Fatigue

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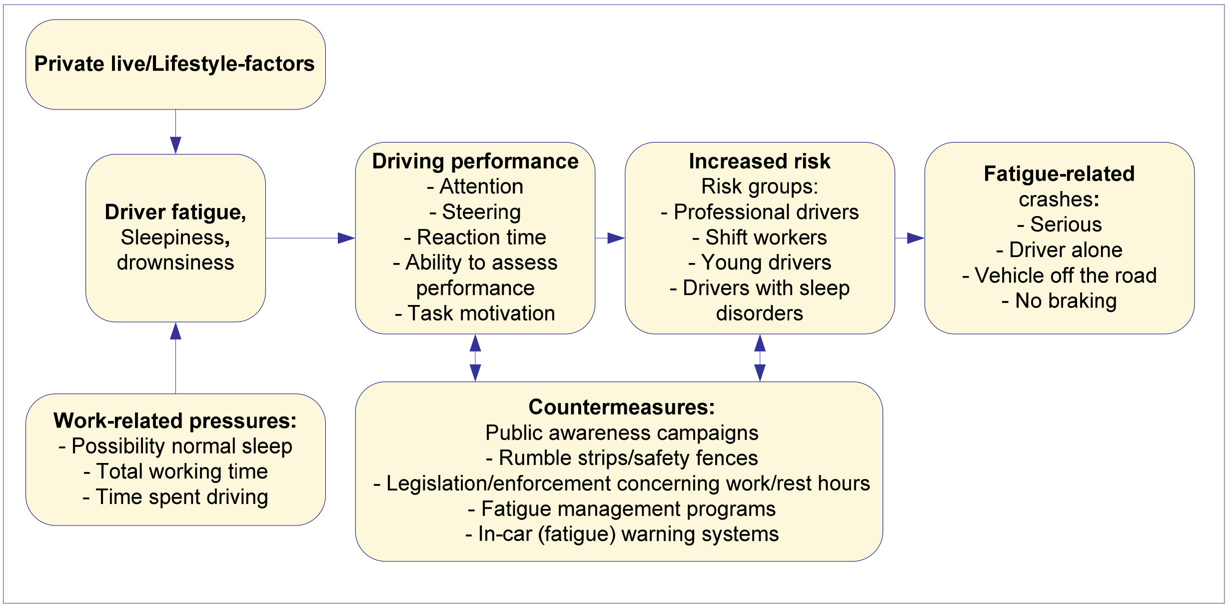
Summary



In the literature many definitions are used for fatigue. The concepts of “fatigue”, “sleepiness” and “drowsiness” are often used interchangeably. Sleepiness can be defined as the neuro-biological need to sleep, resulting from physiological wake and sleep drives. Fatigue has from the beginning been associated with physical labour, or in modern terms task performance. Although the causes of fatigue and sleepiness may be different, the effects of sleepiness and fatigue are very much the same, namely a decrease in mental and physical performance capacity.

The most general factors that cause fatigue are lack of sleep, bad quality sleep and sleep demands induced by the internal body clock. Besides these general factors, prolonged driving (time-on-task) can increase driver fatigue, especially when drivers do not take sufficient breaks. For specific groups of drivers, e.g. professional drivers, these general factors often play a more persistent role due to long or irregular work schedules. A small part of the general population (3-5%) has to cope with obstructive sleep apnoea, a sleeping disorder which contributes to above average day-to-day sleepiness.

Fatigue leads to a deterioration of driving performance, manifesting itself in slower reaction time, diminished steering performance, lesser ability to keep distance to the car in front, and increased tendency to mentally withdraw from the driving task. The withdrawal of attention and cognitive processing capacity from the driving task is not a conscious, well-planned decision, but a semi-autonomic mental process of which drivers may be only dimly aware. Drivers may try to compensate for the influence of fatigue, for instance by either increasing the task demands (e.g. driving faster so that a ‘new’ sensation of driving spurs adrenaline and attention levels) or lowering them (e.g. increasing the safety margins by slowing down or using larger following distances). But crashes and observations of driving performance show that compensatory strategies are not sufficient to remove all excess risk.

Survey research world-wide suggests that over half of all private drivers drive while being fatigued or drowsy at least once a year. Amongst young drivers, driving while fatigued is quite common due to lifestyle factors. Adolescents need more sleep than adults; fatigue may affect youngsters more than adults. Most professional drivers and shift workers have to cope with fatigued driving on a frequent basis due to work-related factors. About half of professional drivers take less than normal sleep time before a long-distance trip.

Fatigue is a major factor in a large proportion of road crashes (range 10-20%). Several studies suggest that fatigue is associated with increased crash risk. A person who drives after being awake for 17 hours has a risk of crashing equivalent to being at the 0.05 blood alcohol level (i.e. twice the normal risk). The increased risk often results from a combination of biological, lifestyle-, and work-related factors. More scientific evidence is needed concerning the exact quantitative relationship between fatigue and risk.

Driver fatigue countermeasures may be directed at drivers, transport companies, roads or vehicles. Drivers may learn how to prevent driver fatigue by campaigns. Transport companies can introduce special policies to educate both drivers and management about the problem. Roads may be equipped with edgelines or centrelines that provide audio-tactile feedback when crossed over. In the future, legislation concerning working and rest hours may be further improved and vehicles can be equipped with devices that detect fatigue-related decrements in driver performance.

1. Introduction

This text provides an introduction on the subject of driver fatigue, its causes, consequences, and possible countermeasures. This first section examines What is fatigue? (Definition), its Physiological components and Psychological components, and the Progression of fatigue.

The five main causes of fatigue are described as:

- Lack of sleep or poor sleep
- Internal body clock (circadian rhythm)
- Time-on-task (long working hours)
- Monotonous tasks (lack of stimulation)
- Individual characteristics including medical conditions

Information is given on how fatigue affects Driving behaviour in general, and Steering, Speed choice and Following behaviour in particular, and how Compensatory strategies to fight off the effects of fatigue are not enough. This section also explains that the Driving without awareness phenomenon should not be confused with driver fatigue and it discusses some important Individual differences.
Research results are given on the prevalence of fatigued driving among: Among private drivers, Among young drivers, Among professional drivers, and Among shift workers.
Descriptions are also given on how to recognise fatigue-related crashes, the frequency of these crashes, and the evidence concerning the fatigue-risk relationship.
Further a focus on risks and circumstances of several driver groups who have a higher risk of driver fatigue: Young drivers, Professional and truck drivers, Shift workers and Drivers with sleep-breathing disorders.
Finally, this web text closes with a discussion of possible countermeasures, such as Publicity, Infrastructural, In-vehicle detection and warning, Legislation and enforcement, Fatigue management programs and a consideration of Further need for knowledge on countermeasures.
At the end of each section main, summarising conclusions are provided:
Conclusions *Introduction*, Conclusions *Behaviour*, Conclusions *Prevalence*, Conclusions *Risk groups*, Conclusions *Crashes*, Conclusions *Countermeasures.*

1.1 What is fatigue?

In the literature many definitions are used for fatigue. The concepts of “fatigue”, “sleepiness” and “drowsiness” are often used interchangeably. Sleepiness is an aspect of fatigue which is perhaps easiest to define. Sleepiness can be defined as the neurobiological need to sleep [79], resulting from physiological wake and sleep drives [55]. Fatigue has from the beginning been associated with task performance. In addition, fatigue also has a psychological meaning: not having the energy to do anything, and a subjectively experienced reluctance to continue with a task [15]. Thus, sleepiness is the drive for sleep while fatigue can be seen as a signal from the body that we should end the ongoing activity, whether it is physical activity, mental activity or just being awake. Although the causes of fatigue and sleepiness may be different, the effects of sleepiness and fatigue are very much the same, namely a decrease in mental and physical performance capacity.

Below we describe physiological and psychological components of fatigue and pay attention to progression of fatigue

1.2 Physiological components

Fatigue is associated with physiological changes in brain wave activity, eye movement, head movement, muscle tone and heart rate. With the onset of fatigue, body temperature, heart rate, blood pressure, respiration rate and adrenalin production are lowered. When fatigued, a person may experience micro-sleeps. Micro-sleeps are brief naps that last for approximately four to five seconds.

One of the most valid indexes of alertness in the driver is the electroencephalography (EEG) [61][64]. The EEG (electroencephalograph) measures brainwaves of different frequencies within the brain. The electrical activity of the brain is classified according to rhythms. These rhythms are defined in terms of frequency bands including delta (0.5-4 Hz), theta (4-7Hz), alpha (8-13Hz) and beta (13-30Hz). Deltawaves are present during transition to drowsiness and during sleep. Theta rhythms replace the alpha components at the onset of sleep. Beta waves are associated with increased alertness, arousal and excitement [61].

1.3 Psychological components

Fatigue affects mood and motivation as well as psychomotoric and cognitive functions [100]. Fatigue is partly a subjective experience, characterized by lack of motivation, feelings of exhaustion, boredom, discomfort, and a disinclination to continue the task at hand. At the cognitive level, studies have linked sleepiness and fatigue to decreases in vigilance (capacity to detect and respond to unpredictable signals or events over a longer period of time), reaction time, memory, psychomotor coordination, information processing and decision making [65]. Its effects are strongest in those tasks that are monotonous, that have long duration that demand constant attention and that have low predictability.

