

# Sleepiness, crashes and the effectiveness of countermeasures

Consolidated report within ERANET node 15

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## Preface

This report is done in collaboration between several research groups in Sweden, Norway, the Netherlands and France, under the framework of ERANET node 15 priority. Except for the knowledge received, the EU added value lies in the joining of resources for a larger impact on knowledge, rather than having separate uncoordinated projects from different countries.

The overall aim of the work done is twofold; the first is intended to provide a deeper understanding of sleep related crashes and the reason behind them; the second is addressed at the effectiveness of different countermeasures. The aim with this report is to consolidate the results from the eight different studies that have been performed thanks to the ERANET node 15.

We would like to thank all of you that have contributed to all the work that has been done in the different projects and to all authors that contributed with their input.

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## Quality review

External peer review was performed on 20 April 2011 by Mats Gillberg and Jan Andersson. Anna Anund has made alterations to the final manuscript of the report. The research director of the project manager Jan Andersson, VTI, examined and approved the report for publication on 3 May 2011.

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## **Sleepiness, crashes and the effectiveness of countermeasures – consolidated report within ERANET node 15**

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### **Summary**

Research shows that the impact of fatigue/sleepiness on traffic safety is high.

The aim of this report is to summarize the findings of different studies conducted as part of the ERANET node 15 priority with a focus on driver sleepiness, its cause and possible countermeasures. It should be stressed that some of the studies are still ongoing at the time of writing (May 2010).

The project included two studies of the role of fatigue and sleepiness in road crashes. Crash victims filled in a survey which asked them about various aspects of sleep and sleepiness prior to the crash. The responses of these victims were compared to those of control subjects stopped on the road by the police and asked to fill in the same survey (administered by researchers). The studies were done in Sweden and France. This consolidated report includes only the results from the Swedish survey. The French study was delayed by financial complications but is now under way.

Other experimental studies were carried out within the scope of ENT 15 to evaluate the effects of commonly used countermeasures such as: blue light, physical exercise, rolling down the window and turning on the CD player. These studies were done in France and in Sweden. The French studies were delayed by financial complications but is now under way.

In addition to the experimental studies two reviews were carried out in the Netherlands. One summarizes the state-of-the-art of methods for counteracting sleepiness at the wheel while the other aims to map those risk factors associated with fatigued driving and discuss them in relation to appropriate interventions.

Finally, two studies were also carried out in Norway: the first is an empirical study about rumble strip effectiveness, specifically in relation to fatigued driving; and the second is a comprehensive review of promising programmes for the management of fatigue by employing organisations.

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To summarize, the present projects have shown that road crashes can to a considerable extent be related to sleepiness. Putative countermeasures, such as rolling down the window or playing music on the CD player, have no alertness enhancing effects, whereas blue light has such effects, but may be problematic for some drivers due to dazzle during exposure. According to driver reports, rumble strips reduce the severity of fatigue-related accidents. Previous studies have shown that taking a break, ingesting caffeine and taking a nap are efficient countermeasures against sleepiness. There are also several promising approaches to preventing sleepiness at the wheel through various intervention programs. This includes fatigue risk management programmes, which require further evaluation.

There is still a need for studies on other types of countermeasures, such as social interaction while driving, combination of alertness monitoring devices and evaluation of intervention programs. Individual differences in susceptibility to sleepiness are another important area of research. Most of the studies included focus on drivers of passenger cars. More knowledge about sleepy driving in professional drivers, especially truck and bus drivers, is needed with respect to the prevalence of sleepiness-related crashes, the underlying causes (e.g. the role of demanding work schedules and long work shifts) of severe sleepiness, and the effectiveness of commonly used countermeasures.



# 1 Introduction

The purpose of this chapter is to provide a background to the project and introduce the research aims. The specific aims will be presented in detail in each chapter, respectively.

## **Crashes and sleepiness**

Driver sleepiness have been estimated to be a contribution factor in at least 15–20% of the crashes (Connor et al., 2002; Horne and Reyner, 1999; Maycock, 1996; McCartt, et al., 1996; Stutts et al., 2003; Stutts et al., 1999). Norwegian data of in-depth accident investigations showed that sleepiness was involved in 29% of the crashes (Moe, 1999). Interestingly, sleepiness related crashes were more common than alcohol related crashes (11%). The 100-car study, in which approximately 100 cars have been monitored during a year, showed that driving under sleepiness resulted in 4 to 6 times higher accident/near-accident risk compared to baseline driving when the driver was in an alert state with high level of attention (Klauser et al., 2006). The prevalence of sleep related crashes (including near crashes) was estimated to 22–24% of all crashes. The number was surprisingly high since night driving was rare in the 100-car study. The US National Transportation Safety Board (NTSB) has in several reports concluded that 15–30% of the accident risk in transportation is due to fatigue (NTSB, 1999).

It should be emphasized that many of the studies above probably underestimate the proportion of sleep related crashes since often head-on and rear-end collisions are not included in this category of crashes. However, it appears that all accident types, except those related to overtaking show a clear night-time peak in risk, that most likely is due to sleepiness (when alcohol is controlled for, Åkerstedt et al., 2001). It also appears that many alcohol-related crashes, which mainly occur at night, equally well could be classified as sleep-related (Keall et al., 2005). This will also underestimate the contribution of sleep-related crashes.

In contrast, most national statistics find only negligible effects of fatigue on road accident risk. The reason may be that official accident investigations do not include fatigue-related issues systematically, as there is as yet no way of measuring it in non-laboratory life situations. Thus may result in an overlook of fatigue as a contributing factor. It seems to enter the mind of the investigator spontaneously and then triggered by factors such time of night of the accident and being a single vehicle accident. This oversight will obviously have consequences with respect to prevention. It may also be a lack of knowledge, routines and tools to ask the most relevant question.

## **The concept of fatigue / sleepiness**

Fatigue, tiredness, drowsiness and sleepiness are vague concepts that may be interpreted in a variety of ways by individuals and scientific disciplines. In the literature of driver sleepiness, terms such as fatigue, sleepiness and drowsiness are used interchangeably. In USA, the term fatigue is often used in the driver context, whereas European researchers often prefer the terms sleepiness or drowsiness. Nevertheless, the concepts sleepiness, drowsiness and fatigue seem to have the same meaning, i.e. they refer to the driver's level of wakefulness and whether the driver has shown signs of falling asleep at the wheel.

Sleepiness is operationally defined as a physiological drive to sleep (Dement and Carskadon, 1982). This is the latent, fundamental type of sleepiness that in some cases can be masked by surrounding factors, such as social interaction, stress, physical activity, coffee etc., and result in manifest sleepiness. Hence, the manifest sleepiness is often lower than the latent sleepiness.

### **The causes of drowsy driving**

The basic factors that determine sleepiness is circadian phase (which refers to the time of day, see Dijk and Czeisler, 1995), time since last awakening (Dijk and Czeisler, 1995), amount of prior sleep (Dijk and Czeisler, 1995; Jewett et al., 1999), and fragmentation of sleep (which refers to whether sleep was physiologically disturbed, see Bonnet and Arand, 2003). Sleep deficit/sleepiness accumulate across days with curtailed/disturbed sleep (Van Dongen et al., 2003).

In terms of road crashes, not all the components of the circadian/homeostatic regulation have been tested but the circadian effect (increased night time risk) is well established (Horne and Reyner, 1995; Åkerstedt et al., 2001). So is the amount of prior sleep (Connor et al., 2002). The context factor has seen less research but Thiffault and Bergeron (2003) have demonstrated soporific effects of monotonous driving, but sleep-related crashes are quite common also during city driving, which presumably is less monotonous than rural driving (Fell and Black, 1997).

Also an important factor is the duration of driving. Common sense suggests that fatigue should increase with the duration of driving and some studies seem to support this (Hamelin, 1987). However, most studies of time at the wheel are confounded with other factors like time of day and time awake. One Australian study has shown that most crashes occur within two hours of driving (Fell, 1995) but there was also a tendency for crashes to occur 15 minutes or less away from the destination also on short trips (Fell and Black, 1997). The latter was thought to depend on a loss of concentration with increasing proximity to the goal. Furthermore, a study on French motorways found no effects of 10 hours of driving on variability of lateral deviation but strong effects of a strong reduction of prior sleep (Philip et al., 2005). This study did, however, use 15 minutes breaks every two hours. Possibly continuous driving may have effects. A recent study examined the effect of extended driving duration at night and found that lane crossing increased for long driving sessions (Sagaspe et al., 2008). This suggests that extended driving at night may be a risk factor for crashes and therefore should be limited.

### **Individual differences in the consequences of sleepiness**

Nocturnal neurobehavioral performance varies widely between individuals and only certain subjects seem significantly affected by sleep loss (Leproult, 2003; Frey, 2004; Philip, 2004; Van Dongen, 2004; Van Dongen, 2004). It is of interest to find biological markers for sleep drive to identify vulnerable drivers to sleep deprivation or to identify responders to sleepiness countermeasures (i.e., coffee and blue light). Sleep duration, sleep architecture, and circadian characteristics are not explanatory variables (Leproult, 2003; Van Dongen, 2004; Taillard, 2006; Galliaud, 2008) of vulnerability to sleep loss. Sleep deprivation-impaired performance particularly in caffeine-sensitive subjects suggests that adrenergic mechanisms contribute to individual differences in waking-induced impairment of neurobehavioral performance (Retey, 2006). Retey et al. (Retey,

2005) have shown that a functional polymorphism of the adenosine deaminase gene (ADA) is associated with inter-individual variability in sleep architecture and sleep EEG in humans. In addition it is well established that there are major differences between drivers when it comes to for example speed and lateral control. Those are present both during alert and sleep deprived driving (Ingre et al., 2009). It could be that the individual differences are greater than inter-individual differences in relation to alert vs sleepy driving.

