SLEEPINESS AT THE WHEEL

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ABSTRACT

Prevention of road crashes is a major priority in most countries. The present thesis focuses on driver sleepiness and road crashes. The general aim of the thesis was to explore the relation between driver sleepiness and driver impairment and the changes that precede a crash or a similar safety-critical event, but also what constitutes good reliable behavioural / physiological measures of sleepiness. A second question concerned particular groups and situations – is post-night shift driving characterized by increased sleepiness, is more complex driving also affected by sleepiness, and are younger drivers affected by sleepiness behind the wheel more than older drivers? A third question concerned countermeasures. What are the preferred self-administered countermeasures and what are the effects of the structural countermeasure like rumble strips?

The results showed that driving home from the night shift was associated with an increased number of incidents (2 wheels outside the lane marking, from 2.4 to 7.6 times). There were a decreased time to first crash, increased lateral deviation (from 18 to 43cm), increased eye closure duration (0.102 to 0.143sec), and increased subjective sleepiness. Moreover, a night of prior sleep loss increased levels of established indicators of sleepiness at the wheel even if the driving situation required frequent interactions with other cars on the road. However, blink duration (mean and variability) was shorter during overtaking, compared to other situations, even during the drive home after a night shift. Young drivers showed a higher risk than older drivers. Sleepiness increased with time on task, with higher levels for young drivers than for older ones, and the results indicate that younger age is associated with greater susceptibility to sleepiness at the wheel. In another study it was shown that a sleepy driver leaving the lane and hitting the rumble strip will be awakened and show an improved driving behaviour. However, the sleepiness signs (KDS, lateral deviation, eye blink duration) returned 5 minutes after the rumble strip hit. It was concluded that various aspects of sleepiness are increased before a rumble strip is hit and that the effect is very short-lived.

In a methodological study a combined scoring of Electrooculogram and Electroencephalogram recordings, the so called Karolinska Drowsiness (KDS) scoring, is a promising method for estimating physiological sleepiness under conditions of driving. At KDS level 30 % (meaning sleepiness signs 30% of the time within a given time frame) the risk of lane departure is 2.6 times higher; at KDS 40% the risk of lane departure is more than 6 times higher. The relation between KDS and variability of blink duration shows that at KDS 30% the blink duration has changed from 0.16 seconds (level 0) to 0.18 seconds

The thesis has also shown the importance of taking into account driver group when working with countermeasures against sleepiness related crashes. The most common countermeasures among drivers were to stop to take a walk, turn on the radio/stereo, open a window, drink coffee and to ask passengers to engage in conversation. None of them has so far been proven to be effective. Counteracting sleepiness with a nap (a presumably efficient method) was practised 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 years. The most endorsed means of information to the driver about sleepiness was in-car monitoring of driving performance. This preference was related to the experience of sleepy driving, not being a professional driver and male gender.

In conclusion, the studies show that sleepiness is a major determinant of impaired driving performance, and many drivers need to be educated of alertness enhancing strategies that can prevent the negative consequences of driving when wakefulness is reduced.

LIST OF ORIGINAL PAPERS

I
Torbjörn Åkerstedt, Björn Peters, **Anna Anund** and Göran Kecklund
Impaired alertness and performance driving home from the night shift: a driving simulator study.
Journal of Sleep Research (2005) 14, 17–20

II
Anna Anund, Göran Kecklund, Albert Kircher, Andreas Tapani and Torbjörn Åkerstedt
The effects of driving situation on sleepiness indicators after sleep loss – a driving simulator study.
Industrial Health, Accepted

III
Anna Anund; Göran Kecklund; Anna Vadeby; Magnus Hjälmdahl; Torbjörn Åkerstedt
The alerting effect of hitting a rumble strip - a simulator study with sleepy drivers.
Accident Analysis and Prevention, (2008) 40, 1970-1976

IV
Anna Anund, Göran Kecklund, Björn Peters and Torbjörn Åkerstedt
Driver sleepiness and individual differences in preferences for Countermeasures.
Journal of Sleep Research, (2008) 17, 16–22

V
Anna Anund, Göran Kecklund, Björn Peters, Åsa Forsman, Arne Lowden and Torbjörn Åkerstedt
Driver impairment at night and its relation to physiological sleepiness.
Scandinavian Journal of Work Environment and Health, (2008) 34, 142–150

CONTENTS

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
EOG	Electrooculogram
EEG	Electroencephalogram
EMG	Electromyogram
ESS	Epworth sleepiness scale
FFT	Fourier Fast Transformation
HOS	Hours of service
HZ	Hertz
KDS	Karolinska Drowsiness Score
KDT	Karolinska Drowsiness Test
KSS	Karolinska Sleepiness Scale
NREM	Non rapid eye movement
MS	millisecond
MV	microvolts
PSG	Polysomnography
REM	Rapid eye movement
SCN	Suprachiasmatic nuclei
SD	Standard deviation
SE	Starndard error of mean
SEK	Swedish Krona
SMS	Safety management system
SSS	Stanford Sleepiness Scale
SWS	Slow wave sleep
VAS	Visual Analogue scale
WHO	World Health Organisation
Vitaport	Mobile recorder for physiological measures

1 INTRODUCTION

One major cause of road crashes is driver sleepiness (NTSB, 1999). The general aim of this thesis is to provide new knowledge on sleepiness and crash risk on the road by investigating driver impairment associated with driver sleepiness. In addition, countermeasures will be emphasized.

The introduction of the thesis starts with a section about traffic fatalities and injuries as a public health problem and driver sleepiness involvement in crashes; followed by a section describing sleep, sleepiness and basic sleep/wake regulation. The next section deals with the cause and characteristics of sleep related crashes and finally countermeasures against sleepiness are discussed.

1.1 TRAFFIC FATALITIES AND INJURIES

1.1.1 A serious public health problem

According to WHO data (Peden, McGee, & Sharma, 2002) deaths from road traffic injuries account for around 25% of all deaths from injury. Worldwide, the number of people killed in road traffic crashes each year is estimated at almost 1.2 million, while the number injured could be as high as 50 million people (Peden *et al.*, 2004). Injuries including deaths represent 12% of the global burden of disease, the third most important cause of overall mortality and the main cause of death among people aged 1–40 years . Worldwide, injuries including deaths are dominated by those due to road crashes. The total number of road traffic injuries including deaths are forecast to rise by approximately 65% between the years 2000 and 2020 (Peden *et al.*, 2002).

Also in Europe road traffic crashes are a major public health issue, claiming about 127,000 lives per year and about 2.4 million injured people. Road traffic crashes are the leading cause of death among young people in Europe and are predicted to increase in countries with low or medium income as they become more highly motorized (Racioppi, Eriksson, Tingvall, & Villaveces, 2004). The WHO has called for research into *"improving the evidence base for practices in crash notification, trauma care (such as fluid resuscitation and head injury management) and rehabilitation, rescue measures (such as the use of helicopters and ambulances) and for interventions related to such risk factors as alcohol, fatigue, medicines and recreational drugs"* (Racioppi et al., 2004).

In Sweden, the government already in 1997 adopted a vision of zero fatalities in road crashes. The present trend, however, is not in line with this "vision zero" – in 2006 in total 445 persons were killed, 3,959 were according to official statistics reported as severely injured and 22,677 as slightly injured (Vägtrafikskador, 2006).

1.1.2 The cause of crashes

Prevention of road crashes is a major priority in most countries. Prevention requires a clear understanding of the causes of crashes. There is no single theory, accepted by the traffic research community, that explains driver behaviour and the relation to events resulting in injuries and deaths in traffic (Michon, 1985). Therefore an overview of different approaches of interest for driver sleepiness is presented.

Analysis of crash data has led to a number of ways of looking at causes. One such is the Haddon matrix (Haddon, 1972). In the matrix, the contributions of human, vehicle/equipment and environmental factors (both physical and socio economical) behind the injuries including deaths, as well as countermeasures, may be described in the three phases pre-crash, crash and post-crash. The major component in crash causation is the “human factor” (as opposed to mechanical failure, weather conditions), involved in around 90 % of the crashes (Glendon, Clarke, & Mckenna, 2006). Some of the key models behind driver behaviour and crashes are summarized below.

Different theories and models have been in focus over the years. There are models saying that there are certain groups of drivers who are more involved in crashes, claiming that this is caused by “crash proneness” (Glendon *et al.*, 2006; Greenwood & Woods, 1919), and others that describe the driver as a victim of a too demanding environment (Rumar, 1985), and those that describe motivational aspects of the drivers’ control of the driving task. Among the latter, the most commonly used are the theory of risk homeostasis (Wilde, 1988), Zero Risk theory (Näätänen & Summala, 1976) and Threat Avoidance Theory (Fuller, 1984). These approaches conceptualize risk either as a quantity to be controlled or as something to be avoided.

Historically, most driver behaviour models have had a crash perspective. There has been a change over the years towards driver behaviour without connection to crashes (Ranney, 1994). The starting point of those models is often a control theory (or process) perspective. Rasmussen (Rasmussen, 1984) describes the decision and control process in relation to driving with help of different hierarchical levels: knowledge-, rule- and skill-based. The difference is mainly due to the familiarity of the situation. Reason (1990) complemented this model by adding a mechanism to describe the relation between those levels and human errors classified into slips, lapses and mistakes. Reason states that a series of planned actions may fail to achieve their desired outcome because the actions did not go as planned or because the plan itself was inadequate. He divided this into *“planning, storage and execution”*.

Also Michon (1985) structured the driver task into three levels: strategic, tactical and operative. At the strategic level, the general planning of a journey is handled; for example, route planning, preparation before leaving. At the tactical level, the driver has to perform manoeuvres allowing him/her to e.g. make a turn or accept gaps to lead or lag vehicles. Finally, at the operative level the driver has to execute simple actions that are automatic, for example, changing the gear, turning the steering wheel. At the strategic level time is not a critical aspect for success. Lack of time will be more and more important as the task is handled automatically. Ranny (1994) combined Rasmussen’s and Michon’s models into a matrix describing the driver task and the demand of information in relation to the drivers' routine and knowledge. The individual’s behaviour is also influenced by other factors, such as experience, age and gender (Groeger & Brown, 1989). Gender is associated with several factors as, for example, sensation seeking among males (Clarke, Ward, Bartle, & Truman, 2006), overestimation of one's capability among young drivers (Gregersen, 1996), driving under difficult conditions (like bad weather or driving late at night) (Forsyth, Maycock, & Sexton, 1995). It should be emphasized that the present focus of “driver sleepiness” has not been included (or discussed) in the models of driving. However, since sleep loss, extended time awake and being awake at night have severe negative effects on human performance (see below), it is likely that driver sleepiness will impair critical attention and higher cognitive functions (e.g. decision making and risk perception), which may result in crashes.

When the causes of crashes are discussed, the focus is usually, but not always, on the pre-crash phase and particularly on the human behaviour. The operative cause of the crash may be behaviours such as high speed, dangerous overtaking or inattention. These behaviours could be seen as tactical or strategic and may be due to, for example alcohol/drug intake, lack of driving skill; stress, aggression , sensation seeking (Glendon *et al.*, 2006). Alcohol may be the single most common cause of road crashes, at least the prevalence of illegal blood alcohol levels (>2‰) in the drivers involved in fatal crashes is approximately 25% in Sweden (Ahlm, Björnstig, & Öström, 2009). The estimated prevalence of drink driving in Sweden is 0.24 per cent (Forsman, Gustavsson, & Varedian, 2007).