The part of fatigue which is psychological in nature has also been called ‘mental fatigue’ [61]. Mental fatigue is a gradual and cumulative process and is associated with unwillingness to put in effort, reduced efficiency and alertness and impaired mental performance (Grandjean, 1988 as cited in: Lal & Craig, 2001). According to Grandjean (1979 as cited in: Lal & Craig [61]), the functional states of a person range from deep sleep, light sleep, drowsy, weary, hardly awake, relaxed, resting, fresh, alert, very alert, stimulated and a state of alarm. In this series, mental fatigue is a functional state, which may result either into sleep or into a relaxed, restful condition.

1.4 Progression of fatigue

The progression of fatigue research has been studied with vigilance tasks. A vigilance task is a type of task where a user must maintain attention on the task while waiting for and responding to an uncommon, unpredictable event, such as monitoring security cameras or a radar display. With the use of vigilance tasks, fatigue research has shown that periods of normal performance (i.e. seeing signals on time and providing right response) alternate with short lapses in functioning (i.e. missing signals or responding very late) [28]. A theoretical explanation is that fatigue is not simply a passive process. Fatigue is the result of an interaction between deactivation processes (e.g. slower functioning; lesser attention) and compensation processes. This means that a person can react actively when he or she notices the onset of fatigue, and may compensate for increased fatigue, for instance, by putting in extra mental or physical effort to perform a task. The interaction of on-going fatigue and compensation (extra effort) leads to a performance that becomes increasingly variable or unstable. Thus, there is not a simple monotonous decrease of performance. Instead there is an increasing variability in performance, with more and faster changes between normal functioning and erratic functioning [28].

1.5 Conclusions

- Fatigue has a physical and a mental aspect.
- Fatigue is associated with both reduced capacity to perform and motivation to perform.
- Although sleepiness and fatigue may have different causes, their effects on performance and motivation are similar, a decrease in mental and physical functioning.
- When fatigued, persons may alternate normal functioning with short lapses in performance (i.e. not noticing or responding to signals). The long term result of fatigue is an increasing variability of performance.

2. What causes driver fatigue?

Knowledge of the causes of driver fatigue is important for deciding on appropriate countermeasures. Brown [15] identified 5 general causes of fatigue in general and driver fatigue in particular:

- Lack of sleep or poor sleep
- Internal body clock
- Time-on-task
- Monotonous tasks
- Individual characteristics including medical conditions

This section closes with Conclusions.

2.1 Lack of sleep or poor sleep

The average person needs 8 hours sleep every 24-hour cycle. Sleep prior to work is the most prominent factor that influences the waking state, the level of alertness of the driver [48][11]. A chronic lack of sleep is the result of not having enough sleep during a long period. An acute lack of sleep can occur after just one bad or short night. If there has been too little sleep during a 24-hour period, we refer to it as a partial, acute lack of sleep. There is a complete, acute lack of sleep if, within a period of 24 hours, there has been no sleep at all.

Besides quantity of sleep, the quality of the sleep is also of great importance. If sleep is regularly interrupted, this leads, just as too little sleep does, to day-time fatigue. The quality of sleep is influenced by, among other things, sleeping disorders e.g. sleep apnoea (a temporary breathing stoppage while sleeping) and narcolepsy (the tendency to suddenly fall asleep). But it can also be a side effect of chronic diseases and/or medication or the result of external factors, such as a noisy or unpleasant sleeping environment.

2.2 Internal body clock

Fatigue is linked to the circadian rhythm. The body's circadian rhythm is an internal biological clock. It coordinates the physiological priorities for daily activities, including sleep, body temperature, digestion, performance, and other variables. Therefore, it has a direct affect on alertness, mood, motivation, and performance.

The body's natural cycle, or circadian rhythm, plays an important role in how fatigue affects people. The brain and the body are so accustomed to the normal body cycle that they resist changes (such as caused by work-schedules). The human body has a greater need for sleep at certain times in the 24-hour cycle than at other times (approximately between midnight and 4 a.m.; and, to a lesser extent, 2 p.m.- 4 p.m.). At these moments, there is a natural tendency to sleep and, if this cannot be given way to, a sleepy feeling occurs.
Shift work for instance interferes strongly with normal sleep patterns. Pronounced sleepiness is therefore a typical characteristic amongst most shift workers [5][6][7].

2.3 Time-on-task

Prolonged activity inevitably leads to physical and mental fatigue. Researchers have related the duration of activity, or the so called time-on-task, to fatigue symptoms. One of the causes of driver fatigue is the time-on-task, i.e. the time spent driving. The fatigue-inducing effects of prolonged driving may be decreased by taking frequent breaks [91]. For professional drivers, the relevant time-on-task is better seen as the total work time (including the time of driving). Professional drivers often perform many more tasks than the job of driving. For professional drivers, long working hours often go together with early waking and reduced sleep.

2.4 Monotonous tasks

A task is monotonous when its stimulants don't change or the changes are predictable or there is a high level of repetition. Suburban highways where road environment changes are limited and there is a small volume of traffic match this definition. O'Hanlon and Kelly [84] pointed out that driving on a monotonous road is equal to a vigilance task, thus driver vigilance decrement is an expression of fatigue. Thiffault & Bergeron [104] found that in a monotonous driving situation, driver steering wheel movement is greater and occurs more often, showing that the fatigue effect and effect on driver vigilance caused by a monotonous road situation is relatively large. Also, driving on a relatively long and monotonous driving environment also has a clear negative effect on driver valid peripheral visual field [95].

2.5 Individual characteristics including medical conditions

Individual characteristics such as age, physical condition, use of alcohol etc. also influence how fast drivers get fatigued and how well they can cope with fatigue. For example, older people (70+) and persons with poor physical condition are more susceptible to fatigue. Changes in sleeping habits accompany the transition from teenager to young adult; teenagers may experience chronic sleep loss which may make them extra susceptible for temporary effects of fatigue induced by alcohol, drugs or bad sleep [38]. Alcohol use has a sedating effect, but alcohol consumed within an hour of bedtime appears to disrupt the second half of the sleep period [62]. Some particular individual characteristics concern sleep disorders. In Box 1 we pay attention to 2 sleeping disorders known to affect driving.

Narcolepsy is a rare sleeping disorder affecting 1:2000 persons [81]. Sufferers commonly have 'sleep attacks' in which they fall asleep without warning. This often occurs in inappropriate settings and even after a good night sleep. Narcolepsy has obvious potential hazards for drivers (http://www.science.org.au/nova/074/074key.htm).
The sleep episode can last between a few seconds and an hour. Possible side-effects of the disorder include hallucinations, temporary paralysis on waking, and cataplexy (loss of muscle control in emotional situations). This disorder is genetically based and can be treated with stimulants and anti-depressants.
Legislation concerning narcolepsy and fitness to drive differs among EU countries. For example in the UK, sufferers from narcolepsy are not usually permitted to drive. In many other EU countries specific legislation in regard to narcolepsy is lacking.
Obstructing sleep apnoea is characterised by the restriction of a person's airflow during sleep, caused by the closure of the upper airway. People with sleep apnoea receive inadequate quantities of oxygen while asleep, causing them to wake frequently, resulting in a fractured and less restful sleep. Sufferers are commonly tired during the day and more prone to symptoms of fatigue, including 'micro-sleeps' (sleep episodes in inappropriate settings that last a few seconds). Symptoms of sleep apnoea may be made worse by the consumption of alcohol and tobacco.
Epidemiological data indicate that at least 5 million patients suffer from sleep apnoea throughout Europe [60]. This is about 0, 7% of the European population. Of course, registered patients are an underestimation of all persons who suffer from this handicap. It is estimated that perhaps as much as 5% of a population may actually be affected by it (see: http://www.science.org.au/nova/074/074key.htm)
In Europe, there are no uniformly accepted regulations concerning driving licensing and sleep apnoea. Many national European licensing make no specific mention of sleep apnoea or excessive daytime sleepiness [60]. Sassani et al [99] concluded that treating all US drivers suffering from obstructive sleep apnoea syndrome with (CPAP) therapy has a favourable cost-benefit ratio. This would cost 3, 2 US billion (dollars) and save 980 lives and 11, 1 US billion in collision costs annually in the USA.

2.6 Conclusions

- The most general factors that cause fatigue are lack of sleep, bad quality sleep and sleep demands induced by the internal body clock
- Besides these general factors, prolonged driving (time-on-task) can increase driver fatigue, especially when drivers do not take sufficient breaks
- For specific groups of drivers, e.g. professional drivers, these general factors often play a more persistent role due to long or irregular work schedules
- For a small part of the general population (a few percent), obstructive sleep apnoea contributes to above average day-to-day sleepiness.