Another study (Viola, 2007) has shown in a healthy population that PER3 (PERIOD3 gene) polymorphism predicts individual differences in the sleep-loss-induced decrement in cognitive performance, and that this differential susceptibility may be mediated by its effects on sleep homeostasis (sleep latency, SWS, theta activity in the waking EEG). Concerning susceptibility to excessive daytime sleepiness, some studies have assessed the association between COMT genotype (catechol-O-methyltransferase is a key enzyme of the monoaminergic neurotransmission) and some neurological pathologies (narcolepsy, Parkinson disease). A study (Dauvilliers, 2001) reported a sexual dimorphism and a strong effect of COMT genotype on narcolepsy severity. Female narcoleptics with high COMT activity fell asleep twice as fast as those with low COMT activity during the multiple sleep latency test (MSLT), while the opposite was true for men.

Hormonal dosage may also make it possible to determine hormonal phenotypes (vulnerable/resistant to sleepiness and responder/non-responder to countermeasures). Salivary concentration of amylase is highly associated to sleep homeostatic pressure (Seugnet, 2006). In this context, we assessed in a pilot study (n=35 young healthy subjects) the predictive value of the salivary amylase concentration on driving performances under sleep deprivation. Another study (Spiegel, 1999) has shown that chronic sleep debt has a harmful impact on carbohydrate metabolism and endocrine function. It is known that chronic sleep deprivation modifies cortisol secretion (stress hormone) in humans with attenuation of the daytime rhythm and increase during the nocturnal period.

### **Occupational factors**

Occupational factors, such as irregular work hours and long working hours, has in some studies been associated with increased risk of car crashes (e.g. Stutts et al., 2003). It is well known that professional drivers that works at night is affected by severe sleepiness, but it may in reality be difficult to stop driving due to feeling sleepy because of time pressure (i.e. the cargo needs to be delivered just in time) and other sources of work-related stress. Thus, in many situations professional drivers will have to continue to drive despite being sleepy. However, it may also be that the drivers underestimate the risk of sleepy driving, and believe that they will be able to stay awake and avoid a sleepiness-related crash.

### **Alcohol**

Alcohol clearly causes sleepiness (Roehrs et al., 1989) and night time accidents in which alcohol is involved is often automatically ascribed to the alcohol effects. This, however, is probably partly erroneous since alcohol consumption will coincide with night time fatigue – both mainly occur during the night – and a large part of the alleged alcohol effect may be due to non-alcohol induced fatigue due to circadian or homeo-

static effects on sleepiness and driving performance. This issue has not, however, been studied before except for one study from New Zealand (Keall et al., 2005).

Alcohol also interacts with sleepiness in epidemiological studies (Philip et al., 2001) and the effects seem to be dramatic. (Åkerstedt et al., 2008). It has been demonstrated experimentally that even small amounts of alcohol, below the legal driving limit (0.5‰ in most countries), will interact with moderate amounts of sleep loss to produce higher levels of fatigue and performance impairment than either does separately (Barrett et al., 2004).

As far as we know there are no studies that have compared the prevalence of driver sleepiness with the prevalence of drunk driving. However, one may assume that driver sleepiness is at least as common as driving under the influence of alcohol.

### **Countermeasures of sleepy driving**

Because of conflicts between physiological needs and social or professional activities, developing safe and affordable countermeasures to sleepiness at the wheel is a key issue in crash prevention. To be well prepared before leaving in order to minimize the risk of sleepiness is high priority. While driving stopping the car is clearly the optimal countermeasure, yet many individuals continue driving. The reason for not stopping is unknown and probably differs between drivers. It has been shown (Anund, 2008a) that counteracting sleepiness with a nap (a presumably efficient method) was practiced by those with experience of sleep related crashes or of driving during severe sleepiness, as well as by professional drivers, males and drivers aged 46–64. One reason among others for not stopping could be related to safety problems at rest stops (especially for women), being far away from any possible rest stops, being relatively close to one's destination or to lack of insight in one's state of alertness or belief in one's superior ability to handle sleepiness. Other reasons could be related to motivation or knowledge about lasting countermeasures. Drivers have developed many strategies to fight sleepiness at the wheel. These strategies rely on popular notion measures like, rolling down the window, turning on the radio, starting a conversation with a passenger, or increasing speed which are among the most frequently used ones (Anund, 2008a). However, they do not seem to be effective, at least not as demonstrated in simulator studies (Reyner, 1998). Still, there is a possibility that the stimulating context of real life driving might combine with the simple countermeasures to provide sufficient alertness to ensure safe driving. This question would seem to be of considerable importance in relation to prevention of sleep related driving accidents.

Other countermeasures, including sleeping (or napping) and the use of alertness-increasing agents, such as caffeine or caffeine-containing beverages, are also much used by drivers. In real-life driving studies, nap and coffee (150–200 mg of caffeine) are efficient countermeasures of sleepiness at the wheel (Philip, 2006; Sagaspe, 2007). However, the effect of caffeine is quick (short onset: 30 min), but brief (1h30–2h) (Quinlan, 1997). Naps beyond 20 min can be counterproductive as they develop into a full sleep, leading to difficulty in arousing and a post-sleep "inertia" (e.g. "thick headedness" "heavy limbs", "difficulty in getting going"). Some subjects had difficulty napping and napping is more efficient in younger than in older subjects (Sagaspe, 2007). The "traditional" acute countermeasures (opening a window, turning on the radio etc.) while continuing driving is considered to be inefficient by simulator studies. Still this is the countermeasure that most drivers often use. The effect of them has not been evaluated and there is a need for more knowledge in order to know what to recommend

to drivers, but also to support them in order to keep them awake until next safe and secure rest area to stop at.

Exposure to bright white (polychromatic) light during night has an acute alerting effects (improve performances, reduce attention failures, suppression of theta-alpha activity of waking EEG) for review see (Cajochen, 2007). Recent studies indicate that very low intensity monochromatic light in the short-wave (460 nanometers, blue) range affects the human circadian timing system by inducing a phase shift similar to that of polychromatic light. Exposure to 2 hours of monochromatic light at 460 nm in the late evening induced a melatonin suppression concomitant with an alerting response and increased core body temperature and heart rate (Cajochen, 2005). Exposure to 460-nm monochromatic light for 6.5 hours during the biological night decreased subjective sleepiness, improved performances, decreased waking EEG power density in the delta-theta frequency range, and increased the high-frequency alpha range (Lockley, 2006). Short wavelength light is a countermeasure of sleepiness and its very low intensity (5 photopic lux or 116 scotopic lux) can be used during nocturnal driving.

Exercise modifies performance impairment induced by sleep deprivation. Alertness is improved immediately following exercise. Short bouts of exercise improve sleepiness and fatigue seen following sleep. Performance of tasks involving short-term memory, complex addition and auditory vigilance showed that sleep loss was associated with significant impairments on all tasks which may be reversed by exercise (Horne, 1975). However, Matsumoto et al. (Matsumoto, 2002) suggested that exercise during an extended period of wakefulness results in an increased risk in human error. It appears that the effects of exercise on cognitive and motor performance whilst exposed to sleep deprivation are still unclear.

During the last decades there has been a large increase in the use of rumble strips along the edge line of the roads for warning drivers against unintentional lane deviations off the road. The rumble strips are either milled into the road or consist of painted, profiled, lines. The rumble strips intend to alert the driver by producing noise and vibration when the drivers hit the strips with the wheels. Several studies have found reduced crash risk when rumble strips are implemented (e.g. Gårder & Alexander, 1995). A simulator study found that a rumble strip hit caused a temporary increase in alertness but that the same level of sleepiness was reached 2–3 minutes after the rumble strip hit (Anund et al., 2008b). Thus, rumble strips may be an effective countermeasure against certain types of crashes (e.g. single vehicle crashes), but it is more uncertain whether it affects driver sleepiness.

Fatigue management programs have been suggested as a promising countermeasure, although the evidence of their effectiveness is somewhat limited (Gander et al., 2011). Fatigue management focus on both managers and employees and the goal is to avoid the adverse effects of sleepy driving. Fatigue management programs often include measures related to increased awareness of the risk of sleepy driving, how the driver should plan sleep (prior to the work shift), how the driver should handle (counteract) sleepiness in order to avoid falling asleep at the wheel, or sleepiness-related crashes, and how work schedules should be organized to minimize the occurrence of severe sleepiness.

## 2 Aim

The overall aim is two folded, one is intended to provide a deeper understanding of sleep related crashes and the reason behind them; one is addressed at the effectiveness of different countermeasures.

The aim with this report is to summarize the different project results made so far in the different studies in relation to the ERANET node 15 priority. It should be underlined that some of the studies are at this date on going.

Research and evaluations show that the impact of fatigue/sleepiness on traffic safety is high. As long as decision makers in most of Europe do not quite understand the prevalence of sleep related accidents preventive measures are not likely to be initiated. An insight needs to be established. The priority is, therefore, on-site **crash investigations** to establish the relative impact of fatigue on safety. This is one the aims for the ERANET node 15 priority. The present project may also be used to obtain data on fatigue/sleepiness and road crashes on a national level, for the purpose of estimating prevalence data via formalized questions in police investigation or in hospital crash statistics data.

The second aim deals with countermeasures addressed both to the strategic level (fatigue management systems), to the tactical level (open window, listen to radio, blue light and moderate exercise) and finally to the operative level (rumble strips). In addition a multi-level Intervention Map would be designed, aimed at fighting sleepiness at the wheel to help designing, implementing and evaluating an intervention program that has a high likelihood of being effective.