The present thesis brings in another strategic cause of crashes – fatigue or sleepiness. For a long time sleepiness related crashes have attracted no official or public interest, since the incidence has been considered very low. Figures have varied between 1 and 3 per cent (Larsson & Anund, 2002; Lisper, 1977; Stutts, Wilkins, Osberg, & Vaughn, 2003). At the same time, scientific estimates have found values between 10 and 30 per cent (Connor, Whitlock, Norton, & Jackson, 2001; Horne & Reyner, 1995b, 1995c; Maycock, 1997; Stutts, Wilkins, & Vaughn, 1999).

In field studies with long term video recording of the driver and the traffic situation (Dingus, Neale, Klauer, Petersen, & Carroll, 2006 ; Hanowski, Wierwille, & Dingus, 2003) sleepiness was found to be the major cause of self-caused crashes/near crashes. The National Transportation Safety Board (US) has pointed out that sleepiness while driving is one of the most important factors contributing to road crashes (NTSB, 1999) and there is a widespread scientific consensus on this estimate (Åkerstedt, 2000). Recently, it was also shown that sleepiness may be a stronger cause of road crashes than alcohol and that the two factors interact in a dramatic way (Åkerstedt, Connor, Gray, & Kecklund, 2008).

The discrepancy between scientific data and official statistics is, very likely, due to the lack of adequate methodological tools for estimating the cause of the crash, and lack of standardized official reporting procedures. Hence, most official registers still do not systematically collect relevant information on driver sleepiness/fatigue in crashes. Exceptions, however, are the Canadian police force and some of the US states (Gertler, Popkin, Nelson & O´Neil, 2002). Apparently, there is a need for raising traffic research activities to include also sleepiness/fatigue. This may be particularly relevant in Sweden, since register studies within the area of public health show that sleepiness is a problem that increases among people in Sweden (SCB, 2006). In this national survey more than 30% of the women and 20% of the men reported sleep problems. It could also be seen that sleep problems are on the increase and especially young people are suffering. It is likely that such changes may affect traffic safety.

1.2 SLEEP, SLEEPINESS AND SLEEP REGULATION

A focus on sleepiness and driving requires a discussion of the definition, measurement, and regulation of sleepiness and sleep. A brief introduction is given below.

1.2.1 Sleep and its measurement

Sleepiness is a result of changes in several regulatory factors. The most central one is sleep. There is no distinct definition of sleep based on behaviour. Carskadon & Dement (1989) made a general definition saying "*sleep is a reversible behavioural state of perceptual disengagement from, and unresponsiveness to, the environment*".

Traditionally, recording of sleep is performed with the help of polysomnography (PSG), which combines the measurement of brain waves (EEG), eye lid movements (EOG) and muscle tonus (EMG) to determine sleep stages. The recorded data are most often scored visually for one or two EEG derivations (Rechtschaffen & Kales, 1968). Wakefulness is labelled Stage 0. Sleep is divided into REM (rapid eye movement sleep) and NREM (non rapid eye movement sleep). A block of REM and NREM takes about 90 minutes and repeats itself several times during sleep. NREM is divided into 4 stages. Stages 1-4 are a gradual decrease of frequency and increase of amplitude. Stage 1: occurs mainly during sleep onset and when sleep is severely disturbed. During this stage alpha rhythms (8-12 Hz) disappear - alpha waves are the normal pattern when you relax and close the eyes and it is replaced by theta activity (4-7 Hz). Stage 2: this stage is dominated by theta waves. Stages 1 and 2 are called light or superficial sleep. In Stage 2 also sleep spindles (12-14 Hz) are observed. Stages 3 and 4 are called slow wave sleep (SWS) and here mainly delta (0.5- 4 Hz) activity is seen. The amplitude in stage 4 is more than 75 microvolts. Stage 4 is reached when more than 50 per cent of a scoring epoch (20 or 30 seconds) contains high amplitude delta waves. Sleep onset is also characterized by the presence of slow eye movements. The physiological characteristic of an involuntary sleep onset, i.e dozing off episodes, will be described in section 1.2.2.

The visual scoring is time consuming and only a fraction of the variability can be recognized by the human eye. An alternative way of analysis of EEG is computer based analysis using different filter techniques (Rémond, 1979). One way is also the spectral analysis that divides the EEG pattern into its component frequencies, for example with help of Fourier transformation (FFT).

1.2.2 Sleepiness

Aldrich (1989) defined sleepiness as *"a physiological drive usually resulting from sleep deprivation"*. Another definition is the one by Broughton (1989); *"the subjective feeling state of sleep needed"*. Kleitman (1963) described sleepiness as involving *"a succession of intermediate states, part wakefulness and part sleepy, in varying proportions"*. Operationally, sleepiness has also been defined as *"a physiological drive to fall asleep"* (Dement & Carskadon, 1982).

Fatigue is a related concept and refers to an inability or disinclination to continue an activity, generally because the activity has, in some way, been going on for *"too long"* (Bartley and Chute 1947; Broadbent 1979; Brown 1997; Brown 1994; Grandjean 1979). Fatigue is often considered to be a generic term, and sleepiness is one of the major sub-components. In this thesis the term sleepiness will mainly be used.

Sleepiness is usually recorded physiologically through polysomnography (PSG). The measurement normally focuses on transitions between Stage 0 (wakefulness) and Stage 1 (Rechtschaffen & Kales, 1968). The multiple sleep latency test (Carskadon *et al.*, 1986) and the maintenance of wakefulness test (Mitler, Gujavarty, & Broman, 1982) are regarded as the *"gold standard tests"* and the outcome measurement is the time until sleep onset (for example the epoch of stage 1 sleep).

However, the sleep latency test and the maintenance of wakefulness test are discrete (often measured every second hour during daytime) and not suitable for continuous monitoring. An alternative is to use the percentage of time with signs of sleep, for example theta or alpha activity and slow rolling eye movements (Åkerstedt, 1990). Both increase with extended time awake and sleep deprivation. A sleepiness scoring model of this type was developed by Valley & Broughton (1983) using different levels of Stage 1 sleep in order to identify sleepiness before the onset with a higher accuracy. A similar method has been developed by Sallinen and co-workers (2004) and a more elaborate one by Santamaria and co-workers (1987).

The Karolinska Drowsiness Score (KDS) is another method that classifies polysomnographic data according to the presence of alpha or theta activity and slow eye movements (Gillberg, Kecklund, & Åkerstedt, 1996; Lowden, Holmbäck *et al.*, 2004). The classification is performed in two-second epochs that yield continuous measurements (0-100%, in steps of 10%, out of each 20-second or 30-second epoch).

Apart from scoring sleepiness visually, it is also possible to use spectral analysis of the EEG and similar methods to automatically quantify the amount of alpha and theta activity (Armington & Mitnick, 1959; Daniel, 1967; Santamaria & Chiappa, 1987).

A strong sensitivity to sleep loss is also shown for the EOG based measurements of blink duration in laboratory experiments (Caffier, Erdmann, & Ullsperger, 2003) and simulator studies (Horne & Baulk, 2004; Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006). The blink duration in an alert normal individual is around 0.10 second and 0.20 second when sleep deprived (Caffier *et al.*, 2003). The blink duration also seems to be task dependent. Also other blink parameters are sensitive to sleepiness. In particular, the delay of lid opening and lid closure speed (Schleicher, Galley, Briest, & Galley , 2008) and the ratio of amplitude and lid opening or closure (Johns & Tucker, 2005). In Figure 1, some principles of measurements from the blink complex are shown. Blink rate as a measurement of sleepiness has been found by some to be sensitive (Campagne, Pebayle, & Muzet, 2005; Summala, Häkkänen, Mikkola, & Sinkkonen, 1999). Stern, et al. (1994) reviewed blink rate as a possible indicator of mental fatigue. They concluded that blink rate increased as a function of time on task. Blink rate normally varies between 10 and 20 blinks per minute. It is often observed that blink rate decreases when the visual demands increase or when the task becomes more difficult (Stern *et al.*, 1994). Thus, reading may decrease blink rate to 5 blinks per minute. An old study by Drew (1951) showed that blink rate decreased when driving in the city, during high traffic density, compared to rural highway driving.

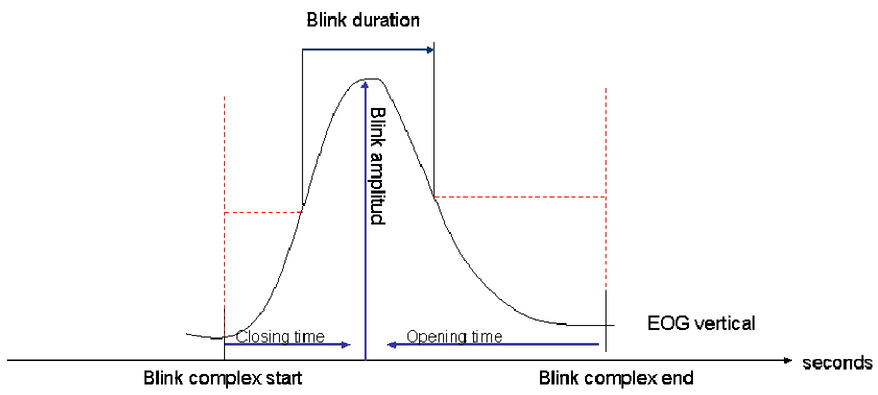

Figure 1 The principle of some measurements calculated from the blink complex. Blink duration is here described as blink duration over half EOG blink complex amplitude; blink amplitude is measured in mv. Closing and opening speed are described in unit mv/s.

However, blink rate is influenced by many factors and therefore lacks specificity when it comes to sleepiness. It should also be kept in mind that closing the eyelids does not always coincide with the moment of sleep onset (Miles, 1929). Instead of EOG based measurements camera based eye movements (Ji, Zhu, & Lan, 2004) could be used to quantify the eye movements. Visual cues of sleepiness are the blink complex, including blink frequency, blink duration, long closure/open time, gaze and sometimes also saccadic eye movements. This is an unobtrusive method highly dependent on the sensor quality and therefore sensitive to for example sunshine, the use of glasses. Furthermore, behavioural signs of sleepiness, such as body movements, gestures, facial tone and head movements (Wierwille & Ellsworth, 1994) could be used to measure sleepiness. These are also based on cameras and video image analysis or on observer ratings.

Retrospectively performed ratings of subjective sleepiness are the simplest way of measuring driver sleepiness. Different rating scales are available but several are of the type "Visual Analogue Scales" (VAS). Normally, VAS is a horizontal line, 100 mm in length, anchored by word descriptors at each end, for example "very alert" to "very sleepy". Another method is the Stanford Sleepiness Scale (SSS) (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973) that uses a Likert type, 7 step scale from 1= feeling active and vital; alert; wide awake to 7=almost in reverie; sleep onset soon; lost struggle to remain awake.

A similar type of scale is the Karolinska Sleepiness Scale (KSS). KSS ranges from 1-9 and the rating step of 7 (sleepy but no problem to stay awake) represents a critical level. Below 7, physiological and behavioural signs of sleepiness are rare, whereas they increase considerably at the level of 8 and 9 (Åkerstedt & Gillberg, 1990). Studies have shown that changes in KSS are closely related to crash risk in driving simulators (Horne & Baulk, 2004; Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006; Reyner & Horne, 1998).

The Epworth Sleepiness Scale (ESS) is also a subjective scale, but used to determine trait-like (subjective) sleepiness (Johns, 1991). This scale is a method to describe the general level of daytime sleepiness during situations such as sitting up reading a book, watching television, as passenger in car for one hour without break. It is not suitable for repeated measurements of sleepiness.

1.2.3 Sleep/wake regulation

The consequence of sleepiness on driving is to a high degree dependent on deviations from the optimal regulation of sleep. The main purpose of normal regulatory components (sleep homeostasis and circadian rhythmicity) is to provide a high level of alertness throughout most of the normal span of wakefulness (Czeisler, Dijk, & Duffy, 1994). Deviations from the optimal pattern will result in a suboptimal level of wakefulness. The sleep/wake regulation is discussed below, as well as some other influences on sleepiness.