3. Effects of fatigue on driving

In general, fatigue affects task performance: a reduction in alertness, longer reaction times, memory problems, poorer psychometric coordination, and less efficient information processing [65]. Fatigue also has an effect on task motivation. The motivation to carry out a task diminishes, the communication and interaction with the surroundings deteriorates, and one gets irritated more quickly and reacts more aggressively towards people and things [15].

Fatigue leads to diminished actual performance and decreased motivation to perform. Not surprisingly, these general effects on task performance are mirrored by similar effects when the task concerns driving. Fatigue has specific consequences for Driving behaviour. Drivers may use Compensatory strategies to (try to) ward of effects of fatigue. A separate phenomenon from fatigue – but often linked to it – is Driving without awareness. Finally, it should be kept in mind that there are Individual differences in how persons react and cope with fatigue. Conclusions are given in the closing subsection.

3.1 Driving behaviour

For the driver the main effect of fatigue is a progressive withdrawal of attention from the road and traffic demands, leading to impaired performance behind the wheel [15]. Research has found that a person who drives after being awake for 17 hours has impaired driving skills comparable to a driver with a 0.05 blood alcohol level. A driver who has gone without sleep for 24 hours has impaired driving skills comparable to a driver with an illegal high BAC of 0, 1 g/l [110]. In the case of sleepy drivers, the ultimate impairment is falling asleep at the wheel.

Several studies [27][91] have shown that fatigue influences driving behaviour in specific ways:

- Slower reaction times: fatigue increases the time taken to react in an emergency
- Reduced vigilance: subjects perform worse on attention-based tasks when sleep-deprived (e.g. a fatigued driver will be slower to notice oncoming hazards, such as roadworks or a railway crossing)
- Reduced information processing: fatigue reduces both the ability to process information and the accuracy of short-term memory (e.g. a fatigued driver may not remember the previous few minutes of driving).

Consequences on specific operational driving aspects
Below findings are reported about specific aspects of driving task control:

- Steering;
- Speed and
- Following behaviour.

3.1.1 Steering

On-the-road studies have indicated that steering performance gradually deteriorates and that performance decrements are correlated with subjective ratings of fatigue [84][94].

In a simulator study, [52] found that even in a limited 2.5-h time-span subjective fatigue and sleepiness increased as a function of time on task. The increase of fatigue and sleepiness was accompanied by an increased aversion to continue driving and a deterioration of steering performance. Interestingly, larger increases of fatigue and sleepiness were associated with larger increases of aversion and a greater deterioration of steering performance. These results suggest that fatigue is accompanied by a decreased motivation to continue with the task.

In a study by Van Winsum [112], participants had to drive for 3 hours in a driving simulator on a two-lane road outside urban areas. As the drive progressed, steering performance became less flexible and the amplitude of steering corrections increased. Van der Hulst et al. [52] also found that, after a 2, 5 hour drive in a simulator, steering performance deteriorated. Desmond [26] found that effect of fatigue on steering performance and on lateral position were greater on straight road sections than in road curves. Desmond concludes that tired drivers have more difficulty regulating attention and performance in situations with low task demand (straight road sections) than in situations with high task demands (curves).

Åkerstedt et al. [10] compared performance in a driving simulator of shift-workers after a normal night sleep with performance after a normal night shift. Driving after the night shift was associated with an increased number of occurrences of two wheels outside lane marking and with an increased lateral deviation of the vehicle. Also, performance after nightshift led to increased eye closure and increased subjective sleepiness.

3.1.2 Speed choice

A German simulator study showed that participants drive faster the longer they performed the driving task [42]. However, driving faster did not diminish general driving performance. The researchers considered this as evidence for the hypothesis that drivers attempt to adapt their attention-level (by changing speed). In other words, by changing speed drivers may change sensory input which may spur the body and mind to put in extra effort to notice and respond to signals from the environment.

In a survey study by Oron-Gilad & Shinar [83], 12% of military truck drivers said that they drove slower when they were fatigued; 14% admitted to having difficulties with estimating own speed correctly. Riemersma et al [94] report that falling asleep goes together with lessened muscle force, manifesting itself also in less force on the accelerator pedal.

3.1.3 Following behaviour

In a study of time-on-task effects on car-following performance, Brookhuis et al [14] found that differences between the speed of the following car and the speed of the lead car became larger after 2.5 h of continuous driving. This indicates that accuracy in following the lead car's speed changes was reduced.

In a simulator study [52], it was found that participants who became more fatigued during the prolonged simulator drive increased their headway to a greater extent than participants who reported only a slight increases of fatigue. This applied to a lesser extent for participants who had to perform the task under time pressure. Time pressure may make the task more challenging and less monotonous thereby sustaining motivation to perform well.

3.2 Compensatory strategies

Prolonged driving is accompanied by a decreased motivation to continue driving and reduced accuracy of lateral and longitudinal vehicle control [15][52]. To a certain extent motivation, i.e. the investment of extra mental effort, can compensate for the performance-decreasing effects of prolonged driving. However, sustained effort may not be enough because the ability to monitor the efficiency of one’s own performance may deteriorate as well as a result of fatigue [16]. On the basis of experimental simulator studies, Matthews & Desmond [69] suggest that task-induced driver fatigue reduces awareness of performance impairment. Moreover, task-fatigued drivers appear to have difficulty mobilizing sufficient task-directed effort (i.e. keeping enough attention on the task and responding to signals). This is especially the case when task demands are low. Theoretically, in a fatigued state, performance goals become de-activated, perhaps due to competition from comfort-seeking goals, and thus the drivers loses awareness of performance deterioration. The same authors link sleep-related fatigue with reduced motivation or inability to mobilise compensatory effort following detection of impairment [69].

Under normal circumstances drivers are likely to increase their safety margins when they become fatigued and performance deteriorates [52]. When performance is starting to deteriorate, taking (frequent) breaks may cause recovery of normal performance. A French on-road study showed that rested, non-professional driver can drive 1000 km from 9 am to 7 pm, with three 15 minutes breaks and one 30 minute break, without noticeable performance decrement [91]. The study demonstrates that fatigue generated by extensive driving has a limited impact on driving skills in normally rested drivers.

3.3 Driving without awareness

A phenomenon which is sometimes confused with driver fatigue, but is quite different is driving without awareness (DWA). Drivers may demonstrate low attention levels during driving without being fatigued by time on task, lack of sleep, bad sleep or time of day. The driver performs in a state in which he has no active attention for the driving task and performs on 'autopilot'. At a certain moment the driver 'awakes' and he or she cannot remember the foregoing drive period. This phenomenon has been labelled as 'Driving without awareness' and also as 'Highway hypnosis' or 'Driving without attention mode' (DWAM). Brown [15] links this phenomenon to the monotony of the driving task or situations that presents the same and predictable visual task demand. During DWA the eyes stay open in contrast to micro-sleep during which the eyes are closed for at least 2 seconds. In Box 2, research on driving without awareness is described.

Karrer et al. [57] let a representative sample of 83 German drivers perform for 2 hours on a monotonous driving task on motorway. Trained observers registered the occurrence of DWA, as being indicated by one or more of the following symptoms:

- The driver began to stare into space
- The drivers began to stare and head shakes upwards or downwards
- Start of rolling eye movement of the driver
- Start of squinting.

During the drive, the EEG (duration and frequency alpha waves), eye jumps (saccades) and the frequency of eye blinks were measured. Also, traffic errors were measured (mainly crossing over edge markings). DWA occurred for 18% of the drivers, and relatively more for young male drivers. The 83 participants in total crossed 260 times edge marking. In 33, 5% of these cases, DWA was present. DWA went together with a decrease in the number of eye jumps and a decrease in the size of the jumps. The higher the frequency of DWA moments, the longer the duration of eye blinks. This last results supports the conclusion that DWA occurs at a low intensity attention level and that this causes more traffic errors to be made.

3.4 Individual differences

People differ in the extent to which they get fatigued and in the way they cope with (driver) fatigue. Investigating driving performance on a 2 hour and 15 minutes night-time simulator drive, Verweij & Zaidel [106] found that persons who were extraverted (assertive, gregarious, excitement seeking) and easily bored, and who had an external locus of control, demonstrated more serious driving errors as a result of fatigue.

Likewise, Thiffault & Bergeron [104] found relations between a personality disposition to driving and fatigue behaviour. In their experiment, 56 male drivers were observed on two different road settings (monotonous environment vs. visually diversified scenery). They showed that higher levels of "sensation seeking" and "experience seeking" went together with higher variability of steering wheel movement. In addition, extraverted persons and "high sensation seekers" were more likely to fall asleep at the wheel.

Van Winsum [112] found that young and elderly drivers became equally tired by a prolonged drive in a simulator. Fatigue had a negative effect on keeping course, but the negative effect was more pronounced for elderly drivers.