The more detailed objectives with respect to the countermeasure studies are:

- To investigate whether “traditional” countermeasures – rolling down the window, turning on the radio to normal listening – would be useful in a real driving situation when sleepiness becomes acute.
- To investigate whether in-car blue light exposure would be useful in a real driving situation when sleepiness becomes acute.
- To investigate in a simulator study the effects of a bout of moderate exercise on participants’ driving ability.
- To assess the potential of rumble strips to reduce sleep-related crashes, by collecting questionnaires data from drivers who have fallen asleep during driving and determine the frequency of drivers (in per cent) awoken by rumble strips.
- To carry out a literature review on the effectiveness of company-based fatigue management.
- To carry out a review that evaluates existing countermeasures and fatigue measurement methods, with the purpose of further development of recommendations related to prevention and enforcements measures.

### 3 Sleepiness and the risk of car crash: a case control study

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#### **Introduction**

Driver sleepiness is believed to be a strong contributing factor to road traffic crashes (Horne & Reyner, 1999; Stutts et al., 2003). Acute sleepiness risk factors, such as driving during early morning hours or having insufficient sleep, was observed in 15% to 25% of the car crash injuries in New Zealand (Connor et al., 2002). Most studies are observational and describe the information about the crashes, whereas controlled studies are rare. One exception is the study by Connor et al. (2002), which used a case-control design and compared 571 car drivers involved in crashes (in which at least one driver was admitted to hospital or killed – “cases”) with 588 representative drivers (controls) recruited while driving on public roads. The results showed a strong association between indicators of acute sleepiness and the risk of an injury crash, whereas measures of chronic sleepiness showed no association with injury risk. The aim of the present study was to carry out a similar study in Sweden and examine the relationship between acute and chronic sleepiness characteristics, including disturbed sleep and other factors that may contribute to driver sleepiness, with the risk of crashes in which the driver was admitted to hospital. There is also an on-going French study (PI: Pierre Philip, University of Bordeaux) using the same design and methodology and the purpose is to compare the results between the countries.

#### **Methods and participants**

Data was collected during 12 months in two middle-sized cities; one in the north of Sweden (Umeå) and one in the south of Sweden (Kristianstad). The regions includes urban and rural areas and has a population of approximately 250,000 people. The regions have similar traffic exposures. The regional ethical committee in Stockholm approved the study.

The selection of cases included all drivers that were admitted to hospital (emergency unit) as a result of a car crash. Truck drivers, taxi drivers and emergency vehicles were excluded from the study. Fatal crashes were very few (<10 drivers) and were also excluded from the study. In total 408 cases were included in the study, which represents a response rate of 68%. An analysis of the non-responders showed that males were overrepresented (60% vs. 40% females) but that mean age was the same as for the responders.

The drivers that were admitted to the hospital were informed by a nurse or a nurse-assistant of the purpose of the study and were given a survey. In approximately 50% of the cases it was not possible to do a face-to-face introduction of the study. At those

occasions the survey and an information letter was sent home to the drivers. The control group (n=2,308, response rate: 95%) comprised a random sample of car drivers that were stopped by the Police. The selection of controls was based on the crash spots and the time of the crash. Thus, the groups were matched by time of day and the road characteristics. The cars were selected one by one and after the police check (that included a breath analyzer test of alcohol and a check of the driving license) were the drivers asked by the experiment leaders if they wanted to participate in the present study. If they agree to participate a survey was filled in at the roadside.

The data collection included a 6-page survey that was filled in at the hospital or at the Police stop. The survey included questions about demographics, work hours, driving duration, crash circumstances, acute measures of sleepiness (including sleep for the last 24 hours), chronic measures of sleepiness and impaired sleep (e.g. symptoms of sleep apnea and restless legs), self-rated health and alcohol/drug intake for the last 24 hours. The questions related to how the cases felt immediately before the crash was framed as “immediately before the police stop” for the controls. It took approximately 10 minutes to answer the questions. All participants received a cinema ticket after they had completed the survey. The medical records were collected for the cases however, the results are not reported in the present analysis.

## Results

Severe injuries were rare among the cases and more than 90% of the drivers had a minor injury that did not need hospitalization. The most common crashes were single-vehicle crashes (n=120), collision with vehicle lying behind (n=91), collision at intersection (n=64), and collision with vehicle in front of oneself (n=57). 63% of the crashes occurred on rural roads (defined as motorways or highways) and the peak crash time was between 12.00 and 18.00h (n=185 crashes). Nighttime crashes that occurred between midnight and 06.00h were rare (n=24).

The comparison between the cases and the controls demonstrated several significant differences. The cases included more females (47% vs. 34% for the controls,  $p<0.001$ ), younger drivers (mean $\pm$ SD, age: 37 years $\pm$ 15 vs. 46 $\pm$ 15 for the controls,  $p<0.001$ ) and more students/unemployed (18% vs. 8% for the controls,  $p<0.001$ ). It was also more common to work shifts among the cases (28% vs. 22% for the controls,  $p<0.02$ ). The cases contained more individuals with long sleep (+ 9 hours, 23% vs. 14% for the controls,  $p<0.001$ ) during the last 24-hours. The last main sleep episode was also poorer in the case group (15% vs. 10% rated their sleep quality as poor,  $p<0.002$ ). The case group also reported a higher frequency of falling asleep before the crash (for the control group the question referred to “before the police stop”); 3.5% vs. 0.1 for the controls ( $p<0.001$ ). The questions related to chronic sleep and sleepiness measures showed only one group difference; the cases included more individuals that reported poor sleep quality in general (21% vs. 12% for the controls,  $p<0.001$ ). Other variables related to chronic sleepiness, such as sleep apnea symptoms and a single item question on excessive daytime sleepiness did not differ between groups. Finally, there was also a group difference with respect to subjective health and 14% of the cases reported sub-optimal health (controls: 6%,  $p<0.001$ ). A multiple logistic regression analysis showed that the difference in “falling asleep before the crash/police stop” remained when the statistical model was adjusted for age, sex, alcohol/drug intake, sleep duration for the last 24-hours, sleep quality and self-rated health. In the multiple logistical analysis,



sleep apnea symptoms was associated with crash risk, although it was non-significant in the crude analysis.

## **Conclusion**

The results partly confirmed the findings observed in the study by Connor et al. (2002) and showed that acute sleepiness measures were related to car crashes and falling asleep at the wheel was the strongest discriminating variable. The chronic sleepiness measures showed few groups differences, although poor habitual sleep quality was higher in the case-group. The study has some limitations, for example it may be that alcohol/drug intake was under-reported among the participants. There was also a sex bias among the cases and the non-responders included more males. This bias might explain the unexpected observation that female sex was associated with car crashes.

The association between driver sleepiness and crash risk has practical implications for traffic safety and interventions targeted to injury prevention should focus on how to avoid specific behaviors related to sleepy driving, e.g. convince drivers to give priority to sleep before days with extended driving times, to increase the drivers awareness of the negative consequences of sleepy driving, and possibly also implementation of in-car technological countermeasures (e.g. fatigue warning systems).

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## 4 Evaluation of in-car systems that prevent sleepiness

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This report provides an overview of methods to prevent drowsy driving of drivers (Wilschut et al., 2009). Several preventive approaches were discussed such as the use of questionnaires, campaigns and fatigue management plans. A search for law enforcement instruments to prevent sleepiness at the wheel did not provide any instruments that could detect sleepiness of drivers objectively and reliably at present. There were four different driver groups defined which among the awareness of fatigue and drowsiness should be promoted professional drivers in the domain of freight traffic, professional drivers in the domain of passenger traffic, private drivers and drivers with sleeping disorders. The main part of the report focused on the state-of-the-art regarding drowsiness detection technology.

In order for a driver-based drowsiness detection system to be effective there are three main requirements that have to be fulfilled:

*1) The system should enhance safety, not reduce safety. The systems should not distract the driver or interfere with driving performance at any time.*

- The allocation of the driver attention while interacting with the system and controls remains compatible with the attentional demands of the driving situation. Thus, the human machine interface (HMI) should be optimal, for instance regarding the modality and timing of the drowsiness detection alarms.
- Installation in the vehicle should be a) securely fitted in accordance with regulations and standards, b) the system should not obstruct the driver's view of the road scene, c) the system should not obstruct vehicle controls and displays required for the primary driving task.
- The system does not distract or visually entertain the driver.

*2) The system should be valid, reliable, sensitive and specific.*

- Criteria have to be set at which point the driver should be warned for his drowsy state.
- The system should be specific and sensitive to measure drowsiness, otherwise a high amount of false alarms or misses will be issued. False alarms will cause a decrease in acceptance of the system by the driver.
- The system should be able to deal with high inter- and intra-subject variability.
- The signal-to-noise ratio should be high and loss of data should be minimal to achieve a reliable estimation of drowsiness.
- To detect drowsiness at the earliest stage, there is a need for online data processing and analysis.
- To be able to measure drowsiness reliably the system should work during all types of circumstances like varying illumination, drivers wearing sun glasses,

head and posture movements induced by both the driver and the vehicle and facial characteristics like heavy eye lids.

3) *The system should be non-intrusive*

- The system should be able to measure drowsiness without attaching equipment to the driver.
- The system should work in a highly automatic way.
- Calibration of a (eye tracker) system should be short and simple or unnecessary.