Sleep regulation

The basic regulator of sleep is homeostasis. This involves time since last awakening and the amount of prior sleep. With increasing time since prior sleep (Dijk & Czeisler, 1995) and with decreasing amounts of prior sleep (Jewett, Dijk, Kronauer, & Dinges, 1999) sleep duration and the amount of Slow Wake Sleep (SWS) will increase, while sleep fragmentation and time awake will decrease. The structures responsible for this regulation are the hypothalamus, which monitors the level of sleep need, and the thalamus which responds to the interpretation of sleep need and drives the sleep process together with the cortex (Saper, Cano, & Scammell, 2005). The second regulator of sleep is the biological clock with its main structure situated also in the hypothalamus (the suprachiasmatic nuclei - SCN) (Saper *et al.*, 2005). The output of the SCN is a rhythmic waxing and waning of metabolism over a period of 24 hours for one cycle. The rhythm is present in most physiological systems and key metabolic variables show pronounced daytime peaks ("acrophase"), such as cortisol (around 0600h), core temperature (1600h), or melatonin (0400h). The low point in the rhythm, called the "trough", usually occurs in the opposite phase (i.e. 12h from the time of the peak). The effect on sleep is a promotion of sleep taken during the hours of low metabolism ("circadian low") and an interference with sleep taken during high metabolism ("circadian high") (Czeisler, Weitzman, Moore-Ede, Zimmerman, & Knauer, 1980). Essentially, this means that the later the bed time (sleep onset) the shorter the sleep will be. Sleep started at 2300h will last for 7-8 hours, while that started at 1100h will last for 4-5 hours (Åkerstedt & Gillberg, 1981).

Sleepiness

With increasing time awake, subjective alertness and performance capacity will decrease in a reverse exponential way towards an asymptote (Fröberg, Karlsson, Levi, & Lidberg, 1972). The process is faster in the beginning, and after 24 hours it begins to level off. After 48 hours there is very little alertness or performance capacity left. However, a person may be able to stay awake for several days more if adequately stimulated, but the level of functioning will be poor (Kales *et al.*, 1970). On top of the decreasing trend, functioning is affected by the circadian influence, which will increase alertness during the day even if no sleep has been taken during the night (Fröberg *et al.*, 1972). In addition to the circadian influence on sleepiness one should also consider the local afternoon reduction in alertness, which appears to have a rhythm of its own (Lavie, 1986).

The regulatory influences have been combined to form quantitative models of sleep/wake regulation. The original idea was presented by Borbély (1982). The model is based on two basic processes; circadian and homeostatic (duration of sleep and time course of slow wave activity). Another approach is the Three Process Model of Alertness that was first presented in 1987 (Folkard & Åkerstedt, 1987; Folkard & Åkerstedt, 1991) and has been extensively validated. The model could be used to present an integrated and quantitative description of the main factors that affect alertness and alertness related performance, it could also be used to predict alertness from knowledge of sleep/wake patterns or only work pattern. The alertness is predictable from three parameters: S, C, and W, see Figure 2. **Process S** is an exponential function of the time since awakening, is high on awakening, falls rapidly initially and gradually approaches a lower asymptote. At sleep onset process S is reversed and called **S'** and recovery occurs in an exponential fashion that initially increases very rapidly but subsequently levels off towards an upper asymptote. **Process C** represents sleepiness due to circadian influences and has a sinusoidal form with an afternoon peak.

Total recovery is usually accomplished in 8 hours. The final component is the wakeup **Process W**, or sleep inertia. Sleep inertia is a post-awakening state that temporarily increases sleepiness. Normally, the sleepiness enhancing effect due to sleep inertia occurs during 30-60 minutes after the awakening but can be increased if sleep was insufficient or if the awakening took place close to the circadian trough (Åkerstedt, Folkard, & Portin, 2004).

The Three Process Model has been shown to predict crashes with a high sensitivity (Åkerstedt *et al.*, 2008).

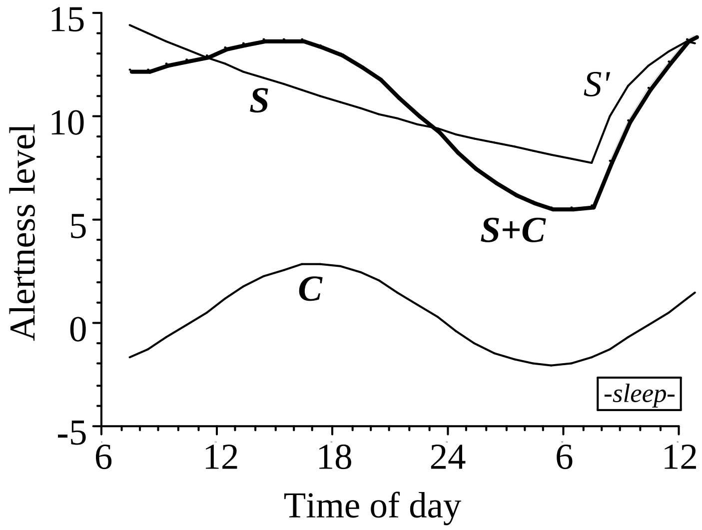

Figure 2 The S (exponential function of the time since awakening), C (circadian influences).

1.3 SLEEP RELATED CRASHES

In order to understand and prevent sleep related crashes it is necessary to describe how physiology and behaviour change during sleepy driving and what is the precipitating cause of the impaired behaviour involved in a crash.

Indicators

The physiological and behavioural changes of sleepiness are previously discussed in a general sense. Many of those measurements are applicable also in relation to sleepy driving. However, many measurements/indicators are unique to driving or need at least to be modified for driving. Finding relevant measurements which describe changes in driving behaviour caused by sleepiness is difficult. One reason, suggested by Brown and colleagues already 40 years ago (1962) was that normal driving is a task with a high degree of automation. Therefore, a sleepy driver may manage rather simple driving fairly well, despite the general functional capacity being clearly deteriorated. Thus, during simple and automated driving negative effects of sleepiness on driving performance will be difficult to observe. However, certain critical situations, which probably seldom occur, may be more vulnerable to sleepiness. Driving during such situations is more likely to show impairment, even with moderate sleepiness, than routine driving tasks (relying on highly automated skills) (Lisper, 1977). One should keep in mind that our knowledge of the interaction between the driving scenario and the sleepiness level is very limited and most of the research involves simple driving without introducing more complex and difficult situations.

An objective way of measuring sleepiness is through driving parameters associated with performance impairment during sleepy driving. Commonly used measurements of driver sleepiness both in simulators and during naturalistic driving are measures related to **variability of the lateral position** (O'Hanlon & Kelly, 1974; Otmani, Pebayle, Roge, & Muzet, 2005; Philip *et al.*, 2005), which increases as the driver becomes sleepy. Lateral position is easily measured in simulators, but is more difficult to track on real roads due to sensor limitations. A measurement based on already existing sensors is the **steering wheel reversal rate**. However, this is a measurement not easily computed since it requires an identification of the maximum and minimum in the signal. A variety of thresholds have been used (Otmani, Pebayle *et al.*, 2005; Wierwille, Ellsworth, Wreggit, Fairbanks, & Kim, 1994) showing different results. **Speed deviations** (from the posted limit) has also shown some relation with sleep loss (Arnedt, Wilde, Munt, & MacLean, 2001; Campagne *et al.*, 2005), but may also be influenced by many other factors. Many of the variables referred to above have been tested in support systems for drivers in order to warn of impending danger due to high levels of sleepiness (Dinges & Mallis, 1998).

The measurement of **brain waves** has been another variable of choice when sleepiness at the wheel is investigated. Spectral analysis of the EEG seems to dominate the sleepy driver studies in this sense (Lal & Graig, 2002). However, the spectral content of the EEG does not involve a definition of sleep, which would be helpful in making estimates of sleep in the evaluation of results. As mentioned in the discussion of sleepiness measurements, there are several approaches (Åkerstedt, 1990; Sallinen *et al.*, 2004; Santamaria & Chiappa, 1987). Another methodological problem is that the EEG signal often contains a lot of noise, mainly due to movements. Thus, removal of noise due to artefacts may cause quite large data loss which makes it unfeasible for an automated sleepiness detection and warning system. Results from simulator studies show that, among the physiological parameters, increased frequency in the alpha and theta bands of the EEG seem to be parameters of interest (Horne & Baulk, 2004; Horne & Reyner, 1999; Sarah Otmani, Joceline, & Alain, 2005), but also parameters based on **blink behaviour** (Wierwille & Ellsworth, 1994). Especially eye blink duration is sensitive to variations in alertness and may involve increased duration of eye blinks (Dinges, Maislin, Brewster, Krueger, & Carroll, 2005) or slow rolling eye movements when driving (Åkerstedt et al., 1990).

Another observation in previous research is that controlled sleep deprivation has been used to induce sleepiness and the overall behaviour (during the entire drive) of sleepiness variables has been observed and conclusions on physiological and behavioural changes have been drawn . However, there are very few studies that have attempted to describe the detailed physiological and behavioural changes that immediately precede *an event* of interest, that is, a crash or a lane departure (defined as a two wheels outside the road). Such detailed information can be recorded in well-controlled simulator studies. In simulators it is possible to obtain data on what precedes dangerous driving, e.g. is there a clear sleepiness event in the pre-incident phase, as well as to provide a deeper understanding of the relation between sleepiness and near-crash incidents, which sometimes would lead to a crash. One wonders, for example, if sleep intrusions in the waking EEG, long eye closure durations, or lane drifting appear immediately before a crash. What are the dynamics of sleepiness indicators: is the sleepiness attack abrupt and rapid or does it develop slowly? Is the driver aware of the sleepiness level? The latter is suggested by Reyner et al., (1998). The same group also indirectly shows that driving incidents, in a simulator, occur at high levels of alpha plus theta activity, but they do not explicitly describe the changes leading to an incident or a crash.

1.2.1 Factors behind sleep related crashes

Earlier, the main causes of sleepiness were discussed in a general sense. Here I focus on what is known about the specific causes of sleep related crashes or, at least, of sleepiness at the wheel.

The present thesis is not focused on sleep disorders as a cause of crashes, but these disorders clearly constitute one important cause. Thus, sleep apnoea and insomnia (George, 2007) are associated with increased levels of road crashes. It has also been shown that drivers with untreated sleep apnoea have an increase in risk of lane departures (Philip *et al.*, 2008) and there have been several international consensus documents establishing the importance of obstructive sleep apnoea as an important factor behind road crashes (Alonderis *et al.*, 2008). Insomnia does not seem to have been studied in this respect.

Work hours and sleep habits seem to be equally important factors. For example, night driving increases crash risk several fold (5-6 times) (Åkerstedt & Kecklund, 2001; Connor *et al.*, 2001; Horne & Reyner, 1995b). Night shift work is also associated with increased reported sleepiness (Åkerstedt, 1998; Mitler, Miller, Lipsitz, Walsh, & Wylie, 1997) and studies have shown that train drivers (Torsvall & Åkerstedt, 1987), truck drivers (Kecklund & Åkerstedt, 1993; Mitler *et al.*, 1997), pilots (Samel *et al.*, 1997), process operators (Torsvall, Åkerstedt, Gillander, & Knutsson, 1989), and others, show clear intrusions of sleep like EEG patterns when working at night. The latter has also been demonstrated in a truck simulator (Gillberg *et al.*, 1996). Also driving home after a night shift is associated with at least a doubling of the risk of a crash (Gold *et al.*, 1992; Stutts *et al.*, 2003). However, no studies seem to be available on driving performance or physiological indicators of sleepiness. The present thesis will bring up this topic in two of the studies (Study I and II).