3.5 Conclusions

- Fatigue leads to a deterioration of driving performance, manifesting itself in slower reaction time, diminished steering performance, lesser ability to keep distance to the car in front, and increased tendency to mentally withdraw from the driving task.
- Drivers try to compensate for the influence of fatigue, for instance by either increasing the task demands (e.g. driving faster) or lowering them (e.g. increasing the safety margins by slowing down or using larger following distances,). These are compensatory strategies that drivers select to ward off the mental and physiological effects of fatigue.
- When drivers are well rested and when they take enough breaks during driving, they can drive for a long time without performance decrement.
- One reason compensatory strategies are bound to fail is that during fatigue persons lose the ability to appraise own driving performance. This is especially the case for driving in monotonous road environments.
- A separate, different phenomenon is “Driving without awareness” which can be induced by monotony of driving environment. Driving without awareness can occur without the driver being particularly tired.

4. Prevalence of fatigued driving

In modern 24-hour societies, getting enough sleep or rest is not always high on the agenda. How many persons are so fatigued that they feel it interferes with their functioning? And how many persons drive while they are fatigued? Survey research provides information on the extent to which fatigue or sleepiness interferes with normal functioning in everyday life. According to the 2002 “Sleep in America” Poll nearly two out of every five American adults (37%) report that a few days a month or more they are so sleepy during the day that it interferes with their daily activities; 16% experience this level of daytime sleepiness a few days per week or more [108]. A comparable survey has not yet been done for EU.

In sections below we present information on prevalence of fatigued driving among private drivers, young drivers, professional drivers and shift workers.
The last subsection provides Conclusions.

4.1 Among private drivers

Survey research in Canada, Europe and USA indicate that driving while tired or sleepy occurs at least once a year for a large proportion of the population. The table below presents findings from studies in four countries.

Country	Author	Key fatigue result
Great Britain	Maycock 1997	29 % of respondents stated that they “had felt close to falling asleep while driving” in the past year
Norway	Sagberg, 1999	10% of male drivers and 4% of females reported to have fallen asleep while driving during the last 12 months; 4% of these events resulted in an crash
Ontario	Vanlaar, 2007	nearly 60% of Ontario drivers admit that they have driven while fatigued at least sometime; 14.5% of Ontario drivers say they actually fell asleep or nodded off while driving at least once in the past year
USA	National Sleep Foundation 2002-2005	60% of adult drivers and 51% of teenage drivers reported driving drowsy at least once a year; 14% of adults and 15% of teens said they drive drowsy at least once a week; 37% of adults and 5% of teens said they had nodded off or fallen asleep at the wheel within the past year

A New Zealand study [20] aimed to obtain reliable estimates of the prevalence of driver sleepiness. A sample of car drivers representative of time spent driving on public roads in a geographically defined region was obtained. 588 car drivers and drivers of light vehicles were surveyed at 69 roadside survey sites. From this sample, it was estimated that in New Zealand 58.7% of driving was undertaken by men. Most driving was undertaken by drivers with Epworth Sleepiness scores in the normal range (The Epworth Sleepiness Scale is a questionnaire intended to measure daytime sleepiness). However, a significant minority was undertaken by drivers with one or more characteristics likely to impair alertness. 3.1% had 5 hours of sleep or less in the previous 24 hours, and 21.9% had 4 or less full nights of sleep in the previous week. 8.1% of those surveyed worked a pattern of shifts likely to interfere with normal sleep. Results also found that 1.6% experienced symptoms associated with sleep apnoea.

The strength of this study is that it measures sleepiness in drivers in proportion to actual driving time on the roads. Therefore, the study directly measures exposure to the risk of fatigue-related crashes and injuries. Previous studies of driver characteristics or vehicle crashes that have considered exposure to risk have most often used driver-kilometres as the denominator, which is highly correlated with driving time but not identical.

4.2 Among young drivers

Amongst young drivers, driving while fatigued is quite common due to lifestyle factors [43]. As adolescents need more sleep than adults, which they do not usually observe, fatigue can affect youngsters more than adults [38].

According to National Sleep Foundation's 2006 “Sleep in America”-poll, only one in five adolescents (20%) gets an optimal amount of sleep during the week, and more than half (51%) report having driven drowsy in the past year.National Sleep Foudation: Sleep in America Poll.

A survey among young drivers (18-25 years) in Victoria indicated the following [43]:

- 43% of young drivers had driven in the preceding week when mentally fatigued or sleepy;
- 40% had driven in the preceding week when physically tired or worn out;
- 10% admitted to driving after more than 24 hours without sleep in the preceding two weeks;

- 3% admitted to nodding off while driving in the preceding two weeks

See also the section about risk groups – young drivers.

4.3 Among professional drivers

The results of different surveys world-wide (Australia, France, Ireland, Netherlands, USA) show that over 50% of long-haul drivers have at some time almost fallen asleep at the wheel [32]. A survey among Dutch, German, Belgian, Danish and Italian long distance truck drivers provided the following results on fatigued driving [87]:

- 43% sometimes almost fall asleep, but have never actually fallen asleep
- 9% actually have fallen asleep but never had a crash
- 7% actually had a crash caused by falling asleep behind the wheel.

In total 60% of European truck drivers reports to almost have fallen asleep. Van Ouwerkerk [86] reports similar figures for USA (64%), Australia (60%) and Ireland (45%).

A Finnish survey research [45][46] amongst 317 male truck drivers showed that especially long-distance drivers had regularly to deal with fatigue while driving; over 40% reported dosing off in the past three months and about 25% reported this to have happened twice in the same period. In contrast, among short-distance truck drivers, only 15% reported dosing off behind the wheel in the past 3 months.

In several studies of European professional drivers (both car drivers and truck drivers), it was demonstrated that long-distance driving often goes together with reduced sleep duration [91]:

- In one study of 567 car drivers, 50% had reduced their normal sleep in the 24 h before departure for a long-distance journey and 10% had no sleep in the 24 hours before the interview;
- In another study of 2197 car drivers, again 50% of the drivers decreased their total sleep time in the 24 h before the interview compared with their regular self-reported sleep time, and 12,5% presented a sleep debt > 180 minutes and 2.7% a sleep debt > 300 minutes;
- In a study on truck drivers, of 227 drivers 12.3% had slept less than 6 h in the 24 h previous to the interview and 17.1% had been awake more than 16 h.

A survey of 573 long-distance truck drivers travelling on New York interstate highways, indicated that 47% of the drivers had ever fallen asleep at the wheel of a truck, and 25% had fallen asleep at the wheel in the past year [74].

See also the section about risk groups – professional drivers.

4.4 Among shift workers

The term shift work describes regular employment outside the normal daytime hours. Therefore, shift workers are likely to experience conflicting demands from work and internal body clock. Most shift workers have at least occasional sleep disturbances, and approximately one-third complain of fatigue [5][6][7].

A Finnish study looked at the combined effects of different forms of shift work, age, leisure-time physical activity, smoking, and alcohol consumption on the prevalence of sleep complaints and daytime sleepiness. 3020 participants were studied using a psychosocial questionnaire. The participants were currently employed men, aged 45-60 years, from a postal and telecommunication agency, the railway company, and 5 industrial companies. The researchers grouped the sleep complaints into the categories of insomnia, sleep deprivation, daytime sleepiness, and snoring. The prevalence of insomnia, sleep deprivation, and daytime sleepiness depended significantly on the shift system. All sleep complaints were more common in 2- and 3-shift work and in irregular shift work than in day work. The prevalence of daytime sleepiness was 20-37%, depending on the shift system. Leisure-time physical activity and alcohol consumption were the most important life-style factors predicting all sleep complaints, except snoring. The effects of physical activity and alcohol consumption differed for different shift schedules. The researchers concluded that different shift systems, also 2-shift work and permanent night work, increase the frequency of sleep complaints. Especially 3-shift work seems to interact with life-style factors by increasing the adverse effects and decreasing the beneficial effects on sleep and sleepiness.

4.5 Conclusions

- Based on American data, over one-third of the adult population has impaired functioning due to sleep loss during one or more days each month
- Surveys suggest that over half of all drivers drive while being drowsy at least once a year. Actually nodding off or falling asleep behind the wheel within the last year occurs for a sizeable proportion of the populations (range 10% up to 40%).
- Amongst young drivers, driving while drowsy is quite common due to lifestyle factors. Adolescents need more sleep than adults and fatigue may affect youngsters more than adults.
- Most professional drivers and shift workers have to cope with fatigued driving on a frequent basis due to work-related factors. According to surveys, half of professional drivers take less than normal sleep time before a long-distance trip
- Even the more acute stages of fatigue, e.g. dozing off behind the wheel, happen at least once a year for a considerable proportion of all professional drivers.

5. Fatigue and road crashes

In studying fatigue and road crashes, researchers first have to find out what accidents are likely related to fatigue. To do this they have to define the characteristics of fatigue-related crashes. The next step is to apply these definitions to existing databases and estimate the frequency of fatigue-related crashes. Research that informs us about the frequency of fatigue-related crashes is not yet scientific proof that fatigue directly leads to risk. The ultimate aim would be to quantify the exact relationship between fatigue state and crash risk. To do this research needs to control for other factors that may influence the relationship between fatigue and risk such as kilometres driven. Below we describe how to recognise fatigue-related crashes, the frequency of these crashes, and the evidence concerning the fatigue-risk relationship.
The last subsection provides Conclusions.