The drowsiness detection systems were subdivided into four types based on: physical activity, ocular measures, driving performance, or a multiple-measure approach. Different approaches have been taken in developing drowsiness detection systems and there are many products and ideas aimed at detecting drowsiness and preventing sleeping while driving. A considerable amount of these systems do not satisfy the non-intrusiveness requirement. For example, the NapZapper, a small device that is worn over the ear and triggers an alarm when head nodding is detected. Besides the fact that this system is intrusive it also produces many false alarms. Other systems require that the driver put on special glasses with eye tracker equipment like the Eye-com system. Non-invasive drowsiness detection systems can be based on physical activity, eye detection, driving performance and multiple measures. The multiple measure approach was considered promising and can provide a solution for the large variations between individuals when they are becoming drowsy. In addition the recent developments of drowsiness detection systems in the automobile industry were described. Unlike alcohol intoxication where the diagnosis of the driver impairment is relatively straightforward (BAC), there are no such direct commonly accepted criteria that can be related to driver impairment (Brookhuis et al., 2003). Because of the lack of this framework for drowsiness detection, the conclusion can be drawn that at the moment no single method or system exists that is commonly accepted and validated to detect driver fatigue. The way forward for the drowsiness detection technology is to implement a multi-measure approach by combining different type of measures, e.g. driving performance eye tracker data and time of day etc. In that way, the accuracy of drowsiness detection and prediction will be enhanced and will be able to deal with individual differences of expressing drowsiness while driving

The report concludes with a list of recommendations:

- Gain insight on the impact of sleepiness on traffic safety in your country. Naturalistic driving experiments can be used to provide detailed information on sleepiness and fatigue and the way it affects driving behavior and accident rates.
- Rumble strips have proven to be successful and reduced the number of accidents related to lane positioning in the USA (FHWA, 2001). This solution is not yet investigated for the Dutch roads.
- Promote and develop self-testing questionnaires that help the driver self-asses their fitness-to-drive.
- Target education and campaigns at different driver groups.
- Promote Fatigue Management Plans for middle- and large-sized companies in the domain of freight and passenger traffic to increase the awareness and to optimize duty schedules.

- Support development of an objective measurement of sleepiness that will make an important contribution to traffic safety. Monitor developments of in-car drowsiness detection systems that are of interest, but not (yet) reliable enough for legislation by the government.

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## 5 Multilevel Intervention Mapping with sleepiness in focus

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Driver fatigue is an important risk factor in traffic safety and an issue for both private and professional drivers. This report provides an analysis of risk factors related to fatigue-related road accidents, and describes intervention goals at multiple levels in order to reduce sleepy driving among drivers. Private drivers who are on their way to or from their holiday were assigned as the specific target group.

When initiating change, governmental agencies tend to jump quickly from problem to supposed solutions, without *systematically* applying theory and research evidence when developing intervention strategies. This can lead to less optimal use of resources with not as much impact as expected. This report, therefore, describes a broader approach that thoroughly examines promising intervention strategies and target groups, the so called Intervention Mapping approach (Bartholomew, Parcel, Kok & Gottlieb, 2001). The Intervention Mapping approach offers a framework for developing effective interventions at multiple levels, and integrates a variety of methods to prevent and decrease fatigue-related accidents.

Intervention Mapping supports making sound decisions about how to influence change in individual behaviour and in the environment of the individual. Intervention Mapping outlines six steps that have to be carried out, in order to arrive at a sound intervention program (see Figure 1). This report describes step 1 and 2.

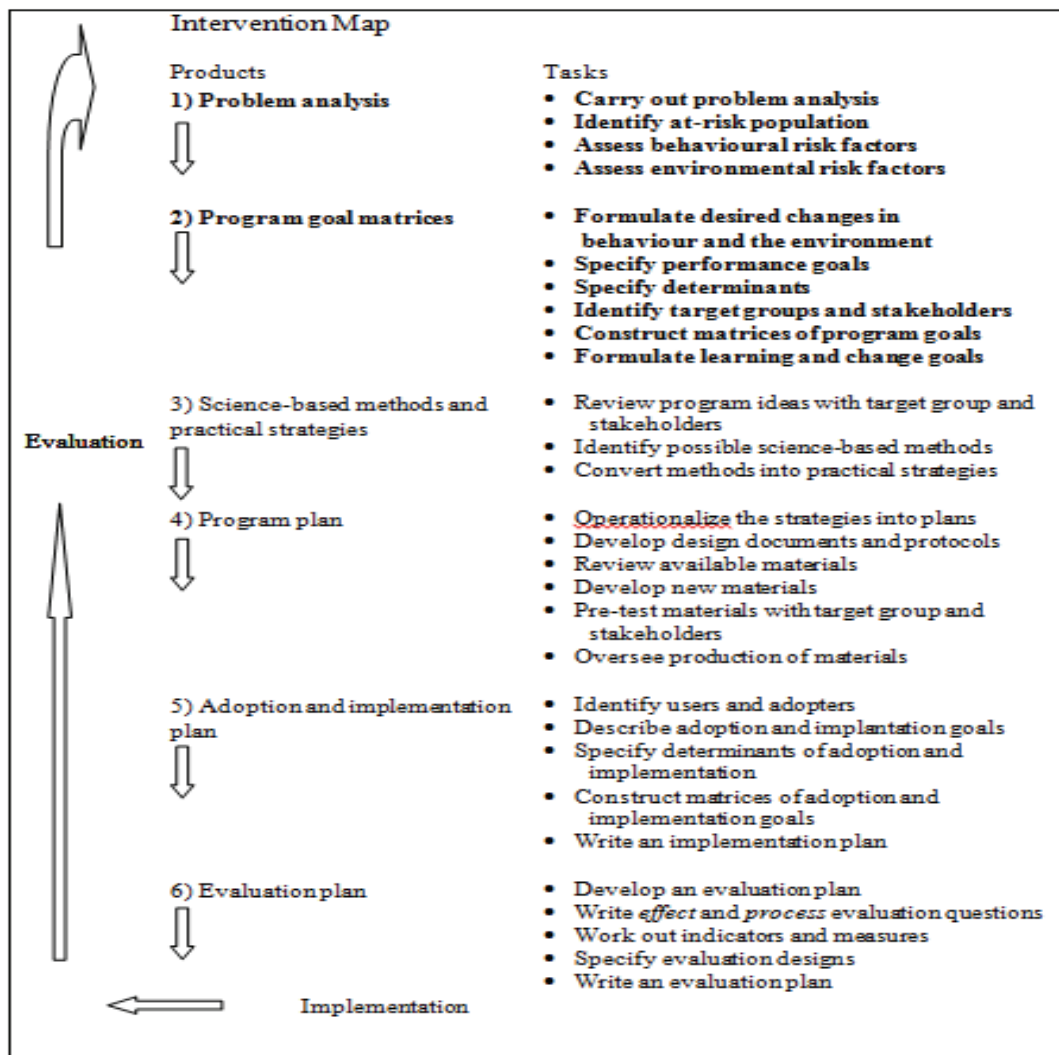


Figure 1 Intervention Mapping. Source: Bartholomew, et al. (2001).

In the first step an extensive analysis of the problem is made, as it is an essential step of developing intervention strategies. In the problem analysis, we get a clear overview of the problem in an at-risk population. Furthermore, we define the risk behaviours and environmental conditions that cause this problem. The risk behaviours are specified at an individual level. The environmental conditions are specified at an environmental level, which contains all sorts of environments in which the individual is embedded. Examples of these environments are: family, social networks, organizations, communities and societies.

In the second step proximal program goals are generated. A key principle is that interventions are most effective when they operate on multiple levels (Sallis & Owen, 2002). Behaviour is not only influenced by a narrow range of psychosocial variables linked to the individual; but also by a wide range of influences at different levels. Multilevel interventions, based on ecological/systems approach, targeting individuals as well as their interpersonal and societal environments, are therefore considered to be able to successfully reduce the number of fatigue-related road accidents. This second step provides the foundation of the interventions, by saying who and what will be expected

to change as a result of the interventions. The product of this step is a set of matrices that describes intervention goals at multiple levels, i.e. individual behaviour, the inter-personal level and the societal level.

Later on, these draft matrices can be further detailed by collecting additional information from the holiday drivers, their partner/peers and driving school directors and policy makers. After this, the more detailed matrices should form the input for the next steps of intervention mapping: developing science-based methods and practical strategies, designing program plans, implementation plans, and evaluation plans. A fully completed multi-level Intervention Map aimed at fighting sleepiness at the wheel helps designing, implementing and evaluating an intervention program that is feasible and that has a high likelihood of being effective.

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## 6 Effectiveness of traditional countermeasures

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### Introduction

Approximately 20% of motor vehicle crashes are caused by sleepiness or fatigue (Philip et al., 2001, Connor et al., 2002, Horne and Reyner, 1995, Fletcher et al., 2005). Therefore, the search of effective countermeasures against driver sleepiness is a key issue in crash prevention.

While caffeine (Horne and Reyner, 1996, Biggs et al., 2007, De Valck and Cluydts, 2001, Cluydts, 2003, De Valck et al., 2003), energy drinks (Reyner and Horne, 2002, Mets et al., 2010) and napping (Philip et al., 2006, Sagaspe et al., 2007) have been reported to improve driver alertness, listening to music and cold air have shown too transient and marginal effects in counteracting sleepiness in a driving simulator (Reyner and Horne, 1998). However, a recent Swedish survey depicted that drivers use turning on the radio and opening a window more frequently as countermeasure than drinking coffee or stopping for nap (Anund et al., 2008). This raises the question if those drivers apply rather ineffective countermeasures or if these countermeasures are more effective when used during actual driving, in contrast to simulated driving. Therefore, this study aimed at assessing the effect of listening to music and opening the window during real driving on motorway.

### Methods

In the experiment, 16 healthy individuals participated in the experimental group (mean age 43.13 + 8.93 years) and 8 in the control group (mean age 38.75 + 10.55 years). Half the subjects in each group were female.