The crash risk is also higher with increased duration of driving (Hamelin, 1987). However, the effects are confounded with other factors like time of day, time awake, and prior sleep, which often covary with the duration of driving. Recently, however, Sagaspe et al., demonstrated, with appropriate control of confounding factors, a pronounced impairment with increasing duration of driving at night (Sagaspe *et al.*, 2008).

Sleep duration would be expected to be related to increased crash risk but very few studies exist. A study by Connor et al., (2002) showed that sleep <5h was associated with a doubling of the crash risk. With respect to simulator studies of sleepy driving, virtually all such seem to have been based on manipulation of prior sleep – total or partial sleep deprivation.

The risk of sleepiness related crashes is strongly related to individual differences. Young drivers, for example, are more frequently involved in road crashes (Åkerstedt & Kecklund, 2001; Corfitsen, 1994; Langlois, Smolensky, Hsi, & Weir, 1985; Pack *et al.*, 1995). Young drivers (18-24 years) had 5-10 times higher risk of being involved in a traffic crash late at night than older drivers. Age differences in driving performance have been observed in earlier studies (Campagne, Pebayle, & Muzet, 2004; Otmani, Joceline, & Muzet, 2005). These studies suggested that young drivers are more susceptible to sleepiness than older drivers. The reasons are not clearly established as to why young drivers show an excess risk of having a crash late at night but factors related to self-confidence, risk-taking and drug use have been suggested (Gregersen & Bjurulf, 1996). The increased night-time risk for young drivers may also be related to increased exposure of car driving during this time of the day. Another very likely reason is sleepiness (Connor *et al.*, 2001; Cummings, Koepsell, Moffat, & Rivara, 2001). It has been a hypothesis that young drivers more easily fall asleep/nod off in sleepy situations and in connection with sleep loss than older drivers (Åkerstedt & Kecklund, 2001; Sagaspe *et al.*, 2007). However, very few studies have studied age effects in connection with o night driving.

Closely related to age is the age of the driving licence. Individuals with a recently obtained licence are involved in a disproportionately high number of crashes (Ferguson, 2003; Laapotti & Keskinen, 1998).

Most studies are carried out using simple driving simulators and with a relatively boring and monotonous scenario without other vehicles on the road that may require actions (Horne & Reyner, 1995c; Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006). The effect of time on task has been proven to be task dependent, in comparisons of a simple vigilance task with a monotonous driving task in a simulator (Richter, Marsalek, Glatz, & Gundel, 2005). It could by hypothesised that this would also be true if the simple scenario in a simulator was compared with a more complex one. Philip et al., (2005) concluded in a comparative study that sleepiness can be studied equally well in real and simulated driving conditions. The effects are the same except that the simulator will show more frequent line crossings and road departures compared to the real environment. One explanation for this could be the difference in complexity in the driving scenario. On the one hand, a more complex scenario will also be more sensitive and vulnerable to sleep loss. On the other hand, a complex scenario may also be more stimulating and activating compared to monotonous driving. Thus, it is difficult to predict how the driving scenario will affect sleepiness and vice versa. In addition, naturalistic driving often includes both monotonous driving and more complex situations characterized by higher traffic intensity and more active driving. It may also be that sleep deprivation impairs driving performance for complex driving tasks, e.g. the distance to cars one has to follow can decrease (with increased risk of collision with oncoming vehicle) and unsafe overtaking can occur more frequently. As far as we know no one has been taking into account the lack of complexity in the driving scenarios. This is clearly needed in order to ensure that simulator studies may be used for generalization to real driving.

1.4 COUNTERMEASURES

Considering the central role of sleepiness in crash causation, knowledge of the use of countermeasures is an important issue. One may structure countermeasures in three levels according to Michon (1985) i.e. strategic, tactical and operative levels as shown in Table 1.

Table 1 Examples of countermeasures at a pre-crash level according to the Michon model (1985).

Strategic	Tactical	Operative
Fatigue management systems	Driver support system (feedback – warning)	Rumble strips
Hours of service regulations	Road signs	Driver support systems (warning & intervention)
Information/Education	Parking areas	
Strategies for planning	Route guidance to parking areas	
Fit for duty test		
Enforcement/Control		

With respect to the strategic level countermeasures, one should obviously avoid night driving and make sure sufficient amounts of sleep have been obtained before driving. Here, for example Fatigue Management Programs and work scheduling for professional drivers play a major role (Dawson & McCulloch, 2005). In most countries there are hours of service (HOS) regulations. However, those do not take into account the underlying problems (circadian and sleep/wake pattern). In a review of theories it was argued that the most promising solutions would be to shift from a focus on HOS regulations to a Safety Management System (SMS) in which fatigue is one component (Dawson & McCulloch, 2005). The suggested theoretical framework was represented using Reason’s hazard control framework (Reason, 1977) and regarded a fatigue related incident or crash as the final segment in a causal chain of events or error trajectory. The model precedes the fatigue related incident for which the hazard and the control are identified on four suggested levels (sleep opportunity-actual sleep obtained-behaviour symptoms-fatigue related errors).

However, more effective countermeasures at the tactical and operative level, during actual driving, are less obvious. No studies seem to exist in the public domain of what effective countermeasures are used. Anecdotally, it appears that actions like opening a window, turning on the radio, or taking a break may be common. However, laboratory studies indicate that these three suggested countermeasures, including exercise during the break, do not improve alertness (Horne & Reyner, 1996; Lisper, 1994). Horne and Reyner have demonstrated that caffeine and taking a brief nap (<30 minutes) significantly reduce driving impairments, subjective sleepiness and electroencphalographic (EEG) indications of drowsiness (Horne & Reyner, 1996). The dramatic alerting effects of these behaviours have also been demonstrated repeatedly in laboratory studies with other performance measurements (Tietzel & Lack, 2002; Wesensten, Killgore, & Balkin, 2005). A matched case-control study indicated that the crash risk was lower for drivers who used highway rest stops, drank coffee within the last two hours or played a radio while driving compared to those who did not. (Cummings *et al.*, 2001). Bright lights suppress melatonin, which peaks at the late night hours (Bjorvatn *et al.*, 2007; Lowden, Akerstedt, & Wibom, 2004). However, it may be difficult to administer bright light in the car without impairing other aspects of vision.

Apart from the interest in understanding what countermeasures are used, one also needs to know whether the use of countermeasures differs between different driver groups. Inappropriate use of countermeasures may be related to long term risk of crash. This type of knowledge may aid in identifying vulnerable groups that do not know how to handle sleepiness while driving. Age is probably such a factor because of its close relation to crash risk and risk behaviour, the group in focus being young drivers (Galvan, Hare, Voss, Glover, & Casey, 2007; Horne & Reyner, 1999). Gender is another factor, with greater risk attached to males (Åkerstedt & Kecklund, 2001). One may also hypothesize that experience of drowsy driving and sleep related crashes, shift work, and being a professional driver may influence the use of countermeasures. The reason for this is that these characteristics may be associated with a greater awareness of the dangers of sleepy driving. Higher education and old age may also be associated with greater insights of sleepy driving and how to handle it. There is also a need to consider that there may also be individual preferences regarding countermeasures.

Apart from driver initiated countermeasures one may also consider various types of information to the driver about fatigue risks in driving. Information in media could be one such way. Public campaigns along the roads may be another one. Information in connection with the annual vehicle safety inspection may be a third. In addition, there has been considerable development in the area of driver support systems, focused on feedback on hazardous driving in terms of impaired lateral control (Brookhuis & de Waard, 1993; Dinges & Mallis, 1998) or focused on the physiological state of the individual sleepiness (Åkerstedt & Folkard, 1997; Horne & Reyner, 1999; Wierwille & Ellsworth, 1994). Since driver support systems are associated with sizeable investments by society and/or manufacturers, it would be of interest to investigate the attitude among end-users towards such countermeasures, as well as to study whether background factors are related to such attitudes.

Another more systematic public intervention approach, not based on individual preferences, is the so called “rumble strips”. A rumble strip refers to a narrow band of built-in unevenness in the road surface, normally placed close to the edge line and/or at the centre line. The purpose is to cause vibrations or noise when a wheel of the vehicle makes contact with the rumble strip. The rumble strip may be profiled (raised) above the road surface or milled into the road surface, see, Figure 3.

Figure 3 Rumble strip milled into the road surface at the shoulder.

Rumble strips have been systematically evaluated in several studies and the introduction of rumble strips at the centre line has reduced crashes by approximately 15% and the effect of rumble strips at the shoulder is even more positive (40 - 50%) (Anund, 2005; Mahoney, 2003; Persaud, Retting, & Lyon, 2003). While the reason for this may be a re-direction of attention in alert distracted drivers, it seems likely that an alerting effect in a sleepy driver also may be as important. However, there is no detailed information available on what actually happens before and after a drowsy driver makes contact with the strip. Is there an increase in indicators of sleepiness before the hit, and, if so, do they subside afterwards, and for how long?

1.5 AIM

To summarize, there is obviously a need for new knowledge in many areas of sleepiness behind the wheel. The general aim of the thesis was to explore the relation between driver sleepiness and driver impairment and the changes that precede a crash or a similar safety-critical event, but also what constitutes good reliable behavioural / physiological measures of sleepiness. A second question concerned particular groups and situations – is post-night shift driving characterized by increased sleepiness, is more complex driving also affected by sleepiness, and are younger drivers affected by sleepiness behind the wheel more than older drivers? A third question concerned countermeasures. What are the preferred self-administered countermeasures and what are the effects of the structural countermeasures like rumble strips?

The present thesis will focus on six major questions:

1) What characterizes the relation between driver sleepiness and driver impairment and the changes that precede a crash or a similar safety-critical event (e.g. a lane departure) and what constitutes good, reliable, behavioural / physiological measurements of driver sleepiness?

2) How does age influence sleepiness during night time driving?

3) How is post-night shift driving characterized in terms of increased sleepiness and how does this affect driving performance?

4) How is a more complex driving scenario affected by sleepiness?

5) Which are the preferred self-administered countermeasures and is the use of these measurements related to individual characteristics such as age, gender, experience of sleepy driving, habitual sleep quality.

6) What are the effects of rumble strips on physiological and behavioural indicators of sleepiness?

2 METHOD

2.1 SUBJECTS

Studies I, II, III and V are based on results from four different driving simulator studies. The subjects were recruited by advertisement in the local newspaper or at the web site of the Swedish Road and Transportation Research Institute. In all studies except study III the drivers drove the simulator twice. The compensation varied between 110€ -220€ depending on number of visits to prepare or to drive the simulator. The number of subjects varied in the driving simulator studies; however the distribution between genders was almost equal, as shown in Table 2.

Table 2 Number of subjects, distribution between gender, driver group and routines for recruiting.

Study	***Male***	***Female***	***Age (sd)***	***Time driven during one condition***	***Driver group***	***Compensation***
I	5	5	37 (12)	120 minutes	Shift workers	€110
II	8	9	43 (2)	60 minutes	Shift workers	€ 220
III	16	19	36 (8)	90 minutes	Shift workers	€160
V	10	10	22 (2) 60 (3)	90 minutes	10 (age:18-24) 10 (age:55-64)	€200

Study IV is a questionnaire study addressed to 3,041 car owners randomly sampled from the national register of car owners. The overall response rate was 62 percent.