5.1 How to recognize a fatigue-related crash?

Unlike the situation with alcohol-related crashes, no blood, breath, or other measurable test is currently available to quantify levels of sleepiness at a crash site. Thus current understanding of typical crash related characteristics come largely from inferential evidence.

In the United Kingdom, fatigue related crashes have been identified using the following criteria:

- The vehicle has run off the road and/or collided with another vehicle or object
- There is an absence of skid marks or braking
- The driver could see the point of run-off or the object hit prior to the crash

- Other causes are eliminated e.g. mechanical defect, speeding, excess alcohol, bad weather; and
- Witnesses may report lane drifting prior to the crash [49][50]

Similarly in the United States, the Expert Panel on Driver Fatigue and Sleepiness [79] characterises a fatigue-related crash as follows:

- The problem occurs during late night/ early morning or mid-afternoon
- The crash is likely to be serious
- A single vehicle leaves the roadway
- The crash occurs on a high-speed road
- The driver does not attempt to avoid a crash
- The driver is alone in the vehicle

5.2 Frequency of fatigue-related crashes

Different methods yield different estimates concerning the frequency of fatigue-related crashes. The following sections present estimates based on various methods:

- Police records
- Questionnaire studies
- Naturalistic observation study
- In-depth investigation

5.2.1 Police records

The police crash reports in different countries (e.g. Netherlands, UK, North Carolina USA) indicate a 1-4% incidence of sleep-related crashes of all registered crashes [100]. For example in the Netherlands, the combined primary cause of a crash that is attributed to sleep/illness occurs in about 1% of all registered crashes. It is likely that these police reports greatly underestimate the problem. In most countries, police are not (yet) so alert to fatigue as crash cause. Also, most drivers will be reluctant to admit that they were very tired or had fallen asleep at the time of the crash. In addition, the crash itself would have made most of the symptoms of fatigue disappear. So the 1% figure certainly represents an underestimation.

5.2.2 Questionnaire studies

Questionnaire studies have provided completely different conclusions about fatigue's role in road crashes [100]. Based on these methods, estimates of the percentage of sleep-related crashes vary greatly, but often are in the range of 10-25 percentage points higher than can be concluded from police reports. The higher percentages have been found particularly in studies that have examined lorry crashes and/or fatal crashes. All these estimates are from abroad.

Based on findings from a survey study amongst 4600 male car drivers in England, Maycock [70] concluded that fatigue played a role in 9-10% of all crashes. This percentage was higher for motorways (20%) than for roads inside urban areas (7%) or for other roads outside urban areas (14%).

5.2.3 Naturalistic observation study

Naturalistic observation of driving behaviour provides the most direct evidence of driver fatigue in real circumstances. A naturalistic driving study unobtrusively registers the actual driving behaviour of drivers who drive their own cars to destinations of their own choosing without an experimenter present. The registration of driving behaviour is continuously done by various instruments over a longer period of time (one year or longer). A naturalistic observation study may link the outward signs of fatigue (such as closed eyes) to real driving behaviour.

The 100-Car Naturalistic Driving Study is an instrumented vehicle study designed to collect a large volume of naturalistic driving data over an extended period of time. The researchers installed instruments and sensors in 100 vehicles that were then driven as ordinary vehicles by ordinary drivers for one year. Drivers were given no special instructions, no experimenter was present, and the data collection system was unobtrusive. In addition, drivers' own vehicles were instrumented for 78 out of the 100 vehicles.

The study collected data on 15 police-reported and 67 non-police reported crashes, 761 near-crashes (situations requiring a rapid, severe evasive manoeuvre to avoid a crash) and 8,295 incidents (situations requiring an evasive manoeuvre occurring at less magnitude than a near-crash). In this study, fatigue was judged to be a contributing factor in approximately 12% of crashes, 10% of near-crashes, and 7% of crash-relevant conflicts [29]. Fatigue was measured by an observer rating of drowsiness, measured on a scale from 0 to 100 in increasing severity of drowsiness. The scale was based on the Wierwille and Ellsworth [109] rating system for driver fatigue. This rating system is based on observable personal characteristics such as facial tone, eye blinks, eye closures, head movements, staring, lack of activity, eye expression etc.

5.2.4 In-depth investigation

In-depth studies investigate characteristics of crashes to find out whether fatigue may have played a role. In an in-depth study, Horne and Reyner [49] established that about 20% of crashes on motorways were sleep-related. The injury level of these crashes is quite high since no braking occurs.

In France, Philip et al. [90] applied the criteria from Horne and Reyner on serious injury crashes in the period 1994-1998. This study looked at single vehicle crashes under good weather and road circumstances on road segments without intersections. They found that about 10% of 68.000 analysed crashes were related to fatigue (as determined by the Horne/Reyner criteria). This is probably an underestimation since collisions with other vehicles that satisfied the Horne/Reyner criteria were not taken into account.

In Germany, a similar in-depth crash study established that about 24% crashes on a German motorway had to do with fatigue [63].

In Finland, all fatal road accidents are investigated in-depth by multidisciplinary investigation teams. The percentage of fatal accidents involving fatigue or falling asleep between 1995 and 1999 fluctuated between 16-19% (Hantula, 2000 in: ETSC [32]).

Haworth et al. [44] estimated sleep or fatigue to be involved in about 20 % of truck-involved fatal crashes. Based on a literature study involving both in-depth and questionnaire studies, Amundsen & Sagberg [1] found that fatigue was a contributing factor in 15 to 20% of truck crashes.

5.3 Fatigue and crash risk

The finding that fatigue is involved in 10-25% crashes does not in itself prove that fatigue increases crash risk. For example, it could be that drivers who are more fatigued also drive more kilometres than other drivers so that the risk per kilometre is the same for fatigued and non-fatigued drivers. Several studies have investigated the relationship between driver fatigue and crash risk and have attempted to quantify the increased risk. Often increased risk of particular groups such as young drivers or professional drivers derives from a combination of factors.

5.3.1 How dangerous is fatigued driving?

Several studies have investigated the relationship between driver fatigue and crash risk and have attempted to quantify the risk increase. Reviewing these studies, Connor et al [21] concluded that nearly all studies were limited in their ability to establish a causal relationship. Study limitations concerned design, biases, and in many cases, small sample sizes. Despite these limitations the better quality cross-sectional studies do suggest a positive relationship between fatigue and crash risk. A reliable estimate of the strength of the association cannot yet be given.

In a case control study of New Zealand drivers, Connor et al [20] compared 571 crash-involved drivers with 588 non-crash involved drivers driving in the same area and at the same times. Driver variables were taken from accident registration and additional interviews. Taking into account possible confounding variables (gender, age, socio-economic status, annual kilometres, speed, road type), they found a strong relationship between acute fatigue (based on loss of sleep the night before) and crash involvement. Crash risk was eight times higher for drivers with a score ≥ 4 on the Stanford Sleepiness Scale (95% confidence interval 3.4-19.7); 5,5 times higher for driving between 2 and 5 am (95% interval 1.4-22.7); and almost 3 times higher when drivers had slept for less than 5 hours in the past 24-hour period (95% confidence interval 1.4-5.4).

In a case-control study, Cummings et al [23] compared crash-involved drivers with a similar group of non-crash involved drivers at the same location, direction, time and day. They found the crash risk was fourteen times higher for drivers who had reported to have almost fallen asleep behind the wheel (95% confidence interval 1.4-147).

The data collected in The 100 Car Naturalistic Driving Study shows that driving while fatigued increases a driver's risk of involvement in a crash or near-crash by nearly four times [59].

Studies of professional drivers (bus, lorry, truck) show that it takes around 9 or 10 hours of driving, or 11 hours of work, before crash risk starts to rise [68]. Hamelin found that after 11 hours of work span the crash risk doubles. The effect of task duration is practically always entangled with the effects of the time of day and sometimes also with the length of time awake and previous lack of sleep. The duration of a trip may be of lesser importance compared to these other factors – many fatigue-related accidents occur after driving for only a few hours [98] [102]. Short trips can also end up in fatigue-related crashes because time of day and long and irregular working hours are stronger predictors of fatigue than time spent driving [15][114].

Connor et al [21]also note blind spots in the research on driver fatigue. The association of non-medical (lifestyle) determinants of fatigue with crash has not been the subject of thorough research. There is still a lack of knowledge concerning the contribution of increasing total hours of work, and shift schedules to driver fatigue. Whereas research into fatigue and sleep apnoea in truck drivers has led to awareness of these problems and some modification of work conditions [34][73][77], occupationally induced fatigue in potentially much larger numbers of commuters has received little attention.

5.3.2 Combination of factors

Frequently a combination of situational and individual factors contributes to increased risk of being involved in a fatigue-related crash. The increased risk may results from a mix of biological, lifestyle, and work-related factors. For teenage drivers, the strong biological need for sleep and going out in weekend-nights may combine to increase fatigue and risk [38]. For professional drivers and long distance drivers, both reduced sleep and long working hours combine to increase fatigue and risk [53][76][91].