A repeated measurements design was used with a (between) group factor for the application of countermeasures (16 drivers received countermeasures and 8 did not). Each subject performed two 90 min drives on the highway E4 between Linköping and Gränna (southern Sweden), during (i) day and (ii) night. The order of the day and night drive was counterbalanced.

The experimental group (n=16) received the following countermeasures in a counterbalanced order: (i) rolling down the window (**window**), (ii) turning on the CD-player to normal listening level (14) (**music**). The control group (n=8) did not receive any countermeasure at all.

The duration of each countermeasure application was 10min, in order to avoid habituation effects. During the day condition countermeasures were applied in a predetermined way: 20 min after passing the starting point and 20 min after the turning point. During the night-time condition, the application of countermeasures was based on subjective



sleepiness level. The particular cue to start using a countermeasure was 2 minutes after the driver rated KSS level 7. KSS was rated every 5<sup>th</sup> minute.

## Results

As expected, subjective sleepiness was higher during the night, in the homebound compared to the outbound direction and increased with time on task. Remarkably, the countermeasure group had a slightly, but significantly less steep increase in subjective sleepiness, as shown by repeated measures ANOVA. The analysis of the direct effects of the countermeasure supported this finding, which is also in line with the simulator study (Reyner and Horne, 1998). However, the reduction during countermeasure application was very small (less than a quarter KSS step) and was only limited to the intervals when countermeasures were actually applied as indicated by the mixed linear effects regression.

The main analysis of driving parameters was made on the part level, i.e. excluding the factor time, in order to account for the data loss (overtaking, sensor problems) and to avoid overvaluing the impact of acute traffic situations. While there was no effect of countermeasure, standard deviation of lateral position (SDLAT) significantly increased during the night drive compared to the day drive, and during the homebound compared to the outbound direction. Linear mixed effects regression on SDLAT indicated a very slight decrease in lateral variability during the actual countermeasure application. Subjects drove significantly closer to the left lane (**lateral position**) during the night and also in the homebound direction. **Speed** increased in the homebound direction, compared to the way out, and this increase was significantly more pronounced during the night. The experimental group decreased their speed during the night drive, while the control group did not.

The main analysis of sleepiness was carried out using subjectively reported sleepiness (KSS) and the EOG (electrooculogram) and EEG (Electroencephalogram) based indicator “Karolinska Drowsiness Score” (KDS). The latter has a metric that corresponds to the amount of time with signs of sleepiness that has accumulated within a given time frame. Signs of sleepiness is here defined as slow eye movements or alpha (8-12Hz) or theta (4-8Hz) activity in the EEG.

The reason for the reduction in speed during the window open condition is not clear. One might speculate that the draft from the window may have contributed. During the day drive, the variability of speed (**SD speed**) was increased compared to the night drive, which is probably reflecting changes in traffic density. The KDS<sub>mean</sub> was significantly higher in the homebound direction and was significantly affected by time. KDS<sub>max</sub> was increased during the night drive and while driving in the homebound direction. Furthermore, the time and interaction condition \* direction \* group reached the level of significance.

The direct effects analysis did not reveal any major differences between the effect of open window and music.

## Discussion

In essence, applying the in-car countermeasures, the music and open window conditions showed only marginal effects in counteracting the pronounced effects of night driving. In line with several previous studies, night driving strongly affected subjective sleepiness and driving performance (Ingre et al., 2006, Philip et al., 2005, Sagaspe et al., 2008, Torsvall and Åkerstedt, 1988), while the effect on physiological sleepiness indicators was less clear (Åkerstedt et al., 2010). The effect of countermeasure was very limited and might be strongest on the subjective level. Since the effect on subjective sleepiness was still minor, and the results suggested that the effect was limited to the intervals of actual countermeasure application it is very unlikely that the countermeasures masked latent sleepiness.

In addition, mixed effects regression showed a small effect of countermeasure application on lateral variability. No major differences between the two types of countermeasures (music /open window) were observed. Despite differences in design, both our study and the previous simulator study (Reyner and Horne, 1998) indicated that the effect of open window and music in counteracting sleepiness is marginal and transient. Therefore opening the window and listening to music might to a limited extent be useful when trying to find a stopping place in order to apply more effective countermeasures such as napping or intake of caffeine (Horne and Reyner, 1996, Philip et al., 2006, Sagaspe et al., 2007). One may also wonder if using weak countermeasures as the present ones might not mask an underlying sleepiness, thus adding to the risk. This needs further studies, however.

## Conclusion

In conclusion, the present study suggests, that despite the widespread common use (Anund et al., 2008), opening the window and listening to music cannot be recommended as countermeasures against severe driver sleepiness.

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## 7 Effectiveness of exercise

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### Introduction

Higher risk of accident is related to nocturnal activity when circadian clocks and sleep pressure increase sleepiness and decrease neurobehavioral performances. Performances assessed by simple reaction times remain stable for about 16 hr of wakefulness, and decrease thereafter to reach a dramatic impairment about 2–4 hr after the peak of melatonin (Cajochen, 1999). At that time the drowsiness that occurs has been identified as the reason behind fatal many individual and industrial accidents (Mitler, 1988). Nocturnal neurobehavioral performance varies as a function of age. They are also widely dependant of individuals and only certain subjects seem significantly affected by sleep loss.

Studies have demonstrated the efficiency of some countermeasures such as sleeping (or napping) and the use of alertness-increasing agents (i.e. caffeine) on driving. If alertness is improved immediately following exercise (Tomporowski, 2003), during the day, this potential countermeasure has never been study during the night. Furthermore, Matsumoto et al. (Matsumoto, 2002) suggested that exercise during an extended period of wakefulness results in an increased risk in human error. The effect of physical exercise on cognitive and motor performance depends both on the intensity and the duration of the exercise (Etnier et al., 1997; Kamiyo et al., 2007; Tomporowski, 2003). It is a physical exercise of moderate intensity and duration which appears to ameliorate brain function (Clarkson-Smith & Hartley, 1989; Hogervorst et al., 1996).

Consequently, moderate physical exercise may minimize the declines of driving performances due to sleep deprivation. Furthermore, these effects may be dependent of the age of the participants.

### Participants

Two groups of 12 young and 12 middle-age males have been selected. They were free of any exclusion criteria (questionnaires, polygraphic recording (respiratory sleep disorders and periodic leg movements) and actimetry (sleep efficiency, Total sleep time)).

### Methods

In this study, standardized bouts of 20 minutes of exercise at 50% of the maximal aerobic capacity of the participant has been compared with either those of rest (placebo) or caffeine (2\*200 mg) on 6 hours night-time simulator driving performance (Figure 2).

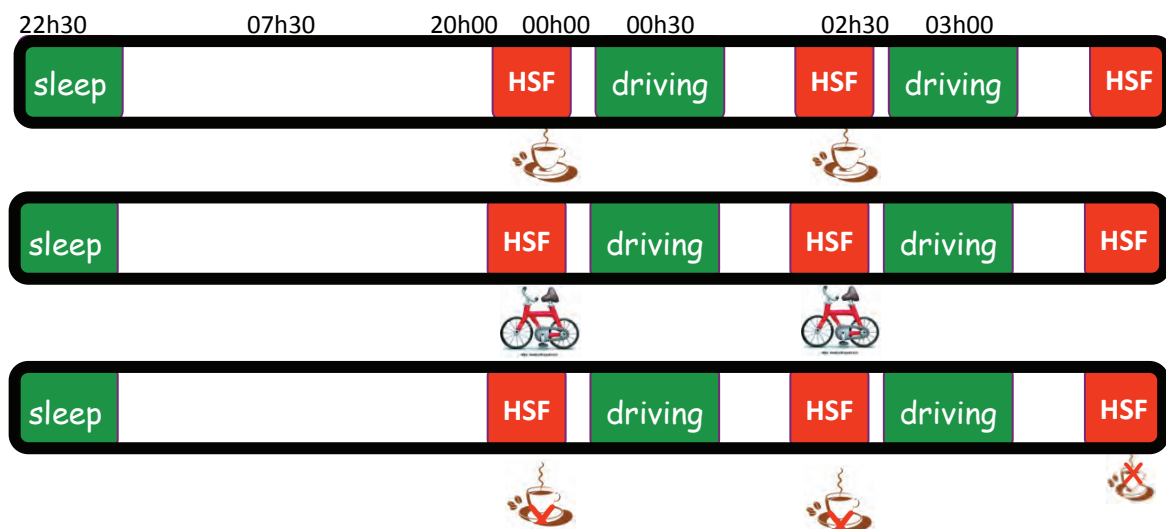


Figure 2 Study design of different type of treatment (Coffee – exercise – placebo).

Beverages (coffee and placebo) and exercise were undertaken at 0:00 and 2:35 and participants had to drive just after, 2 hours from 0:30 to 2:30 and 2 hours from 2:55 to 4:55.

All participants drove 2x200 km (250 miles) on the same 2-lane highway at a constant speed of 130 km/h. Performance criteria on driving simulator were number of inappropriate line crossing (ILC) and standard deviation of the position of the car. Self-rated sleepiness and self-rated fatigue were also recorded before and after each period of driving.

### Statistical analysis

Binomial negative regression. One-, two- and three-way analysis of variance for repeated measurements (ANOVA).

### Results

There are still 2 participants to record (2011-04-10) and as it is a double-blind study, we have to wait for the code of coffee-placebo administration to do statistical analysis. Nonetheless, a comparison between responses to driving of young and middle-age participants after exercise show that the later are less sensitive to sleep deprivation and that exercise as a countermeasure is more efficient in these participants. These effects are observed for the 4 hours of driving.