2.2 DESIGN AND SCENARIO

For studies I, II, III and V an advanced moving base driving simulator[1] was used, see Figure 4. The car body consisted of the front part of a Volvo 850 with a manual 5 shift gearbox. Noise, infra-sound and vibration levels inside the cab corresponded to those of a modern car. There were three channels of forward view of a total of 120° x 30° from the subject's position in the simulator. The driving simulator model has been extensively validated (Aurell, Andersson, Fröjd, Jerand, & Nordmark, 1999; Aurell, Nordmark, & Fröjd, 2000; Jerand, 1997).

Figure 4 Moving base driving simulator (version III) at VTI, Sweden.

Three of the simulator studies (studies I, II and V) used a within-subject design, in which all subjects participated across all conditions. The order between the baseline (no sleep deprivation) and sleep deprivation condition were balanced for subjects and gender. The drivers visited the simulator twice: once after a night's sleep and once after no night sleep. In studies I, II and III the subjects arrived directly after a night of regular work during the sleepy condition. There were at least 3 days between the alert (baseline) and sleepy (sleep deprivation) conditions. In study V, the subjects arrived late in the afternoon and drove in the alert condition in the afternoon/early evening. They stayed at the laboratory and drove in a sleepy condition late at night.

The scenario used for studies II and III was almost the same, with a rural road, 9 metres width and with milled rumble strips both at the centre line and at the shoulder (Table 3). For study I the scenario was similar, but with an even narrower road and without rumble strips. For study V the scenario used was a motorway with 2 lanes in each direction and with a speed limit at 110 km/h.

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[1]Swedish National Road and Transport Research Institute (VTI)

Table 3 Scenario used in driving simulator studies described in studies I, II, III and V.

Study	***Road Width (m)***	***Lane Width (m)***	***Hard Shoulder (m)***	***Signed speed limit (km/h)***	***Rumble strips – hard shoulder***	***Rumble strips – centre line***
I	8.2	3.6	0.5	90	No	No
II	9	3.75	0.75	90	Yes	Yes
III	9	3.5/3.25	1.0 / 0.5	90	Yes	Yes
V	2 lane motorway			110	Yes	No

In all simulator studies the road had a smooth curvature with high friction and dry summer conditions. The ambient light conditions corresponded to daylight; cloudy but with good visibility (Figure 5).

Figure 5 Example of scenarios used in study III (left) and study II (right) ***(The number was not visible for the driver)***

In studies I and III there was oncoming traffic, but no vehicles in front. The scenario was the same during the whole drive. The latter was also true in study V, but here there was no other traffic on the motorway. In studies II, III and V the sound and vibrations from real milled rumble strips were reproduced in the simulator.

For study II the scenario was not consistent through the drive. The scenario was repeated every 9,800 metres and yielded 9 identical “laps”. For each lap three different types of scenarios were designed; free driving without any slower vehicle on the road ahead, catching up with a slower vehicle, with or without visible oncoming vehicles. Furthermore, in study II a bus parked on the right hand side was passed twice, once without information beforehand (lap 4) and once with information in the vehicle 600 metres before (lap 9) (Figure 6).

Figure 6 In-vehicle information of school bus ahead.

2.3 PROCEDURE

The procedure in the studies (Studies I, II, III and V) was more or less the same.

Before arrival

About one week before the experiment, the subjects received documents describing the experiment and how they should prepare before arriving.

For studies II, III and V the drivers were instructed : not to drink alcohol for 72 hours before the experimental day, not to eat, drink coffee or tea for 3 hours before arriving at the laboratory and not to use make-up. They were also informed about how to use the subjective Karolinska Sleepiness Scale (KSS) (Åkerstedt & Gillberg, 1990).

In order to control that the sleep / wake restrictions were adhered to, the subjects were monitored through actigraphs the day before the experiment (studies III and V, however, the results are not reported in the studies). For study I only sleep/wake diaries were used and for study II the drivers sent SMS at 02h and 04h in order to ensure wakefulness

On arrival

On arrival, the drivers were taken to the laboratory. The subjects received verbal information on what was going to happen during the experimental day. They filled out background questionnaires, if not already done at home, and informed consent forms. Then the electrodes for the physiological measurements were applied. For studies II, III and V a modified version of the KDT preceded driving. During the KDT the subjects were seated with their eyes open, focusing on a stimulus (dark circle) placed on the wall approximately 50 cm from the head or at the simulator screen 3 metres ahead. The duration of the KDT varied between 3 and 5 minutes for the different studies. In addition, a bio-calibration of the physiological signals was carried out before the experiment started.

Driving

The drivers were then taken to the driving simulator, the recording equipment was connected and an instruction was read to the driver. Before the experiment started the subjects carried out a 10 minute test drive (Studies II, III and V). In study I, the subjects practised for 20 minutes.

During the drive there was no communication between test leader and subject. The subject reported the KSS once each 5th minute. The reminder was displayed on the screen in front and the subject reported the rating verbally. The subject was restricted not to: have mobile phones, listen to radio or music, to smoke or use snuff.

After driving

The subjects filled out post questionnaires after each driving session, in order to capture their experience of the drive.

In study V the subjects stayed at the laboratory during the night, without sleep and supervised by an experimenter until the next drive. They were served dinner at about 00.30 h and the first driver drove a second time between 02.30 h and 04.00 h, followed by the second driver between 04.00 h and 05.30 h.

For driving after night work condition (studies I, II and III) the subjects were brought to the laboratory and back by taxi. This was also true after the experiment presented in study V.

2.4 MEASUREMENTS

2.4.1 Physiological sleepiness and scoring

A Vitaport II system was used to record the EOG (electrooculogram), EEG (Electroencephalogram) and EMG (electromyogram). The electrodes used for EOG and EMG were of the disposable Ag/AgCl type. The two EMG electrodes were placed under the chin. The EEG was measured through three bipolar derivations positioned at Fz-A1, Cz-A2 and Oz-Pz. The electrodes were silver plated and not disposable. Six electrodes were used to record the EOG; 2 vertical (left and right) and one horizontal. The EOG was DC-recorded. The sampling frequency was 512 Hz for the EOG/EMG and 256 Hz for the EEG. This was true for all studies except study I, which used a sampling rate of 128Hz with a bandpass filter set at 0.3-25Hz.

EOG

EOG was a measurement used in studies I, II, III and V. Raw data were analyzed with a modified MATLAB program developed by the Centre for Applied and Environmental Physiology in Strassbourg (Sharabaty, 2008). It essentially comprises a low pass filter to establish a stable baseline for the signal, establishing a threshold that has to be exceeded to score a blink (done visually), with definition of the start/end of the blink based on slope and with computation of blink duration at midslope. To reduce problems with concurrence of eye movements and eye blinks, blink durations were calculated by finding the half amplitude of the upswing and downswing of each blink and computing the time elapsed between the two.

EMG

The EMG signal was used to detect artefacts in the EEG due to facial muscle activity, e.g. yawning.

EEG and KDS

EEG was a measurement used in studies III and V. EEG and EOG data were scored visually for sleep-related patterns using conventional criteria (Rechtschaffen & Kales, 1968). Twenty second epochs were divided into 10 steps of 2 seconds each, scored with respect to whether alpha waves (8-12 Hz), theta waves (4-8 Hz), and slow rolling eye movements occurred. Slow eye movement (SEM) is defined as a slow, rolling excursion of the EOG of at least 100 µV amplitude that lasts >1 second (Torsvall & Åkerstedt, 1988). Each epoch was assigned a value between 0-100% based on the proportion of signs of physiological sleepiness. This score is called Karolinska Drowsiness Score (KDS). For example, an epoch which includes three 2-sec. segments with physiological sleepiness would be represented by the KDS value 30% (Gillberg *et al.*, 1996). The KDS has been validated against performance and subjective ratings in study V. Epochs including more than 50% of artefacts were removed from the analysis.

2.4.2 KSS

The KSS (Åkerstedt & Gillberg, 1990) ranges from 1-9 where 1= very alert, 5=neither sleepy nor alert, 7=sleepy but no effort to remain awake, and 9=very sleepy, an effort to stay awake, fighting sleep. The scale was modified to have labels also on intermediate steps, as shown in Table 4. It is well validated against other measurements of sleepiness. (Åkerstedt & Gillberg, 1990). Subjective sleepiness was rated by the subjects every 5 minutes (studies I, II, III and V) prompted by an instruction displayed on the windscreen, with the response given orally, using the scale pasted to the steering wheel. The drivers were trained beforehand and the instruction was to report a value corresponding to the feeling during the last 5 minutes.

Table 4 KSS with verbal descriptions at each step

Rate	Verbal description
1	extremely alert
2	very alert
3	alert
4	rather alert
5	neither alert nor sleepy
6	some signs of sleepiness
7	sleepy, but no effort to keep alert
8	sleepy, some effort to keep alert
9	very sleepy, great effort to keep alert, fighting sleep

2.4.3 Driving behaviour

Driving behaviour was sampled at different frequencies in the four driving simulator studies. In study I it was 12.5 Hz, in study II 10 Hz, in study III and in study V 33.33 Hz. The maximum sampling rate in the simulator is 200 Hz. Depending on the aim, a different frequency was selected (all divisible by 200). Also different measurements of driving behaviour were used as shown in Table 5. Lateral position was analyzed in all driving simulator studies. Speed was analyzed in studies I, II and V. In study I steering wheel angle and time to line crossing were used. Events in terms of lane departures were used in studies I, III and V. The definition used was either close to an incident or a crash. In study I, both were included.

Table 5 Driving behaviour measurements used in study I, II, III and V

Study	***Speed***	***Lateral position***	***Steering wheel angle***	***Time to line crossing***	***Lane departure "events"***
I	mean, sd	mean, sd	mean, sd	mean	Four wheels outside the left or right lane marking ("accident") and 2 wheels outside the lane markings (incident)
II	mean	mean, minimum, sd	NA	NA	NA
III		mean, sd	NA	NA	Two wheels touching the milled rumble strips in centre line or on the shoulder
V	mean, sd	mean, sd	NA	NA	Two wheels touching the centre line or edge line

NA=not applicable

2.4.4 Questionnaires

Studies I, II, III and V – driving simulator

Inclusion criteria, background questionnaires and sleep and wake diaries were used in all four driving simulator studies. After each driving session, the drivers filled out a post questionnaire, in order to capture their experience of the simulator, their self experienced performance and for studies II and III also their opinion about rumble strips.

Study IV – questionnaire

Study IV was based on a questionnaire using knowledge received from three focus group discussions; one with young drivers, one with professional drivers and one with middle aged commuters (Anund, Kecklund, & Larsson, 2002). The definition of sleepy" or "sleepiness" was given to the subjects:*"By "sleepy" or "sleepiness" we refer to situations when you as a driver have to make efforts to stay awake while driving"*. The questionnaire consisted of 38 questions divided into the following parts; background, health and sleep, what makes drivers become sleepy, experiences of being sleepy while driving, experience of sleep related crashes, the awareness of sleepiness signals, and finally actually used and potential countermeasures. Most of the response options on the questions about health and sleep were given on a semantic differential scale from 1(=very bad) to 5(=very good) with anchored end points.

In order to capture the driver's knowledge of efficient and lasting countermeasures, the drivers were asked if they "*normally do anything to reduce their sleepiness or to be more alert while driving*". They were presented a menu of 22 different items and asked to tick those alternatives that corresponded to what they would normally do. The items presented to the respondents were chosen based on the discussions within the focus groups and from the results from the test questionnaire. No limit was set on the number of items that could be ticked. Questions related to the drivers' attitude to the means of information were structured in the same way.

2.5 STATISTICS

The statistical analyses normally comprised 2 and 3 factor ANOVAs with repeated measures. The results were corrected for sphericity using the Huyhn-Feldt method. The factors were condition (night sleep vs. no sleep), time on task (most often described within 5-minute intervals) (studies I, II and III).