Stutts et al [102] investigated both situational factors and individual differences in fatigue-related traffic risk. The database consisted of police accident reports and surveys from 312 drivers who fell asleep at the wheel, and surveys from 155 drivers who had caused an accident as a result of fatigue. The study used as a control group 529 drivers, who were responsible for an accident, which was not caused by fatigue and 407 accident-free drivers.

The researchers found that drivers responsible for a fatigue related accident had more often several jobs, were shift workers or had unusual working hours. In addition, these drivers reported to sleep less hours at the average, to feel more tired during the day, to drive more often at night-time and to have experienced drowsiness at the wheel more frequently. In comparison to drivers with accidents without fatigue origin, these drivers drove on average longer, were awake more time, slept less at night and used barbiturates more often. 23 % of the drivers with fatigue related accidents reported to have driven in the past year 10 or more times in a fatigued state. 19% of these drivers reported to have been awake more then 20 hours before the crash. The authors conclude, that the crash risk due to fatigue is significantly increasing, if the driver sleeps less than 7 hours. Compared to driver averaging 8 hours of sleep or more, drivers who sleep less than 5 hours per night on average are 6 times as likely to be involved in a fatigue related crash (versus not being in a crash at all).

5.4 Conclusions

- Fatigue-related crashes are often associated with high injury levels
- Fatigue is a major factor in a large proportion of road crashes (range 10-20%)
- Several studies suggest that fatigue is associated with increased crash risk
- The increased risk often results from a combination of biological, lifestyle- and work-related factors
- More scientific evidence is needed concerning the exact quantitative relationship between fatigue and risk.

6. Risk groups

Specific groups of drivers engage more frequently in fatigued driving and thus have a higher risk of being involved in a fatigue-related crash. According to reviews, groups of drivers that have a higher risk to be involved in a fatigue-related crash are young drivers (< 25 years); professional drivers; long-distance drivers; shift workers; drivers with sleeping disorders [75]. Below we focus on risks and circumstances for several risk groups:

- Young drivers
- Professional and truck drivers
- Shift workers
- Drivers with sleeping disorders

The section about risk groups is closed of with final Conclusions.

6.1 Young drivers

Based on a literature review, Lyznicki et al [65] concluded that younger drivers are a high-risk group for fatigue-related crashes. They suggested that higher risk of younger driver is primarily due to chronic sleep debt accumulated through poor sleep habits related to the young person's lifestyle. Within the general group of young drivers, teenagers may be even more susceptible to effects of sleep loss than young adults.

Several studies found that young drivers, and males in particular, were the most likely to be involved in fall-asleep crashes [88][49][71][9]. For example, Åkerstedt & Kecklund [9] studied the factors associated with involvement in early-morning crashes (from midnight to 6 am), controlling for driving exposure. They reported that the highest risk for early-morning crashes was for younger drivers. Their crash risk at this time was at least five times higher than their risk when driving at other times. The high risk for younger drivers was greatest for young males.

The age factor may also play a role with professional drivers. In a simulator study, Otmani et al [85] found that young professional bus and coach drivers had more difficulty to drive in a low traffic condition and felt sleepier during low traffic driving in the late evening than middle-aged professional drivers.

6.2 Professional and truck drivers

Fatigue is a particular problem for professional drivers, and especially truck drivers. In practice, the particular job demands of long-haul transport industry often interfere with normal rest. World-wide transport industry work practices include working long hours, prolonged night work, working irregular hours, little or poor sleep, and early starting times. Many truck drivers work more than 12 hours per day, of which at least 60% is usually spent driving [17]. A working week of over 70 hours is common practice for many owner drivers. These long hours of work may result in drivers obtaining less than the necessary 7 to 8 hours of sleep and cause fatigue [17]. In the USA about 20% of all crashes and fatalities involving a long-haul truck, occur between midnight and 6am, the peak period of driver fatigue (Blower et al., cited in: ROSPA [96]).

French research into lorry driver working times and habits showed that risk levels vary with three key factors as regards the general problem of fatigue [39][40][41][18]. There is an increased risk of crashes at night, an increased risk the greater the length of the working day, and also with irregular working hours.

Research points to an increased crash risk the greater the number of hours driven. However, studies show different results concerning the length of driving time needed before risk increases. Mackie & Miller [68] found some aspects of driving performance deteriorated after 8 to 9 hours driving. They analysed 750 truck crashes which clearly involved driver fatigue or were single vehicle crashes (which made it very likely they were driver fatigue related). They found twice the probability of a crash in the second half of a trip, as compared to the first half of the trip, and the odds of a crash started to rise after 5 hours driving. Folkard [36] undertook a meta analysis of several studies of hours of driving and crash risk. Folkard found that there was a rise in likelihood of a crash at two hours into the trip before risk dropped back to starting levels at 4 hours into the trip. The likelihood of a crash then started to rise again the more hours driven until at 11 hours the risk was higher than at any previous time. The US Federal Motor Carrier Safety Administration [33] has published data showing the relative risk of a fatigue crash and hours driven. As in Folkard's 1997 data and Hamelin [39], crash risk starts to rise after 10 to 11 hours of driving. The US data shows that the risk of a crash rises seven fold after this period of driving. In summary, the results of various studies are not quite consistent and should be interpreted with some caution. In these studies, the effects attributed to hours of driving may also have been influenced by a down turn in the circadian rhythms or by prolonged wakefulness [17].

The US National Transportation Safety Board (1995) examined 107 single heavy goods vehicle crashes where the drivers survived and records of their activities over the previous 4 days were available. 58% of those crashes were judged to be due to fatigue; and in 18% of those crashes the driver was asleep at the wheel. In the fatigue crashes the Safety Board found that more drivers had: an inverted sleep/waking cycle; driven at night with a sleep debt (chronic sleep shortage); had slept only 5.5 hours in the past 24 hours compared to 8.8 hours in other crashes not due to driver fatigue; and had fragmented sleep between night and day.

A Dutch survey study amongst 537 truck drivers investigated determinants of both chronic and acute fatigue (defined as actually dozing off or falling asleep behind the wheel) [53]. Surprisingly, drivers who worked for 60-65 hours per week did not feel more tired than drivers who worked for shorter time (52-56 hours). Factors that were linked to chronic fatigue were, in decreasing order of importance: few possibilities to learn new skills, competence or apply creativity; not taking the time to eat well; sleeping problems; relative ill health; being a parent; use of medicine; large pressure of working times on family life; smoking; large pressure of family life on work; lack of vegetables intake. Indirectly, long working hours play a role in the causation of chronic fatigue. The two factors indicating interference between professional and private life belong to the most important factors in explaining chronic fatigue.

In that same study, the factors that were most strongly linked with acute fatigue were in decreasing order of importance: lesser general health; amount of alcohol intake; good (comfortable) cabin climate; more frequent violations of official work and driving times regulations; being busy with other things besides driving (e.g. using mobile phone); driving singly instead of in a team; more often having work progress meetings; not having a fixed contract.

6.3 Shift workers

The shift worker cannot sleep when sleep is desired, needed, or expected by his own body, and thus, is likely to suffer from chronic sleep loss [4]. Not surprisingly, being engaged in shift work is associated with increased traffic risks. For example, a study by Folkard [37] showed that the risk of being in a single-vehicle accident at 3 o'clock in the morning was 50% above the baseline after four successive night shifts.

Fatigue-related crashes tend to occur in two distinct periods of the day – between midnight and 6 am, and between about 2 pm and 4 pm [72][96]. These periods coincide with typical low-points in our daily pattern of alertness, or circadian rhythm.
Drivers who work irregular schedules are most likely to be affected by the body's natural desire to sleep during the night. Studies on driver fatigue have typically used vehicle control and psychophysiological measures as indices of driver drowsiness. These studies have found that time of day has a larger impact on driver fatigue than time on task [15][77].

Shift workers form a large part of the working population. Approximately 24% of the European population work on a regular 8-hour schedule during daylight hours (07.00-18.00) and 5 days per week. 17% are engaged in shift work and 14% have long shifts (at least 10h) on a regular basis [4].

6.4 Drivers with sleep-breathing disorders

Obstructive sleep apnoea syndrome (OSAS) is a common sleep breathing disorder leading to a fragmented sleep and daytime sleepiness. There is evidence that persons with this medical condition have a higher crash risk. Terán-Santos et al [103] performed a case-control study that compared drivers who received hospital emergency help after a traffic crash with gender and sex matched group of patients who sought medical help for other reasons than chronic illness or a traffic crash. The analyses controlled for many factors such as alcohol use, use of medicines, body weight, and annual kilometres driven. The key result was that persons with sleep apnoea had a 6 times higher crash risk.

In a case control study, Teran-Santos et al [103] present findings from 102 drivers who had crashed on motorways and required emergency room treatment, compared with 152 randomly selected, primary care patients who had not crashed in the past two months. After in-home screening followed by laboratory polysomnography, it was found that those with OSAS (apnea-hypopnea index (AHI) >9.9) had an independent odds ratio of 6.2 (2.4–16.2) for having a crash. Consumption of alcohol further increased the risk of accident in those with OSAS. This study had the drawback that the cases drove around 7000km/year more than the controls, which may explain some of the increased risk observed.