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## 8 Effectiveness of blue light

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### **Background:**

At night, driving ability is impaired by sleepiness induced by sleep deprivation. To meet societal demand, it is necessary to develop countermeasures to fight this drowsiness. Currently, caffeine and naps are effective countermeasures but they have some limitations (differences between individuals in terms of efficiency, limited efficiency duration, side effects). The development and evaluation of new and easily usable countermeasures is wished for the prevention of accidents related to sleepiness. A light wavelength of 480 nm (light blue) improves performance and increases the night time arousal. This countermeasure will be tested under real driving conditions. Since there are differences between individuals in the driving ability degradation induced by sleep deprivation and in the countermeasures efficiency duration, this study will also attempt to determine whether some gene polymorphisms (e.g. PER3, COMT, ADORA2A and ADA polymorphism) or some hormone concentrations (e.g. cortisol and amylase concentrations) involved in regulating the sleep / wake cycle can explain the differences between individuals. Basal cognitive performance of subjects could also explain these inter individual differences. Age is an important factor to consider because half of fatal and nonfatal accidents involving young people occur at night and nocturnal performance were considerably more impaired in young than in older subjects.

### **Objectives:**

The main objective of this study is to compare the effects of continuous blue light exposure during driving with those of coffee (2\*200 mg of caffeine) and coffee placebo on 4h night-time driving performance in young (20–25 years) and middle-aged (40–50 years) healthy volunteers. Our aims are also to determine the effect of age on the effectiveness of these countermeasures (blue light and coffee) and to examine individual differences (cognitive, genetic and hormonal) in the impairment of neurobehavioral functions induced by sleep loss and in the effectiveness of countermeasures (blue light and coffee). The whole study will permit to improve nocturnal driving ability with countermeasures to sleepiness in sleepy drivers in a real situation and to reduce the accidental risk in sleepy drivers according to their own physiology. The outcomes will also be to develop markers able to predict the risk of sleepiness at the wheel or the optimal countermeasure for each driver according to their own physiology.

## **Method:**

The experiment on the effect of blue light on the nocturnal real driving performance included 48 subjects (24 young and 24 middle-ages). The experiment was open label, randomized, crossover, and comparative versus referent countermeasure of sleepiness: coffee (2\*200 mg of caffeine) and placebo.

- Selection period: without treatment between selection and inclusion visits to check the absence of exclusion criteria with questionnaires, polygraphic recording (respiratory sleep disorders and periodic leg movements) and actimetry (sleep efficiency, total sleep time).
- Acute treatment period: each volunteer will be randomly allocated to receive either continuous blue light exposure during driving or 2\*200 mg of coffee or placebo of coffee before and during break with at least 1 week between treatment. All participants will drive 400 km (250 miles) on the same 2-lane highway for 4 hours. After 2 hours of driving (200km, 125 miles) subjects will take a 15-minute break. The night-time driving session will start at 1:00 AM and Stop at 5:15 AM. Saliva will be collected before and after the driving session and after sleep recuperation. Cognitive tests and blood samples will be performed another day.

The main outcome measures will be the number of inappropriate line crossings (ILC) and the standard deviation of lateral position (SDLP) identified from the video recordings. These measures were selected because epidemiologic findings have shown that 65% of sleep-related accidents occur after an ILC. The variability of lateral position of the vehicle is a measure that quantifies the stability of the trajectory. Since SDLP increment ultimately results in lane crossing into the adjacent traffic lane, SDLP can be regarded as an index of driving safety. The others criteria were self-rated sleepiness and fatigue during driving ; sleep latency, sleep efficiency and time course of EEG slow wave activity during subsequent sleep ; chronotype, caffeine sensitivity, habitual sleep patterns, reaction time and percentage of errors at cognitive tests, PER3, COMT, ADORA2A and ADA polymorphism, saliva cortisol and amylase concentrations before and after the driving session and after sleep recuperation.

## **First results:**

Actually, 22 participants (14 young and 8 middle-ages) completed the whole experiment.

3 participants (1 young and 2 middle-age) complained about dazzle during blue light exposition and were thus removed.

Results from the 19 other participants showed that age, countermeasures and time of driving session influenced the driving performance ( $F(2,30)=4.69$ ;  $p<0.05$ ). Indeed, for middle age participants, the number of ILC with placebo was higher during the 2<sup>nd</sup> night-time driving session than during the 1st night-time driving session ( $p=0.003$ ), whereas this was not the case for young participants ( $p=0.51$ ). Moreover, it was found that both countermeasures (coffee and blue light) improved the number of ILC of middle-age drivers during this 2<sup>nd</sup> driving session ( $p<0.001$  and  $p<0.05$  for coffee and blue light respectively).

Our first results thus suggest that middle age subjects are more sensible to sleepiness and fatigue than young drivers. Moreover, blue light impairs performance driving in



14% of subjects (dazzle). Among drivers who tolerate blue light, some of them present a benefit as important as caffeine. These subjects belong largely to the mature group.

The study ends in June 2011. The final analysis will confirm the beneficial effect of blue light on driving performance in sleepy drivers. It will also demonstrate individual differences in the impairment of neurobehavioral functions induced by sleep loss and in the effectiveness of countermeasures.

## 9 Reports of rumble strip interactions by drivers who have fallen asleep at the wheel

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### **Introduction and aim**

Rumble strips are seen by road safety planners as systematic interventions that may help prevent fatigue-related accidents. There is little evidence, however, for how or even whether rumble strips intervene to prevent specifically those accidents related to fatigue in real-world driving. In a large scale survey we therefore asked drivers who actively recalled falling sleeping behind the wheel, about their interactions with rumble strips.

### **Method**

Self-report data were collected on the fatigue and rumble-strip experiences of 2,567 accident-involved Norwegian drivers who were not-at-fault for the accident. This was done by including relevant questions in an internet survey, invitations for which were sent to over 30,000 drivers involved in an accident over the preceding 12 months (whether or not they were at fault).

### **Results**

The share of drivers reporting they could recall a time when they had nodded off behind the wheel was 26 per cent. Responses of these “sleeping” drivers were then analysed to draw the following conclusions:

- Rumble strips were present in 28 per cent of cases of sleep behind the wheel.
- Rumble strips woke 64 per cent of those drivers sleeping on roads on which rumble strips were present.
- The share of sleep-behind-the-wheel incidents resulting in a road departure is lower if the sleep occurs in the presence (1.9 per cent) rather than absence (4.9 per cent) of rumble strips.
- There is little evidence that being woken by rumble strips “panics” the driver and results in more serious consequences (either driving off the road or into the opposite lane).
- It is likely that being woken by rumble strips increases the chance that the consequence of sleepy driving is less serious in nature i.e. driving outside the edge-line rather than off the road.

### **Discussion and conclusions**

As far as we know, this is the first time that large-scale reports of real-world driver experiences are available to supplement evidence that rumble strips reduce accident numbers by reducing the severity of consequences specifically of fatigue-related driving.

Our analyses show that real-world driver experience supports claims that rumble strips act by reducing the severity of the consequences of fatigued driving. Most notably we found that significantly fewer sleep-behind-the-wheel incidents resulted in road departure accidents where rumble strips were present.

In considering the findings it should be remembered that they are based on driver recall; and in particular that the saliency of rumble strips in the memory may depend on whether or not the driver drove over them. We recommend therefore that these findings be validated by objective studies that further inform about the mechanism of rumble strip effects, so that rumble strips may be more effectively deployed by road authorities in the future. Analysis of data from naturalistic driver studies would be particularly informative in this regard.

### **Reference**

Phillips, R.O. & Sagberg, F. (2010). Woken by rumble strips. Reports from drivers who have fallen asleep at the wheel. TØI Report 1094/2010, Oslo: Institute of Transport Economics.

## 10 Managing driver fatigue in occupational settings

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### Introduction

Fatigue is a major cause of road accidents (Horne and Reyner, 1995; Philip, Vervialle et al., 2001). It has the potential to affect any driver, but is an increasing problem for professional drivers who must drive further than ever before to enable their employers to compete in an increasingly global 24/7 economy (Gertler, Popkin et al., 2002; Jettinghoff, Starren et al., 2005).

Through delivery at organisational level, Fatigue Management Programmes (FMPs) could be more effective than mass media campaigns for tackling the problem of fatigue in professional and private drivers alike. The company is more able to target its employees using tailor-made measures, and it can more effectively monitor and manage fatigue outcomes. Systematic assessment of FMPs carried out to date is lacking, but is needed to evaluate their efficacy and, if appropriate, encourage the wider uptake and implementation of FMPs by relevant road transport companies in the EU.

### Aim

This report is a review of company-based programmes for fatigue management based on a literature search. It aims to:

- Assess the extent to which FMPs are based on current research
- Describe and catalogue various component measures of FMPs
- Assess qualitatively the accident reduction potential of FMPs
- Document knowledge gaps and research needs as a basis for subsequent studies aimed at quantifying the effectiveness of FMPs.

### Results

*Current research on occupational driving fatigue – influences, outcomes and management*

A substantial proportion of truck drivers routinely experience fatigue in a way that influences their performance (Feyer, Williamson et al., 2001; Barr, Yang et al., 2005). The consequences of this are implicit in the high prevalence of bus and truck driver accidents – especially serious ones – in which fatigue is the main causal factor (Boivin, 2000; Hartley, 2007; Craft, 2009). To tackle the problem there has been substantial research to identify factors associated with fatigue in private and occupational driving. This finds that a routine, extended, non-interrupted sleep obtained at night is the most effective way fatigue can be limited, implying an important role for the individual driver in fatigue management (Arnold, Hartley et al., 1997; Smiley, 1998; Rupp, Wesensten et al., 2009). Other research suggests that good sleep hygiene and a healthy lifestyle should be promoted among drivers, who should also be screened and treated for health conditions associated with fatigue (Knipling, Hickman et al., 2003). Fatigue risks associated with physiological and psychosocial influences during and outside work

hours should be carefully considered, as should those risks particular to younger and older drivers (Holland and Leutzinger, 2003; Barr, Yang et al., 2005).