For comparisons of crashes and incidents in between conditions (study I) Wilcoxon's non-parametric test was used because of skewed distributions.

In study II lap (1-8) was used as "time on task" and "situation", that is, driving scenario (free driving vs. car following) was also included as a factor in the ANOVA.

In addition, in study V a mixed model (GLM) was used with a fixed factor also for age (young/older) and subject as random factor. In order to analyze the risk of lane departure at different levels of KDS sleepiness a Cox regression was performed. The Cox regression is based on a survival function and in this case the event was considered to be the lane departure (2 wheels at least touching the lane boundaries). An enter method was used. To minimize problems with unbalanced data, only data up to and including the fifth lane departure for each subject were used. The time dependent covariate (T_Cov) was set as a function describing whether specific data were obtained from before the first lane departure, from between the first and the second lane departure, from between the second and third lane departure and so on. The covariates were the time driven and KDS level.

For the questionnaire study (study IV) logistic regression was used in order to relate use of efficient countermeasures to age, gender , education, professional driving, being a shift worker, having experience of sleepiness while driving, sleepiness-related crashes, persistent sleepiness, snoring or reduced sleep quality or sleep less than 6 h during normal working days. In a first step, a univariate model was used. Secondly, variables with significant odds ratios were included in a multivariate logistic regression (forward stepwise approach). The same analysis approach was used for questions related to information about awareness of driver sleepiness.

For other comparisons in all five studies, paired t-tests were used.

All analyses were carried out with SPSS (versions 14.0 and 15.0). All tests used a significance level of $\alpha=0.05$.

3 RESULTS

Impaired alertness and performance driving home from the night shift: a driving simulator study (Study I)

One safety-critical situation for shift workers is going home after the night shift. Study 1 is a driving simulator study with the aim to investigate driver impairment during a simulated drive home from a night shift.

The results showed that driving home from the night shift was associated with an increased number of incidents (2 wheels outside the lane marking, from 2.4 to 7.6 times). After the night shift they also had a decreased time to first accident, increased lateral deviation (from 18 to 43cm), increased eye closure duration (0.102 to 0.143sec), and increased subjective sleepiness. The drivers rated higher sleepiness (KSS) after the night shift compared to after normal night sleep ($F=60.1$; $p<0.001$) for condition, $F=38.2$; $p<0.001$ for time, and $F=2.1$; $p< 0.05$ for interaction), as shown in Figure 7.

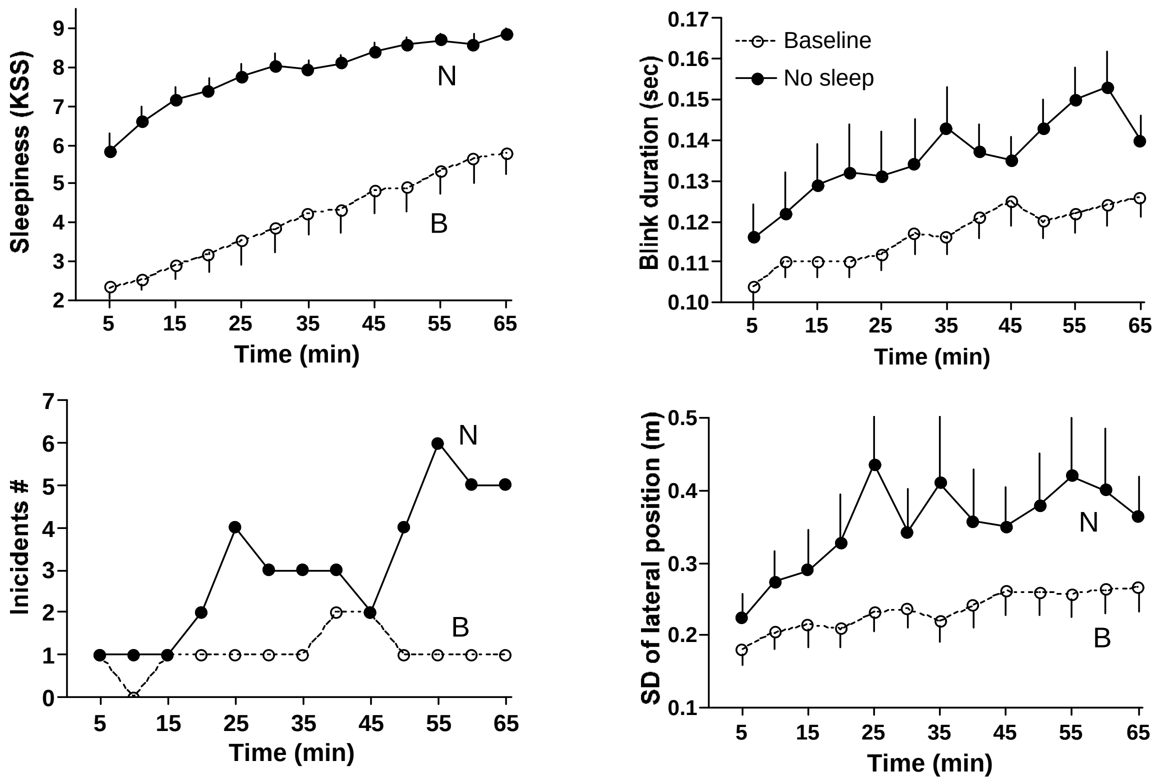

Figure 7 Mean of KSS, blink duration and incidents; variability of lateral position during the drive (minutes 5-65). The bars represent the SE. N denotes no sleep while B denotes baseline, i.e. normal sleep.

Thus, sleepiness was higher after the night shift, increased across time and increased faster after night sleep. The results indicate severe post-night shift effects on sleepiness and driving performance. Driving in the early morning is associated with increased accident risk, affecting not only professional drivers but also those who commute to work.

The effects of sleep loss on driving behaviour and sleepiness in a complex traffic scenario– a simulator experiment (Study II)

The main question of Study II was to study the effect of sleep loss and time on task, on eye closure duration; KSS and variability of lateral position in a more complex driving situation than typically seen in driving simulator studies.

The pattern of results was similar to previous studies in monotonous settings. The results showed an increase in eye closure duration, lateral variability and subjective sleepiness due to sleepiness both in the free situation and in the car following situation.

The effect of lap was significant for all measurements except for variability of blink duration. Blink duration and variability of lateral position increased, but also the lateral position and its minimum increased across laps. There were no major significant interactions. Since the data suggest a start-up effect, an analysis was also carried out with the first lap removed. This caused the significant effects of lap to disappear for blink duration (F=2.59; p=0.075), speed (F=1.990; p=0.099) and variability of lateral position (F=0.991; p=0.421).

Lateral position and minimum of lateral position were closer to the edge line during the free driving situations compared to car following situation. During the following situation the variability in distance to the car ahead was 15.91 metres (sd 4.31 m) after night sleep and 15.80 metres (sd 4.72 m) after no sleep. The difference was not significant (t(15)=0.085; p=0.934). Fifteen subjects overtook at least one car both after night sleep and after no sleep. Among those there were 175 events of overtaking during laps 2-8. There were 5.93 (sd 1.94) overtakings after a night sleep compared to 5.73 (sd 1.83) after no sleep. The difference was not significant ($t_{(14)}$=0.284; p=0.781). No changes in blink duration were seen between no sleep and night sleep condition during overtaking, see Figure 8. However, blink duration (mean and variability) was shorter during overtaking compared to other situations.

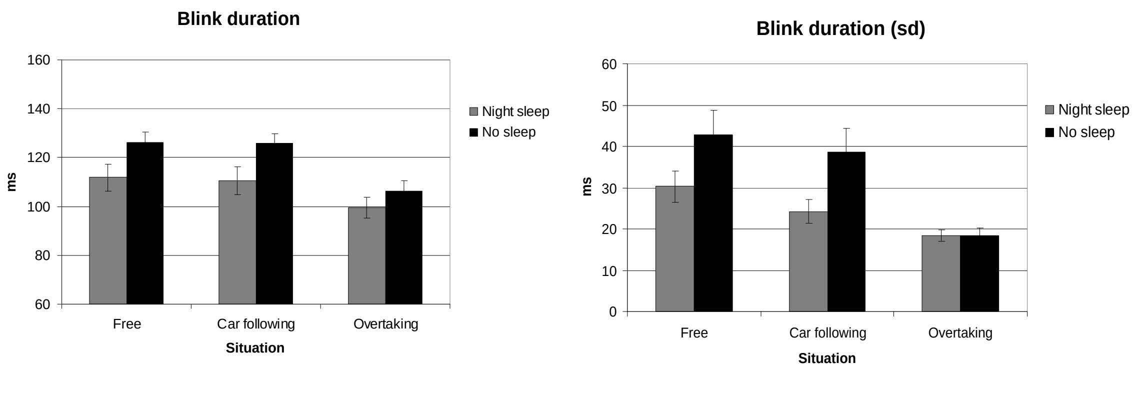

Figure 8 Mean blink duration (mean and sd) during situations free, car following and overtaking. Error bars represent SE.

A night of prior sleep loss will increase levels of established indicators of sleepiness at the wheel even if the driving situation requires frequent interactions with other cars on the road. No interaction effect with situation was seen which indicates that the effects were similar regardless of situation. The effect of in-vehicle information beforehand on the presence of a school bus was significant under both conditions. Information caused speed to be reduced.

Compared to studies using only a monotonous scenario the level of variability of lateral position, blink duration and subjective sleepiness show a tendency to be lower in the more combined and complex scenario. The blink duration during the no sleep condition in the present study started at around 120 ms and was at its maximum, 140 ms, after no sleep. In study I it was also 120 ms in the beginning of the drive during the no sleep condition but around 150 ms towards the end of the drive. The same was seen for KSS which in the simpler scenario is about KSS 9 in the final end compared to slightly under 8 in the present study. These findings may reflect lower sleepiness in the present study due to the more challenging scenario. In conclusion, a more demanding driving scenario did not seem to increase sleepiness or driving impairment during sleep loss conditions, contrary to the hypothesis.

Effect of milled rumble strips on sleepy drivers: a driving simulator study (Study III)

One potential countermeasure against the risk of sleepy driving are milled rumble strips in the centre of the lane or at the edge line, or both. However, the effect in terms of changes in sleepiness and the lasting effect are not known. Thus, the purpose of Study III was to investigate if behavioral, physiological and subjective indicators of sleepiness were increased before contact with a milled rumble strip, if sleepiness was reduced after the contact, and if so, for how long.

The main results showed an increase in sleepiness indicators from start to before hitting the rumble strip and an alerting effect in most parameters after hitting the strip, as shown in Table 6.

Table 6 Results from paired t-tests start – before and before - after; t- and p-values after Bonferroni correction.

	t-value Start – Before $t_{.05\ df=28}$ (p<)	t-value Before – After $t_{.05\ df=31}$ (p<)
Lp	1.26 (0.219)	-0.01 (0.995)
sd lp	**-6.67 (0.000)**	**3.96 (0.000)**
kds mean	**-3.24 (0.003)**	**5.04 (0.000)**
kds max	**-3.92 (0.001)**	**3.61(0.001)**
Blink duration	**-5.51 (0.000)**	**4.35 (0.000)**
KSS	**-7.36 (0.001)**	**-3.04 (0.010)**

The only significant result for change across the five minutes before the hit was seen for lateral position. For the five minutes after the hit the only non-significant effect was seen for lateral position. Minutes 1-3 differed significantly from the minute before hit for variability of lateral position, blink duration and mean KDS and max of KDS. Blink duration showed a significant difference for minute 1-2 and minute 4 compared to the minute before hit. Furthermore the participants rated themselves (KSS) significantly more sleepy before the hit (KSS average =8.1; sd=1.02) compared to the beginning of the drive (KSS average=6.7; sd=1.11).

