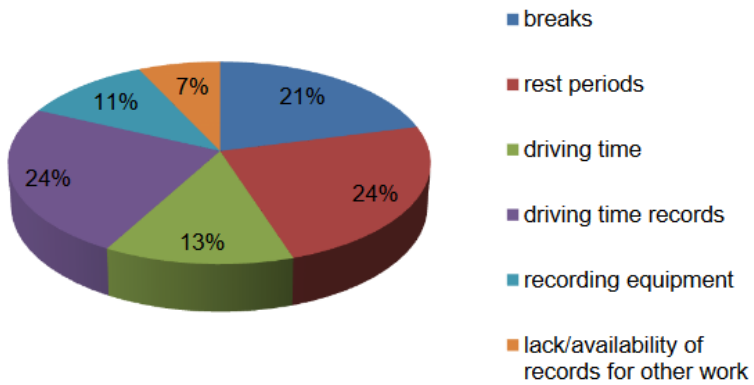
7 Which countermeasures help prevent fatigue?

7.1 Regulation/enforcement

For professional drivers driving time and rest period regulations exist (see Section 6 *Which rules and legislation exist to combat fatigue?*). Enforcement of these regulations takes place through on-road checks of the on-board tachograph and through inspection of the transport company's administration. Bi-annual reports from the European Commission, based on data provided by the Member States, provide information about the enforcement efforts (number of checks) and the number and type of infringements. In 2015/2016, (European Commission, 2018b) EU-wide just over 6% of the working days were checked (ranging between Member States from less than 1% to 12%). The European Union requires a minimum of 3%. This meant that in 2015/2016 almost 132 million working days were checked. The total number of offences reported was around 3.46 million. The figure below shows the type of infringements that were reported.

Improving road safety is one of the aims of these regulations. To what extent they do indeed increase road safety is hard to ascertain. This would imply comparing road safety before and after the introduction of the regulations. Since all western countries have different forms of driving time and rest period legislation, this is virtually impossible in practice. Research into the effect of changes in existent regulations, mainly from the United States, leads to the conclusion that the effect is probably positive (Goldenbeld, 2017).

Figure 3. Categories of driving time and related offences. Source: European Commission, 2018b.



7.2 Education and information

7.2.1 Non-professional drivers

Many countries implement mass-media publicity campaigns to inform non-professional drivers about causes, effects, and symptoms of fatigue and to give advice on how to

limit fatigue effects. In general, publicity campaigns can help raise awareness of a specific road safety issue, which may have a positive effect on behaviour in the long run. However, as a stand-alone countermeasure without supporting enforcement – which in the case of fatigue is virtually non-existent – direct behavioural effects are generally limited (SWOV, 2017). In general, the effects of a road safety campaign are larger if the message is personalised and given at locations and times where the intended behaviour is supposed to be shown (Phillips, Ulleberg & Vaa, 2011).

7.2.2 Professional drivers

For professional drivers, employers have an important role to play. They should plan the work in such a way that their drivers can abide by the driving times and rest periods, and they should actively ensure drivers comply with these requirements. International drivers should have the possibility to sleep in a quiet and cool environment, e.g., by installing a stand-alone air-cooling system that works without the motor running. In this, self-employed drivers have their own responsibility. Moreover, employers should inform their drivers about causes and consequences of fatigue. As far as the onset of fatigue is concerned, the impact of drivers' individual circumstances (lifestyle) and their own responsibilities should not be forgotten. Finally, screening drivers for (untreated) sleep disorders, particularly sleep apnoea, may be considered a company task.

Fatigue management programmes, especially in Australia and North America, are based on these starting points. Examples may be found in a special issue of the journal Accident Analysis and Prevention[3].

7.3 Road infrastructure

7.3.1 Reducing the prevalence of fatigued driving

Road infrastructure options for combatting fatigued driving are limited. An infrastructural countermeasure aimed at reducing the prevalence of fatigued driving is the provision of sufficient locations and facilities allowing truck and car drivers to take a rest while not jeopardising traffic safety or social safety.

7.3.2 Mitigating the consequences of fatigued driving

Other road infrastructural countermeasures aim at mitigating the consequences of fatigued driving. One type of countermeasure is meant to prevent running off the road which is a typical fatigue-related crash type (see Section 4.3 *Typical fatigue-related crashes*). The countermeasure mainly involves the implementation of longitudinal rumble strips to warn drivers, both auditorily and kinetically, that their vehicle is about to run off the road. Rumble strips reduce the number of single-vehicle crashes by, as a best estimate, 25% with a 95% probability that the actual reduction is between 5 and 41%, making it a cost-effective countermeasure (Elvik et al., 2009). In addition, safety barriers and obstacle-free zones are very important to limit the injury consequences of a running-off-the-road crash (SWOV, 2013).

3. https://www.sciencedirect.com/journal/accident-analysis-and-prevention/vol/126

7.4 Vehicle technology

7.4.1 Advanced driver assistance systems (ADAS)

Advanced driver assistance systems (ADAS) may contribute to reducing the number of fatigue-related crashes, e.g., by warning the driver or by actually intervening. Examples of *warning systems* are Lane Departure Warning (LDW) and Forward Collision Warning (FCW) systems. Examples of *intervening systems* are (Cooperative) Advanced Cruise Control and Lane Keeping Systems (LKS). These systems do not prevent fatigue itself; in some cases they may even be conducive to fatigue due to reduced workload (see Section 2.2 *What is the problem - causes?*). They do, however, in principle, limit the consequences of fatigue, by preventing running off the road or driving into vehicles in front.

Warning systems are theoretically effective but there is little or no real crash data available yet to validate this assumption and quantify their real contribution. There are also doubts about public support for intervening systems (Hynd et al., 2015; Vlakveld, 2019). However, a recent US study on the effectiveness of FCW systems on large truck crash rates concluded these systems are effective (Teoh, 2020). And the new EU Regulation on motor vehicle type approval (European Union, 2019) has introduced mandatory safety features including an intervening LKS mandatory for passenger cars and light commercial vehicles/vans, and a warning LDW system mandatory for buses and trucks.

7.4.2 Automatic fatigue detection systems

In recent years, much research has been done into the possibilities offered by automatic fatigue detection systems, and several studies in this field are still in progress (Matthews et al., 2019). These systems should detect that the driver is getting so tired that they can no longer drive safely and should then warn the driver or intervene. Some of the systems take input from driving behaviour: does the car swerve more than usual, does speed fluctuate more than usual, are brakes more often used abruptly? Other systems take input from physical driver characteristics, such as eye blinking, facial muscle spasms and yawning.

At present, several car brands are equipped with fatigue detection systems. These systems generally take input from driving style changes, notably steering movements. The new EU Regulation on type approval requirements for motor vehicles makes a driver drowsiness and attention warning system mandatory for all vehicle categories (European Union, 2019). The Impact Assessment of the General Safety Regulation (European Commission, 2018a) provides further detail.

The major challenge is to detect driver fatigue consistently and validly, avoiding false positives (warning or intervening when there is no question of fatigue) and false negatives (failing to warn or intervene when fatigue is indeed at issue). The former will lead to irritation and possible system sabotage, the latter will affect confidence in the system. It is feared that fatigue detection systems tempt tired drivers to keep driving until the system responds. So far, however, there is no empirical evidence to support this fear (Vlakveld, 2019).

8 Further reading

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