The most important organizational level influence on fatigue appears to be the driver's schedule (Dinges, Maislin et al., 2006), not least because it determines whether the opportunity for sleep is:

- long enough for sufficient recuperative sleep in the context of demands placed on the driver
- given at a time of day that is appropriate for recuperative sleep
- routine and predictable.

A driver's schedule also prescribes the time of day at which the driving is performed, a factor which is strongly linked to self-reported driver fatigue and fatigue-related incidents in operational environments (Smiley, 1998). More general research suggests that by designing jobs, organizations also prescribe the extent to which drivers can manage their own fatigue, and the knowledge, information and feedback they are given in order to do so (Parker, 2002; Furnham, 2005). The prevailing safety culture of the organization is strongly implied in the level of fatigue risk that will be perceived by the driver as acceptable, and in particular what a driver perceives that other drivers do about fatigue (Parker, Axtell et al., 2001; Arboleda, Morrow et al., 2003). Research also suggests that fatigue risks will be increased if fatigue-related behaviorally anchored competencies are not used as the basis for driver selection and recruitment (Arnold, 2004). The external driving environment may also be a factor for fatigue development in long-haul trucking (Brown, 1994).

Various outcomes of fatigue can be measured to guide its management. These include (i) direct reports of fatigue as *explicitly* experienced by drivers; and (ii) the effects of fatigue *implicit* in cognitive or driving performance, aspects of driver physiology, and various organisational outcomes such as near miss incidents, accidents, costs due to lost productivity, absenteeism, turnover, reduced morale, increased wear and tear on equipment, and driver health and wellbeing (Åkerstedt, 1990; Knippling, 1998; Kecklund, 2009; Wilschut and Caljouw, 2009).

The company can intervene at four levels to control factors associated with fatigue and manage associated fatigue outcomes. It can:

- (i) limit the consequences of fatigue on driving performance
- (ii) prevent a fatigued driver from sleeping
- (iii) prevent fatigue developing during driving
- (iv) prevent a driver entering a vehicle while fatigued.

Analysis suggests the organisation should focus on targeting measures at levels (iii) and (iv) (Phillips and Sagberg, 2010). Specific measures should be selected by the individual company based on the findings of a needs analysis in which subjective fatigue, driver sleep, behavioral indicators of fatigue and/or driving performance are recorded over a period to inform the subsequent intervention.

Management of fatigue can be assisted by tools and technologies in the following areas:

- Programme implementation – fatigue policy development, needs analysis tools, competency development (Jettinghoff, Starren et al., 2005).
- Driver, manager or other stakeholder education – training modules to increase knowledge and awareness of fatigue, outline coping strategies, or explain how diet and health is connected to fatigue (Rosekind, Gander et al., 1996; Griffin and Neal, 2000; McCallum, Sanquist et al., 2003).
- Schedule development and analysis – software packages available based on biomathematical models can help account for sleep history, circadian influences and in some cases sleep inertia; the models predict future fatigue risks (Fletcher and Dawson, 1998; Booth-Bourdeau, Marcil et al., 2005; Åkerstedt, Anund et al., 2008)
- Fitness-for-duty measurement – using relatively well-established psychovigilance tasks, which can be performed in the cabin on palm-top computers (Jay, Dawson et al., 2005), and bench-top instruments for pupil analysis (Heitmann, Bowles et al., 2009).
- Driver performance assistance – eye-closure monitors to warn a driver that he is fatigued (Dinges, Maislin et al., 2006); and devices that can help drivers with the physical effort of driving in high winds (e.g. SafeTRAC).

Particular considerations should be made when using these tools. Modular training packages should be adapted to suit the particular organisation in which they are used. Any training should be designed based on a needs analysis for that organisation, outlining the competencies that need to be trained (Rosekind, Gander et al., 1996). The effects of training packages on actual behavior, performance or operational measures are not clear, and directed group discussions may be a more inexpensive alternative (Gregersen and Morén, 1990).

Scheduling tools are useful ways to implement evidence-based knowledge on fatigue in ways that managers can understand, and in some cases practicality and functionality has been demonstrated. There are some problems to address: manager over-reliance on fatigue risk predictions; that they do not account for considerable inter- and intra-individual variations in fatigue proneness; and that they only consider a few of the many influences on fatigue (Dawson, Noy et al., 2010).

More field studies are needed to assess the validity of fitness-for-duty indicators. Although still in development, technology that can measure and assist driver performance is becoming an increasingly realistic option, especially for large long-haul companies.

Surprisingly, no tool is available that helps managers select FMP elements according to the particular contingencies of the organisation.

#### *Managing fatigue at organizational level – pros and cons*

Industry developments and increasing recognition about limitations of hours of work regulation has led to the growth of organizational-level management of fatigue and FMPs, especially in Australasia and the USA (Phillips and Sagberg, 2010). Other lines of evidence also support that organisational-level management of fatigue would be beneficial (Clegg 2000; McCallum, Sanquist et al., 2003).

However, FMPs have potential drawbacks. They are expensive to implement, and small companies are likely to be daunted by the staff consultation, policy drafting, technology purchase, documentation, auditing and change in organisational culture that FMP implementation may demand (Dawson and McCulloch, 2005). A challenge for regulatory authorities is therefore how they can encourage companies to take on more responsibility for fatigue management (Neville, 2000). Recent trends are towards persuading companies that they need to manage fatigue like any other risk, within an effective safety management system (Moore-Ede, 2010).

### *FMP evaluation*

A robust evaluation is required to learn whether an FMP has been successful and/or inform its further development (Campbell and Stanley, 1963). Operational limitations will prevent ideal experimental design, but organisations should at least aim to evaluate a time series of measures recorded over two periods, each lasting at least several months, one before and one after the intervention (Williamson, 2008). Ideally, the change between periods should be compared with a corresponding change at similar sites or organisations where there is no intervention.

Many independent evaluations of FMP interventions need to be carried out and reported to inform regulatory authorities, safety associations, politicians and transport organisations about their effects. Alongside the change in outcomes reported, evaluations should report on the culture and context of the organisation involved. Only then will we be able to begin generalising about the effects an FMP is likely to have for a given organisation.

### *Analysis of an inventory of FMPs / FMP guidelines*

To qualitatively assess FMPs carried out to date, we retrieved and reviewed a total of 61 documented FMPs (Phillips and Sagberg, 2010). The programmes range from a single measure implemented by a single company to comprehensive guidelines issued by a regulatory authority. They come from North America, Australasia and Europe. Fifty-three per cent are described for the road sector, 23 per cent for aviation, ten per cent for rail and 11 per cent for the maritime sector. Forty-seven per cent are pilot or demonstration projects carried out by regulatory bodies, safety associations, research institutes or universities. Forty-two per cent are descriptions or evaluations of manuals, “toolboxes” of elements, codes of practice, standards or guidelines for FMPs issued mostly by regulatory authorities.

We found that the most commonly implemented FMP components among the 61 programmes described were schedule management, education and sleep disorder management. In other words the FMPs reported employ elements described in the research literature as serving to tackle the causes of fatigue. Encouragingly, this suggests that current FMPs are evidence-based.

Furthermore several FMPs incorporated additional elements suggested by research as promoting the management of fatigue by the driver. These include feedback on sleep or fatigue levels, with personal or training advice on coping strategies that might be effective (Gertler, Popkin et al., 2002; Moore-Ede, Heitmann et al., 2004). Sleep contracts were also used in some FMPs, and there is some research basis for this (Holmes, Baker et al., 2006).

Guidelines on FMPs have been issued by authorities or institutes (Gertler, Popkin et al., 2002; Booth-Bourdeau, Marcil et al., 2005; Friswell and Williamson, 2005; Gall, 2006; Gander, Hartley et al., 2010). Although they are nearly always evidence-based, the effect of implementing the guidelines is not normally evaluated. The guidelines emphasize the three core elements above. Commitment to fatigue policy and a need to address the work environment are also emphasized, and these elements are not uncommon in FMPs actually implemented by organisations.

However, several guidelines recommend measures that do not often appear in reports by organisations actually implementing FMPs. These include fitness-for-duty monitoring, explicit promotion of an open reporting ('just') culture, competency-based selection, and recruitment and procedures to ensure the fatigue of temporary or contract personnel is addressed.

For FMP implementation, resistance to change is a recognised issue (Gertler, Popkin et al., 2002; Jettinghoff, Starren et al., 2005). Transport companies have attempted to tackle this using nominated fatigue management coaches or champions; visibly effective demonstration projects; involvement of all stakeholders from the outset; multi-level, multi-disciplinary project teams; and end-user participation in FMP design.

The majority of FMP evaluations are not controlled. The time the evaluation measures were taken in relation to the programme roll-out is often not clear. Many of the available evaluations are not independent. Most outcome measures reported are training outcomes or reports of subjective fatigue. Evaluations of organisational context coinciding with FMP implementation are wholly lacking.

### **Knowledge gaps and research needs**

In reviewing the research we identified several research needs (Phillips and Sagberg, 2010). Primarily there remains a need to improve understanding of the causative relationship between fatigue and safety outcomes in order to design effective measures for fatigue and help convince organisations to take on the problem (Williamson, Lombardi et al., 2010). Likewise there is a need to map fatigue effects as they diffuse through organisational systems.

Despite increasing numbers of FMPs, we still know little about what most of today's road transport companies actually do to manage fatigue. An industry survey to chart safety culture in EU road transport companies and link this to the way they manage fatigue would improve understanding. Knowledge of the drivers and limiters of FMP uptake would also help design measures to increase the number of FMPs implemented.