The results showed that the alertness enhancing effect was short and the sleepiness signs returned 5 minutes after the rumble strip hit. It was concluded that various aspects of sleepiness are increased before hitting a rumble strip and that the effect is very short-lived, as shown in Figure 9.

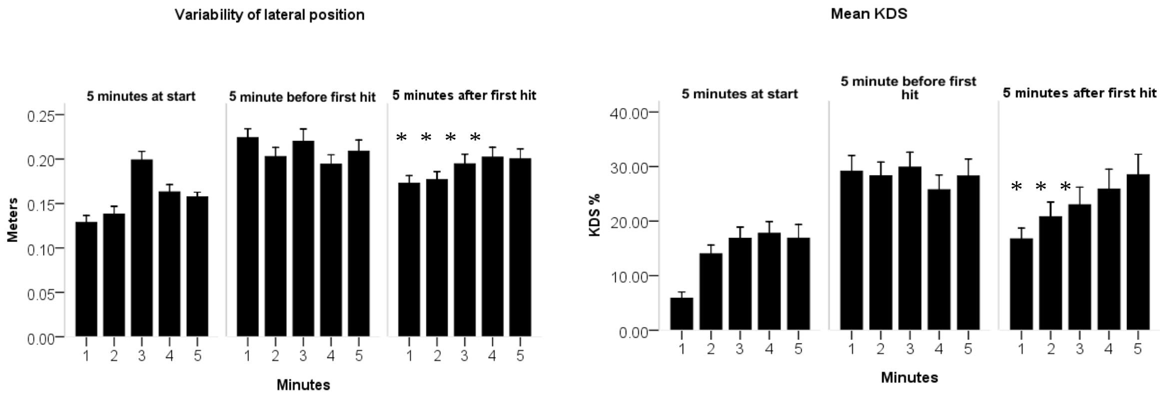

Figure 9 Mean ± SE for Variability of lateral position (middle of the car in relation to the right edge line), and mean of Karolinska Drowsiness score (KDS); n= 32 *= Significant difference (paired t-test) from minute before or after hit.

Driver sleepiness and individual differences in preferences for countermeasures (Study IV)

In order to find promising countermeasures addressed to sleepy drivers there is a need for knowledge about driver sleepiness and individual differences in preferences for countermeasures. The aim of Study IV was to investigate the use of sleepiness countermeasures among drivers in a national representative sample and relate this usage to possible explanatory factors such as age, gender, education, professional driving, being a shift worker, having experience of sleepy driving, sleep related crashes, problems with sleep and sleepiness in general and sleep length during working days. Also the attitude to countermeasures related to information or driver support systems was studied.

The results showed that the most common countermeasures were to stop to take a walk, turn on the radio/stereo, open a window, drink coffee and to ask passengers to engage in conversation. Logistic regression analysis showed that counteracting sleepiness with a nap (a presumably efficient method) was practised 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 years, as shown in Table 7.

Table 7 Univariate logistic regression. Dependent variable: efficient = stop for a nap (n=303). Odds ratio= Exp(β); 95% CI = confidence interval for odds ratio and p-value in bold= significant level.

	Efficient = stop for a nap		
Model with univariate predictors	Odds Ratio	95% CI	p
Age			
18–25			
26–45	1.22	0.82-1.83	0.32
46–64	1.86	1.28-2.70	**<0.01**
65 or older	1.01	0.68-1.50	0.97
Gender – Male vs female	2.83	2.04-3.93	**<0.01**
Higher education vs lower	1.28	0.98-1.66	0.07
Professional drivers vs non prof	3.43	2.05-5.73	**<0.01**
Exp of sleepy driving vs not	2.76	2.11-3.60	**<0.01**
Exp of sleep related crashes vs not	2.80	2.01-7.19	**<0.01**
Shift workers vs day workers	1.25	0.87-1.81	0.23
Persistent sleepiness vs not	0.87	0.60-1.25	0.45
Snoring vs not	1.70	1.16-2.50	**<0.01**
Poor sleep quality vs good	1.43	0.88-2.32	0.15
Sleep duration < 6h vs more	1.74	1.30-2.32	**<0.01**

The most endorsed means of information to the driver about sleepiness was in-car monitoring of driving performance. This preference was related to experience of sleepy driving, not being a professional driver and being a male.

Driver impairment during night driving and the relation with physiological sleepiness (Study V)

Studies of sleepiness detection need reference points of physiological sleepiness for comparison. The aim of Study V was to validate the Karolinska Drowsiness Score (KDS) as an indicator of physiological sleepiness against driving impairment and eye blink duration. The aim was also to investigate the effects of age on sleepy driving.

The results show that sleepiness increased with time on task with higher levels for young drivers, as shown in Figure 10. Except for lateral position, performance did not differ between the age groups.

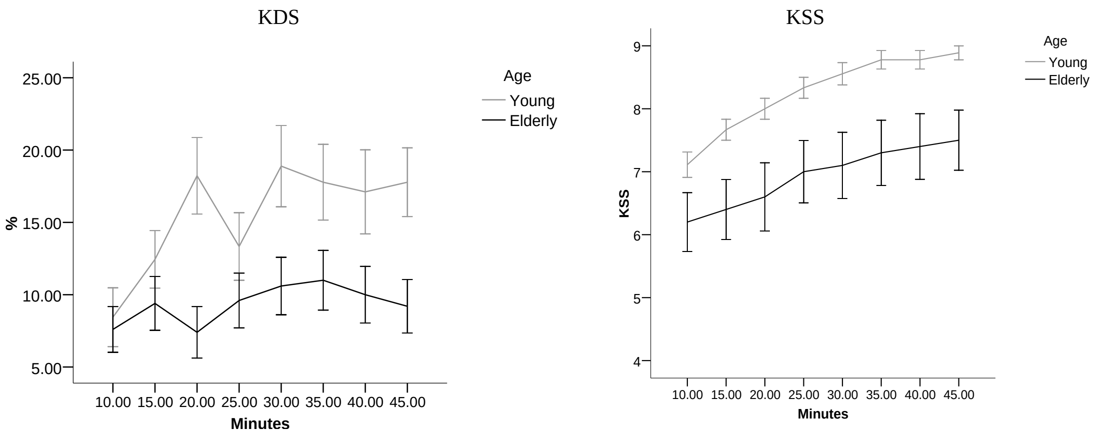

Figure 10 Mean (±SE) Karolinska Drowsiness score (KDS), Karolinska Sleepiness scale (KSS) ratings across driving time (Minutes: 8 levels) for young and older drivers; n= 19 subjects.

The distribution according to the KDS level was the result of the experiment. In the analysis, the participants (n=8) who experienced a KDS level of 50 were included. Of the 19 participants, 8 reached a KDS of ≥50%. Six KDS levels were used (0%, 10%, 20%, 30%, 40%, and ≥50%). Altogether there were 412 observations (53%) in which the participants had signs of sleepiness (KDS of ≥10%). There were 48 occasions with KDS levels of >50%, but only 13 out of these resulted in lane departures (27%).

The variability of lateral position and the mean and variability of blink duration significantly changed when sleepiness increased to KDS 20% and above. Furthermore, there was an increase in the risk of lane departure from KDS 30%, as shown in Figure 11.

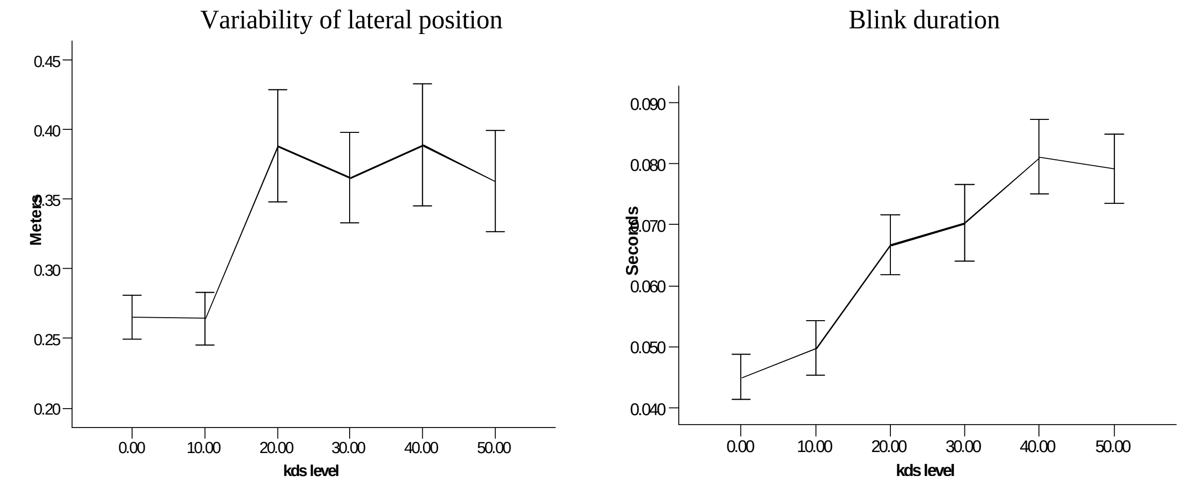

Figure 11 Mean (±SE) variability of lateral position and blink duration for Karolinska Drowsiness Score (KDS: 6 levels), n=8 that had KDS levels for every step from 0 to 50%.

The results suggest that the KDS scoring method is a reasonable procedure for estimating physiological sleepiness under conditions of driving. The results show that younger age is associated with greater susceptibility to sleepiness at the wheel compared to older age.

4 DISCUSSION

The general aim of the thesis was to explore the relation between driver sleepiness and driver impairment and the changes that precede a crash or a similar safety-critical event, but also what constitutes good reliable behavioural / physiological measurements of sleepiness. A second question concerned particular groups and situations – is post-night shift driving characterized by increased sleepiness, is more complex driving also affected by sleepiness, and are younger drivers affected by sleepiness behind the wheel more than older drivers? A third question concerned countermeasures. What are the preferred self-administered countermeasures and what are the effects of the structural countermeasure like rumble strips?

Sleepiness at the wheel in the morning after night work

Study I showed that simulated commuting back from normal night shift work caused incidents, decreased time to crashes, increased variability in lateral position, increased eye closure durations, as well as increased subjective sleepiness. Studies II and III had different purposes but made use of the same post-night-shift design. They also showed pronounced effects on similar sleepiness indicators. As expected, the three studies demonstrate that working the night shift is associated with pronounced sleepiness.

The studies are the only ones of their type and there are no other studies to compare with. However, driving *during* night work, some hours earlier than the post-night-shift studies, shows very similar results to those demonstrated in study V, for example in a study by Gillberg et al., (1996) using a truck simulator. They found small but significant effects on driving: night driving was slower, with a higher variability of speed and lane position. Subjective and EEG/EOG measured sleepiness were higher during the night conditions. Horne and Reyner (1999) simulated night shift driving in a car simulator and found an increased number of crashes and incidents. However lateral variability was not analyzed. They also reported increased subjective sleepiness, as well as sleep intrusions in the EEG.

The reason for the crash risk associated with the post-night shift commute is, most likely, the combination of driving close to the circadian low (around 04h-05h) and an extended time awake (often awake since the previous morning and without any nap) as has been demonstrated in many laboratory studies (Dijk & Czeisler, 1995). The total effect on road crash risk of the circadian low, prior time awake and prior amount of sleep has recently been demonstrated (Åkerstedt et al., 2008). The results show a strong capacity to predict crash risk.