In New Zealand, Yee et al [115] investigated sleep breathing disorders in people reporting for treatment in the Emergency Department of Wellington Hospital following a motor vehicle crash. Of a potential 120 drivers, 40 completed overnight polysomnography and sleep questionnaires. Fourteen of the 40 (35%) were found to have OSAS and 9 (22.5%) had another sleep disorder or chronic sleep restriction. Of the same sample, 15% had OSAS with an AHI of >15 – a severity that has been shown to increase the risk of motor vehicle crashes. Although this was an uncontrolled study and response rate is low, the results were comparable to the findings of Teran-Santos et al.

6.5 Conclusions

- Compared to the average driver, professional drivers, long distance drivers, shift workers, young drivers, and drivers with a sleeping disorder, have an increased risk to be involved in a fatigue-related crash
- Compared to average drivers, drivers with obstructive sleep apnoea syndrome may be six times more likely to be involved in a fatigue-related crash
- The increased risk often results from a combination of biological, lifestyle- and work-related factors.

7. Countermeasures

Driver fatigue countermeasures may be directed at drivers, transport companies, roads, or vehicles. Drivers may learn how to prevent driver fatigue by campaigns. Transport companies can introduce special policies to educate both drivers and management about the problem. Roads may be equipped with edgelines or centrelines that provide audio-tactile feedback when crossed over. In the future, legislation concerning working and rest hours may be further improved and vehicles can be equipped with devices that detect fatigue-related decrements in driver performance.

Below further attention is paid to particular countermeasures. We start out with the most general countermeasure Publicity campaigns. Since nearly all drivers have to cope with fatigued driving at least once in a while, general public education is an indispensable part of a countermeasure strategy. Next, we discuss more specific countermeasures such as, future possibilities for producing In-vehicle detection and warning devices and Legislation and enforcement. The discussion of countermeasures closes with a view on Fatigue management programs. The next section discusses the Need for further knowledge on countermeasures. This section closes with Conclusions.

7.1 Publicity campaigns

Publicity campaigns may raise awareness about the problem of driver fatigue and possible countermeasures. Possible campaign themes may include [35]:

- Driving when fatigued is a risk equal to driving drunk
- Tactical use of driver rotation, caffeine, napping
- Encouraging drivers to consider fatigue-related driving risk as a personal responsibility
- Educating the community on minimum sleep requirements and fatigue warning signs
- Challenging existing incorrect beliefs about personal ability to cope with fatigue
- Targeting specific populations (such as driving schools, sleep disorder clinics) with direct education.

Fatigue awareness campaigns have been used in USA, Australia, New Zealand, UK, France and Germany. 'Don't drive tired' messages feature on variable message signs in Europe and some US states. The UK Department for Transport has featured tiredness in its Think! Road Safety campaign since 2000. A qualitative research led to recommendations for improvement of the campaign:
http://www.thinkroadsafety.gov.uk/campaigns/drivertiredness/drivertiredness.htm

At the moment evaluations of campaign effects on behaviour and crashes are lacking. In general, a road safety publicity campaign, by itself, has only modest impact on attitudes and behaviour and no significant impact on crashes. Campaigns work best when combined with other interventions, such as enforcement of traffic laws and regulations, or provision of other safety services and products [24].

In the area of driver fatigue as in other health-related areas, awareness may not be enough to motivate drivers to adopt self-protective behaviour. Reyner & Horne [92] note that perception of sleepiness does not result in cessation of driving. Nordbakke & Sagberg [82] found that a large proportion of drivers did not get sufficient sleep before a long drive or did not stop and take a nap when they experienced sleepiness while driving. The drivers did not take these precautions despite their awareness of the risks involved in these behaviours. Although it is possible to educate or teach drivers to become more aware of the early signs of fatigue or sleepiness, it is probably very difficult to make them take a break from driving. Sagberg [98] believes that a strong motivation to reach their destination in time will make driver try various ways of combating fatigue. However, this is exactly the combat that the driver often loses. In this regard, a problem for public fatigue campaigns is that fatigued driving by private drivers is not punishable by law. It is therefore difficult if not impossible, at least where private drivers are concerned to link public campaign themes with enforcement or legal consequences. For professional drivers, the case is different since there is legislation and the possibility of enforcement concerning work and rest hours.

7.2 Infrastructural measures

Infrastructural measures to reduce fatigue-related crashes are improved delineation treatments (e.g. rumble strips, profiled lane markings), safety fences on the central reservation or at the road side. These measures are aimed at preventing drivers from driving off the road or hitting drivers from opposite directions. In various countries, these measures have been effective in reducing the chance of driving of the road or hitting a vehicle or obstacle [31].

Rumble strips are raised or grooved patterns on the roadway shoulder that provide both an audible warning (rumbling sound) and a physical vibration to alert drivers that they are leaving the driving lane. In addition to warning inattentive drivers, rumble strips help drivers stay on the road during inclement weather when visibility is poor.

The use of milled shoulder rumble strips (SRS) has been very effective in reducing single-vehicle run-of-the-road crashes caused by driver inattention, distraction, or drowsiness. Milled can be placed on either new or existing asphalt or cement concrete. A milled SRS is made with a machine that cuts a smooth groove in the roadway's shoulder. A SRS pattern results when SRS are repeated at regular intervals. This type of SRS modifies the pavement surface and provides for a vehicle's tires to drop, which creates high levels of vibrational and auditory stimuli. In Virginia, a 3-year (1997-2000) experiment with continuous shoulder rumble strips (CSRS) on the State's 1,476-kilometer interstate highway system showed that run-off-road crashes were reduced by 51.5 percent, saving an estimated 52 lives. Similarly, the judicious use of centreline rumble strips on undivided roads reduces the number of head-on collisions. http://safety.fhwa.dot.gov/roadway_dept/rumble/synthesis/pro_res_rumble_library.htm

Mackie & Baas [67] refer to shoulder and centre line rumble strips as audio tactile profiled (ATP) edge and 'no overtaking' centrelines. Based on New Zealand data, Mackie & Baas [67] report favourable benefit-cost ratios (BCR) for ATP- treatments on roads with relatively modest traffic counts and much higher BCRs from higher traffic counts.

7.3 In-vehicle detection and warning devices

Several related concepts 'Driver Vigilance Monitoring', 'Drowsiness Detection Systems', 'Fatigue Monitoring Systems' refer to in-vehicle systems that monitor driver and/or vehicle behaviour. These systems monitor the performance of the driver, and provide alerts or stimulation if the driver seems to be impaired.

Driver and vehicle monitoring systems may monitor both driver and vehicle behaviour. Information can be gathered from driver input and control of the vehicles lateral position and speed, such as acceleration, steering wheel movement and lane position. Likewise, user behaviour such as eye movement, facial feature movement, brain waves (EEG) and steering wheel grip may all be monitored.

Estimations of the approximate reductions expected with lane driver monitoring systems in Germany (assuming 70% penetration of the passenger vehicle fleet) were reported by eSafety Forum [30]. It was expected that 50% of fatigue-related crashes would be affected, leading to a 35% reduction in these crashes. This would equate to a 2.9% reduction in all crashes.

Fatigue warning systems (FWS) have been proposed as specific countermeasures to reduce collisions associated with driver fatigue. These devices employ a variety of techniques for detecting driver drowsiness while operating a vehicle and signal a driver when critical drowsiness levels are reached. However, the detection of driver fatigue using valid, unobtrusive, and objective measures remains a significant challenge. Detection techniques may use lane departure, steering wheel activity, ocular or facial characteristics.

Several authors point out that fatigue warning systems may result in driver behavioural adaptation [98]. A possible negative effect of in-car warning systems may be that driver's use them to stay awake and drive for longer periods rather than stopping and have a nap; i.e. risk compensation by relying too much on the safety system.

This was confirmed by a study of Vincent, Noy & Laing [107]. They evaluated a fatigue warning system that measured ocular and face monitoring, vehicle speed, steering position and lane position. They found the users of the system did not take more or longer breaks, and did not show different fatigue levels to controls. Drivers generally ignored the FWS signals received. The physical aspect of the warning signals used in the study had no impact on driver fatigue levels. Voluntary rest stops, lasting on average 30 minutes, only had a minor impact on decreasing driver fatigue with short-lived effects. The authors concluded that voluntary breaks were ineffective in substantially counteracting the effects of fatigue associated with prolonged night time driving. Whereas normally rested drivers may successfully use breaks to prevent or postpone fatigue during a daytime drive [91], the use of breaks seems less successful in reducing fatigue resulting from prolonged nigh time driving and associated sleep loss.

In Europe, the project AWAKE has furthered our knowledge about driver vigilance systems. The EU project AWAKE (System for Effective Assessment of Driver Vigilance and Warning According to Traffic Risk Estimation) (http://www.awake-eu.org/) has developed guidelines for fatigue warning systems. A successful approach for on-road driver fatigue detection has to combine driver state and driver performance measures [111]. The AWAKE project has adopted this approach.