This latter recommendation assumes that FMPs are effective, and we still don't know that they are. Neither do we know which FMPs are suited to what types of organization. Development and publication of a simple-to-use evaluation tool to standardize and promote robust evaluations by organizations would help researchers reach valid conclusions about FMP effects. A better understanding of the organizational contingencies for different FMP elements is also required.

Knowledge of the normal variability in fatigue levels within and between individual drivers is required, as is a better understanding of how different influences on fatigue interact.

Finally, we still know relatively little about the effectiveness of incentives and sleep contracts as FMP elements.



## Recommendations

Using the FMP inventory it is also possible to highlight recommendations for road transport companies wishing to implement an FMP.

From the outset the FMP should be underpinned by a clear fatigue policy, which should in particular explicitly set out how managers and drivers should deal with the paradox between need for punctual delivery by driver and driver need for rest (conflict between fatigue management and logistics). Organizational conditions important to FMP acceptance and effectiveness should be explicitly considered and changed if necessary e.g. management trust, openness of reporting culture, driver autonomy. Procedures to explicitly address the fatigue of temporary or contract personnel should be referred to.

As part of implementation there should be up-front consultation with key stakeholders, and procedures to manage resistance to change. Behaviorally anchored competencies should be described and used as a basis for recruitment and selection in line with fatigue policy. An important issue to address is how to increase the visibility of driver fatigue as an issue to all stakeholders.

The FMP measures themselves should be selected based on a company-specific needs analysis to prevent driver entering a vehicle while fatigued, and prevent fatigue developing during driving. In addition to core FMP elements (schedule management; education; health monitoring and treatment) the company should consider the use of valid, usable, acceptable, practical, reliable, cost-effective technologies to assess fitness for duty as they become available. The company should be careful to ensure through training that those using scheduling software do not over-interpret group-based predictions of fatigue risk.

It will be important to evaluate the intervention independently, using a battery of implicit and explicit measures of fatigue, not least to enable the FMP to be evolved against stated aims. While a competitive organisation may have little reason to openly report the results of FMP evaluation, we recommend that regulatory bodies encourage open reporting by transport companies through promotion and funding of independent evaluations.

Finally, we recommend that the incorporation of FMPs as part of normal HSE management in **all types** of companies (i.e. not just road transport companies) be considered as a way to improve the limited impact of road safety campaigns on employee fatigue during private driving.

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## 11 Conclusions

The present projects show that road crashes can to a considerable extent be related to sleepiness, in particular to the extent that one has nodded off while driving. Putative countermeasures, as rolling down the window, or playing music on the CD player have no alertness enhancing effects, whereas blue light has such effects, but may be problematic to use for some drivers due to dazzle during blue light exposition. According to driver reports, rumble strips reduce the severity of fatigue-related accidents. Previous studies have shown that taking a break, ingesting caffeine and taking a nap are efficient countermeasures against sleepiness. There are also several promising approaches to preventing sleepiness at the wheel through various intervention programs. This includes fatigue risk management programmes, which require further evaluation.

The project included two studies of the role of sleep in road crashes in which the victims filled in a survey with respect to various aspects of sleep and sleepiness prior to the crash. This was compared to control subjects interviewed after being stopped on the road by the police and asked the same questions (by the researchers). The studies were done in Sweden and France. This consolidated report only includes the results from the Swedish site. The French study was delayed by financial complications but is now under way.

In the Swedish study 408 cases and 2,308 controls completed the survey. The latter was oversampled to maximize the possibility of obtaining a representative control group. The results show that the best predictor of any type of accident that leads to a hospital visit was the report of having had nodded off during the drive. Also low age, subjective health, sleep apnea, nodding off during daytime contributed in a moderate way. Alcohol used was very rare. This is in contradiction with the results of Connor et al., 2002.

Furthermore within the scope of ENT 15, there were several experimental studies evaluated effects of countermeasures as: blue light, physical exercise, rolling down the window and turning on the CD player.

The experimental study of rolling down the window and turning on the CD-player as sleepiness countermeasures was carried out with 16 participants. The particular countermeasures were selected because they had been demonstrated to be the most common countermeasures. It was run between 0300h and 0500h for duration of 90 minutes. The results showed a pronounced rise of subjective and EEG based (sleep intrusions or slow eye movements) sleepiness during the drive. However, there were no clear effects of the countermeasures on the sleepiness indicators, except for a marginal trend towards a reduction of subjective sleepiness. A previous study of the same countermeasures applied in a car simulator showed a similar lack of effects (Reyner & Horne, 1998). The latter and the present results suggest that rolling down the window or putting on a CD is unlikely to be an efficient countermeasure against sleepy driving.

The study of blue light as a countermeasure is close to completed (missing 16 participants) and was preliminarily analysed. It was carried out with 48 participants during a night drive on a real road between 0100h and 0500h. The results showed that blue light was about as efficient alertness enhancers as was caffeine, especially in middle-age drivers. However, 14% of the participants were “dazzled” by the blue light and could not complete the study. Previous studies of blue light indicate alertness enhancing effects of blue light (Lockley et al., 2006; Phipps-Nelson et al., 2009). However, there may be other side effects of blue light and further research is needed to guard against such effects. The final analysis will confirm the beneficial effect of blue light on driving

performance in sleepy drivers. Individual differences in the impairment of neuro-behavioral functions induced by sleep loss and in the effectiveness of countermeasures will examine.

The study of moderate exercise as a countermeasure is close to completed (missing two participants). It was carried out with 12 young and 12 middle-aged men. This was a simulator study with standardized bouts of 20 minutes of exercise at 50% of the maximal aerobic capacity of the participant has been compared with either those of rest (placebo) or caffeine (2\*200 mg) on 6 hours night-time simulator driving performance. The study is a double-blind and therefore the code of coffee-placebo administration is not possible resolve until all results are available. The study is still ongoing. Nevertheless, a comparison between responses to driving of young and middle-age participants after exercise show that the later are less sensitive to sleep deprivation and that exercise as a countermeasure is more efficient in these participants. These effects were observed for the 4 hours of driving. That young drivers are more sensitive is in line with other findings (Lowden et al., 2009) and may be explained by a combination of “better” sleep and worse capability to resist the feeling of sleepiness (Åkerstedt & Kecklund, 2001; Dijk & Duffy, 1999).

An empirical study of the effects rumble strips in relation to accidents was carried out in Norway. In total 2,567 accident-involved drivers who were not at fault were surveyed. 28% of the drivers reported that they had fallen asleep at the wheel, 64% of these were woken by the strip, and the presence of a rumble strip reduced the risk of a road departure. There was little evidence of panic reactions after hitting the rumble strips. The results agree with simulator studies of rumble strips (Anund et al., 2008b) and with field studies of accident incidence on road sections with and without rumble strip (e.g. Gårder & Alexander, 1975).

Apart from the empirical studies also two reviews were carried out. These were intended to collect broad information on methods for counteracting sleepiness at the wheel.

One review concerned an evaluation of approaches that can prevent sleepiness at the wheel. Questionnaires, campaigns, fatigue management plans were reviewed. The main focus was on drowsiness detection techniques. A main conclusion is that no such techniques are available today, at least not with an established validity and reliability. A multi-measure approach may be the way forward for now.

A second review focused on fatigue management in occupational settings. This includes training of operators in the mechanisms of fatigue and resulting risk levels, as well as in the most efficient countermeasures. It also includes reporting systems of fatigue incidents and pre-testing of driving schedules for fatigue sensitivity using mathematical models. It was judged that this is a promising way of increasing awareness about fatigue risk and of reducing road crashes, that is relevant to both professional and private drivers alike, as long as they work for some sort of organisation. There is a need, however, for further research on successful interventions.

A third review involved multilevel intervention mapping approach to fight sleepiness at the wheel. With regard to the latter the first step involves an extensive analysis of the problem – risk behaviors, population at risk and environmental factors. In the second step proximal program goals are generated – who and what will be expected to change as a result of the interventions. This results in draft matrices that form the input for the next steps of intervention mapping.

There is still a need for studies on other types of countermeasures, such as social interaction while driving, combination of alertness monitoring devices and evaluation of intervention programs. Individual differences in susceptibility to sleepiness are another important area of research. Most of the studies included have the focus on drivers of passenger cars. More knowledge about professional drivers, especially truck and bus drivers are needed. This is both in relations to prevalence of sleepiness driving and to the reason behind, but also to effectiveness of countermeasures.

## 12 Practical implication and recommendations

Sleepy driving (fatigue at the wheel) is a common cause of road crashes and attempts to reduce crash risk need to focus on fatigue countermeasures in addition to drink-driving and speeding. Structural measures to counter fatigue include more forgiving road environments, rumble strips, monotony-reducing road construction, availability of and information on rest areas. Another approach concerns driver support in terms of sensors that monitor sleepiness levels (provided sufficiently sensitive and specific devices can be developed). Another approach is Fatigue Risk Management, that is, combined use of existing knowledge on sleep inducing mechanisms and countermeasures with evaluation of the situation-specific fatigue-inducing properties of driving, in order to better inform schedule managers, drivers and other stakeholders (e.g. families) using training, software support systems and other forms of communication. There is a great need for research and validation work in most areas discussed above.

There is still no proof that there are countermeasures that is working on severe sleepiness. The only promising one is to avoid driving. However, one should be causes to generalize the results to professional drivers. They need to handle sleepiness while driving more appropriate. This is an area were more research needed both regarding the prevalence of sleepiness, the reason behind, and countermeasure to support them to reduce the hours driving under sleepiness.



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