The AWAKE project aimed to demonstrate the technological feasibility of driver vigilance monitoring systems. To do this the project also looked at the non-technical issues that influence the use of such systems. The theoretically developed AWAKE system employs both driver state measures and traffic risk measures to arrive at a conclusion about the need for warning the driver and the type of warning called for. The driver state measures include eyelid movement, changes in steering grip and driver behaviour (including lane tracking), use of accelerator and brake, and steering position. These measures are input to a driver warning system that determines if and what information or warning messages need to be communicated to the driver. “Traffic risk estimation” data are used to re-assess driver’s state and consequently, re-assess the conclusion about the type of warning needed. The risk of the traffic situation is estimated via a combination of data from digital navigation maps, anti-collision devices, driver gaze sensors and odometer readings. The project has produced several design guidelines for the assessment of driver vigilance and warning signals. These guidelines are fairly comprehensive. Although they do not address all questions, they are likely to influence future implementation of fatigue detection devices.

Despite progress made by the AWAKE project, there is still no golden standard and reference data for micro-sleep phenomenon. This hinders the success chances of further developing the tested systems. First, further research is needed to identify physiological data that are better able to distinguish between various states of sleepiness, inattention or stress). Currently, no single method exists that is commonly accepted to detect driver fatigue. Wright et al [113] have evaluated the sensitivity, intrusiveness, operational and market status of sleepiness detection devices. A subset of 15 devices was identified as being worthy of further evaluation.

7.4 Legislation and enforcement

European legislation has imposed regulations (EU 3820/85 and 3821/85) on the trucking industry to improve driver safety. The regulations limit the amount of time truckers are allowed to work during a 24 h period to a maximum of 9 hours per day, with the possibility of working 10 hours per day two days a week. After six consecutive working days, drivers are mandated to take a weekly rest period of at least 45 consecutive hours of freely disposed time. This legislation may not be enough, since sleep loss is cumulative and EEC law cannot influence sleep behaviour during weekends [89].

Driving hours regulations which are applied in Europe and a number of other countries are intended to reduce the risk of drivers suffering from fatigue. It seems self-evident, that if obeyed, these regulations will reduce the risk of crashes involving fatigue. However, ETSC [32] argues that the current European regulations are not very effective in delivering safety benefits. According to the ETSC, the EU regulations allow an average work span of 13 hours or more during one week, while the crash risk doubles after 11 hours of work span. ETSC [32] concludes that working and driving time are controlled in the same regulation. It is essential to reduce permissible driving time to an extent that will bring total working time within acceptable limits. Furthermore, the ETSC notes that there is no consistent enforcement strategy across the Union. There is a large variation in enforcement agencies and also a large variation in sanctions. Also, the legal accountability for driving hours violations – the driver or the company? – is not clearly worked out.

Jones et al [56] compared legislation concerning fatigue in Australia, Canada, United Kingdom and USA on eight criteria. These criteria were based on their established relationship with fatigue. These criteria were: time of day; the 24-hour rhythm; duration of sleep; quality of sleep; predictability of sleep; sleep deprivation; duration of task performance; and presence of short breaks. The authors conclude that for neither of four transport modalities (road, air, water, rail) legislation takes these criteria fully into account. They argue for a mix of prescriptive legislation and non-prescriptive guidelines (e.g. fatigue management programs) in order to obtain the best counter-fatigue strategy.

7.5 Fatigue management programs

'Fatigue management systems' aim to prevent fatigue-related crashes by introducing a set of interrelated measures, at different levels of the organization. These measures are directed at the management, the planning section, and the drivers. Typically, the measures include special driver training, new procedures, improved trip planning and feedback on crashes. Information about the effectiveness of these systems is still scarce. "Fatigue Management" programs in Australia and the United States are based on several starting points (SWOV Factsheet Fatigue in traffic: causes and effects):

- First of all by supporting the application of maximum driving and resting hours companies may take the human need for rest and sufficient night-time sleep into account.
- As a consequence, haulage companies have to plan the work so that drivers can really keep to the rules.
- Compliance control of these rules remains important. In addition, haulage companies should also have a certain responsibility for informing their drivers about the causes and results of fatigue.
- If possible company programs should pay attention to the influence of personal living circumstances (life style) of individual drivers and their own responsibility.
- Another possible task of haulage companies is screening drivers for sleeping disorders, especially sleep apnoea.

Expert opinion identifies a number of factors that determine the success of these systems [54]:

- Management and drivers have a positive view on the importance and usefulness of the fatigue management system;
- Somebody actively steers the process and takes responsibility for progress;
- Management clearly points out the importance of several fatigue-related measures in reducing risk;
- Clear company procedures and guidelines regarding safe behaviour;
- Feedback on crashes is used to increase insight into the problem of fatigue;

- Driver training is part of a progressive learning cycle.

The ideas about a Safety Culture for haulage companies clearly also fit in to this. The ERSO web text "Work-related road safety" provides further information on Safety Culture http://www.erso.eu/knowledge/content/60_work/strategies_measures_and_their_implementation.htm

A Driver Fatigue Management Plan (DFMP) sets out the requirements and procedures relating to how a company will schedule trips; roster drivers; establish a driver's fitness to work; educate drivers in fatigue management; manage incidents on or relating to commercial vehicles; and establish and maintain appropriate workplace conditions.

In relationship to driving and rest schedules, research may provide valuable information. Driving schedules should be planned to minimise exposure to prolonged driving under monotonous conditions during the more vulnerable times of the day and night [51]. A study among professional long-haul drivers showed that a 3-hour napping opportunity in the afternoon preceding a nightshift has beneficial effects on driving performance and alertness, measured up to 14 hours later [66]. A study among long-haul truck drivers indicated that single drivers were more frequently involved in critical incidents while exhibiting extreme drowsiness than were team drivers by a factor of 4 to 1 [58].

Fatigue management as part of safety culture

The importance of organizational culture for safety programmes is not just an idea, but has been supported by empirical research. Bomel Ltd [13] showed how organisational culture in the workplace is important in terms of levels of work-related road accidents. Cross-company comparisons showed that the lowest accident rate (and highest positive scores on a driver attitude scale) were shown by a company with 'clear driving standards and rules, excellent driver training and a policy to report and try and learn from all driving incidents'. The company with the worst accident rate (and most negative driver attitudes) had 'no formal driver training, unclear rules/reporting requirements, and relatively ineffective lines of communication'. Corbett [22] also regards organisational culture as a key component in road safety, and points out that there is a general societal tendency to 'blame working drivers for crashes rather than seek root causes that may be connected with the safety culture of organisations'.

Although the ideas of safety programmes are inspiring, practical implementation may proceed less than optimal, partly due to economic imperative. For example, Arnold & Hartley [3] interviewed 84 managers of transport companies in Western Australia on the implementation of fatigue management programs. Key results were the following. Few companies had a formal fatigue management plans or policy. More than two-thirds of companies either set daily driving limits of more than 14 h or did not set a limit at all. Half of the companies either set weekly driving limits greater than 70 h or did not set a weekly limit at all. Many of the companies that had limits for work hours did not communicate those limits to drivers but relied upon word of mouth. Many companies relied upon drivers' self-regulation for the management of fatigue. The authors conclude that promoting better fatigue management in the road transport industry requires first of all a cultural change.

7.6 Need for further knowledge on countermeasures

Up until now, very little research on the cost-effectiveness of measures to reduce the number of fatigue related crashes has been carried out (an exception is Sassani et al [99]). This is awkward because, first of all, it is already problematical to objectively determine if a crash was indeed a consequence of fatigue. Yet it is certainly something that needs to be taken seriously. This is why the objective determination of costs and benefits of fatigue management is seen internationally as one of the challenges in fatigue research during the coming years. Also, when one wants to implement fatigue detection systems on a large scale, their cost effectiveness will certainly be a topic of discussion; a lot more will need to be known.

Besides determining the cost-effectiveness of measures, further development of useable and reliable fatigue detection systems and the accompanying criteria is a subject of research that is getting a lot of attention especially in Europe. Determining the extent of the fatigue problem for road safety seems to be regarded as less relevant in Europe. One reason may be the consideration that it is sufficiently well known that fatigue is an important factor. In spite of this, a well-designed, large-scale epidemiological study on the risk-increasing effects of fatigue could be an important contribution to knowledge about this problem.

7.7 Conclusions

- Publicity campaigns may help educate the general public about the problem of driver fatigue and possible countermeasures. Care should be taken to provide drivers with clear and practical messages. It should be quite clear that drivers should prevent fatigue rather than try to overcome it, and that they should stop driving when they feel very tired.
- Within transport companies, fatigue management plans may be successful in combating driver fatigue provided they are endorsed at all company levels and part of a more general safety culture.
- Further improvement in legislation concerning driver fatigue will take time, but is a necessary part of the total solution. The current EU legislation does not take into account all factors relevant to fatigue and EU Member States legislations are highly variable in terms of legal rules for driving fitness for persons with a sleeping disorder.
- In the future, driving assistance systems may warn the driver when the driver or vehicle show signs of fatigue-induced behaviour.
- Knowledge about cost-benefit of various countermeasures is needed.

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