The sleepiness effects during the morning commute are in line with the epidemiological studies that have demonstrated an increased crash risk in shift workers travelling home after a night shift (Czeisler *et al.*, 1995; Gold *et al.*, 1992; Stutts *et al.*, 2003). They are also in line with a number of studies that demonstrate increased risks of road crashes in connection with early morning driving (Åkerstedt & Kecklund, 2001; Connor *et al.*, 2002; Horne & Reyner, 1999). Observations on strong effects of reduced sleep on sleepiness have been made in many studies of sleep loss, daytime driving, for lateral variability (Arnedt, Wilde, Munt, & Maclean, 2000) or eye closure durations (Wierwille & Ellsworth, 1994).

The effects on sleepy driving of a more complex scenario

Driving without interacting with other vehicles or interference from the environment is very much like a traditional tracking task, that is, monotonous (Balkin *et al.*, 2004). Simulator studies normally also use a very simple and monotonous scenario in order not to alert the participants, but also to reduce confounding factors. The consequence is a reduced ecological validity with lack of realism in terms of driving on real roads. One interesting aspect is whether there are changes in magnitudes of sleepiness indicators (driving and driver behaviour) if the scenario has a higher degree of ecological validity, i.e. with a more complex scenario.

Study II shows that sleep loss appears to have the expected effects on sleepiness indicators as in Studies I, III and V. Following another car did not affect sleepiness, which had been hypothesized. There are no similar studies to compare with, but it is possible that just following another car and getting ready for overtaking may not be challenging enough to affect indicators of sleepiness.

Overtaking reduced physiological sleepiness more than the other two situations and seems to have eliminated, at least temporarily, the sleepiness induced by sleep loss. This is remarkable, considering that Study I in the thesis, but also Studies III and V and other studies, show severe effects of sleep loss on eye blinks. As mentioned above, no comparable data seem to exist, but in a study of effects of time of day on the risk of different types of crashes it was found that the only type of crash without a late-night peak in relative accident risk was overtaking crashes (Åkerstedt & Kecklund, 2001). This suggests that the assumed stressfulness of overtaking counteracts sleepiness. However, it is not entirely clear if the effect seen in the present study is one of increased alertness. Instead, the stress of the task may mask a latent sleepiness, although one may still argue that at least temporarily alertness had been present.

One may also suppose that the task itself may affect blink duration without having anything to do with alertness or that the overtaking was attempted only when the driver felt alert. There is, however, no support in the literature for this. One would expect a larger number of overtakings during the night sleep condition and in the beginning of the drives if there were a relation between the willingness to overtake and lack of driver sleepiness, but this did not occur. One practical implication of the effects of overtaking is that the driving situation must be taken into account when results from field operational tests of sleepy driving are evaluated.

If the more complex scenario did contribute to reduced sleepiness there would be expected a lack of effects due to time on task. When all laps were included in the analysis the effect of laps was significant, but disappeared for several indicators of sleepiness, e.g blink duration and lateral variability when the first lap was removed from the analysis. The impression is that the linear increase in sleepiness, which was seen in Studies I, III and V and in many other driving simulator studies (O'Hanlon & Kelly, 1974; Otmani, Joceline *et al.*, 2005) was not as clear in the present more complex scenario. The modest effect of laps (time on task) again suggests that the alternating interaction with other vehicles may have had combined alerting effects, counteracting accumulation of sleepiness with duration of the drive. This, however, will have to be studied separately.

Most sleepiness indicators describing driving behaviour focus on lateral positions. Also longitudinal measurements, like speed, should be of interest, especially when related to perception and cognitive information processing. One variable to study would be the effect on speed reduction after prior information of potential risks, for example school bus at stand still.

The results from the school bus situation showed no effect of sleep loss on speed. This suggests that the warning signals are acted upon regardless of alertness. The information per se, however, caused speed to be reduced. Thus, it seems likely that this type of information may be useful in intelligent transport system (ITS) approaches to provide driver support about upcoming hazards. One may compare the present lack of effect with studies showing increased latency to braking when a sudden obstacle appears on the road (Haraldsson, Carenfelt, Laurell, & Törnros, 1990).

Subjective sleepiness was not part of the evaluation of the effect of the driving situation in Study II but was included as reference. It clearly related to sleep loss, as well as to time on task. The pattern is similar to the one in Studies I, III and V, but also to the results from another study using the same scale (KSS) (Otmani, Joceline *et al.*, 2005). However, the peak level in Study II was about one unit lower than the usually encountered level 9. This is in line with the results showing a task dependent difference for subjective sleepiness when a simple vigilance task is compared with a driving simulator task using a monotonous scenario (Richter *et al.*, 2005).

Sleepiness behind the wheel before and after hitting a rumble strip

The results from study III showed an increase in sleepiness indicators from start to before hitting the rumble strip and an alerting effect in most parameters after hitting the strip. The effect lasted a short time after the hit and was back to pre-hit levels after 3-4 minutes.

The increase in the levels of sleepiness indicators before the hit was expected based on previous studies of sleep loss and driving presented in Studies I and V, and also in another study (Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006). That study show increased levels of EEG alpha and theta activity, increased eye closure durations, increased lateral variability in connection with lane crossings and driving off the road. Here these changes were closely linked to a behaviour that is seen as an absolute measurement of improper driving behaviour and one that constitutes a driving incident. Had the strip not warned, the vehicle may have left the road or ended up in the opposite lane. To the best of my knowledge the precursors of similar events (leaving the lane, for example) have not been described before.

Looking at the variables involved it appears that the highest F-value (most significant) for change from start to the minute before the hit was subjective sleepiness. This variable has been shown to be a very sensitive sleepiness indicator in many studies (Åkerstedt & Gillberg, 1990; Horne & Baulk, 2004; Ingre, Åkerstedt, Peters, Anund, Kecklund *et al.*, 2006). Apparently, most individuals are clearly aware of their state of sleepiness to a sufficient degree to use it as a warning not to continue driving. It has also been shown to be increased before road crashes, at least as obtained retrospectively (Connor *et al.*, 2002).

Among the other variables, the highest F-values were obtained for variability of lateral position and blink duration. This finding also agrees with a number of studies (O'Hanlon & Kelly, 1974; Otmani, 2005). Lane position was clearly of little interest. It was closer to the rumble strip before the hit but was back to normal during the first minute after the hit. The latter agrees with the lack of major erratic or avoiding manoeuvres when a rumble strip is hit in alert condition, seen in an earlier study (Miles, Pratt, & Carlson, 2006). The KDS as an indicator of sleepiness-related risk of hitting a rumble strip seems somewhat weaker than subjective sleepiness, lateral variability and blink duration. However, the values reached are similar to values in Studies I and V. This suggests that EEG theta/alpha activity or slow eye movements do not necessarily indicate sleep before danger occurs. Moderate increases seem sufficient. In Study V it was demonstrated that lateral variability and eye blinks seem to rise rapidly across the first levels of the KDS and then level off.

The level of KDS before the hit reached almost 30%. This is in line with Study V which shows a significant increase in risk of lane departure by almost 3 times at KDS 30% and 6 times at KDS 40%. Sleepiness reached a level of 8 on the KSS, which is similar to the levels when incidents and crashes start to occur in the study by Ingre et al., (2006). For lateral variability the value was above 0.35m compared to the value of 0.36m in a previous study (Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006). For blink duration it was 0.18s compared to 0.14s in the previously mentioned study. Even if studies are different and there will be individual differences (Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006) one gets the impression that incidents tend to occur at certain levels of the sleepiness indicators. Possibly this knowledge may be used in the development of warning devices in driver support systems.

An important observation is also the lack of "final" increase in sleepiness indicators during the minute before the hit. One could, of course, conceive of a very short increase in the levels of the sleepiness indicators the last few seconds before a hit, but this was not picked up with the present one-minute resolution. The results indicate that the risk of a lane crossing is present over a rather long period of increased sleepiness. In this case the period was 5 minutes; this in turn was the longest period that could be analyzed without losing too many subjects because of overlap with the first five minutes. Possibly, this state of high risk drowsiness may be present for long periods of time, as suggested by Horne and Reyner (1995a). This finding suggests that the first signs of sleepiness should be taken seriously and that there will be no easily discernible "final warning" before an adverse event.

Another main result of the experiment was that a rumble strip contact had an alerting effect that caused reduced variability of lateral position (less swerving), and decreased the physiological sleepiness level. However, the alerting effect was rather moderate and baseline levels of sleepiness, i.e. those at the beginning of the driving session, were not reached. Furthermore, the alerting effect only lasted for 2-3 minutes, and 5 minutes after the rumble strip contact the indicators of sleepiness had returned to the same level as before the hit. I am not aware of any similar data and thus need further corroboration, but the results fit anecdotal data on the temporary effects of sudden jolts into wakefulness. Indeed, many subjects had 9 or more hits and thus repeatedly fell asleep. Also subjective sleepiness increased after the hit, but sleepiness was rated several minutes after the hit and probably reflects the rapid return to pre-hit levels.

At some low level of noise the alerting effects should disappear and one should obtain a significant difference from the higher levels. There is also a clear need for more systematic research on optimal design of rumble strips. At present, the design appears to be based on intuition. However, there was a difference in lateral position between the types of strips, and the most aggressive rumble strip caused an increased distance to the centre of the road. This, however, does not represent an alerting effect, rather something like the driver's attempt to keep away from a slightly unpleasant experience.

Relation between EEG/EOG based sleepiness scoring method (KDS) and other parameters of sleepiness

The results from Study V show that KDS increased with time across the drive, and so did the variability of the lateral position, the mean and variability of the blink duration, and the KSS. The increased subjective sleepiness, driving impairment, and long eye blink durations agree with Studies I and III, and the level of sleepiness at the end of the drive was pronounced. They also agree with other studies (Horne & Reyner, 1996; Otmani, Joceline *et al.*, 2005).

One major purpose of study V was to investigate the relation between the KDS and other indicators of sleepiness, in order to be able to interpret changes in the KDS. This is of interest, since the KDS at levels above 50% fulfills the criteria of the initiation of sleep. The KDS include alpha or theta activity and slow rolling eye movements (Rechtschaffen & Kales, 1968). Thus, the KDS is intended to be an absolute indicator of the appearance of sleep during supposedly waking activity (Åkerstedt & Gillberg, 1990; Gillberg *et al.*, 1996). The assumption is that lower levels of the KDS, while not reaching the formal criteria of sleep, should reflect tendencies to sleep, that is, "sleepiness". The other variables used in the present studies are separate indicators of sleepiness but do not reflect sleep.

The results of the analyses of the KDS data versus those of the other variables showed that there was a relation between the level of KDS and the mean and variability of the blink duration and the variability of the lateral position. When physiological sleepiness increased (KDS 0–50%), there was an increase also in these variables. Furthermore, when the KDS level increased, there was an increased risk of lane departure, particularly at a KDS of 40% (>6 times).

The drivers showed signs of sleepiness (KDS >10) during more than 50% of the time. The results indicate that the lowest level of increase in the KDS did not show any increase in lateral variability or risk of lane departure. Such effects did not occur until a KDS of 20%, and first became significant at a KDS of 30%. This finding suggests that performance does not become seriously impaired until the EEG or EOG recording indicates sleep onset processes for more than 6 seconds (30%) out of a 20-second scoring interval. The very high risk at the KDS level of 40% is difficult to interpret. However, since the risk was lower at a KDS of 50%, we assume that the peak in risk at a KDS of 40% may have been spurious and due to a few persons with very high risk, as suggested by the increased standard error of mean at a KDS of 40%. We also speculate that the lack of a continuous increase in driving impairment above a KDS of 40% could have been brought about by the participants becoming aware of their sleepiness and therefore increasing their effort and taking counteraction. However, activities to counteract sleepiness were not monitored in our study.

KDS applies the traditional criteria of polysomnographical sleep onset to recordings obtained under conditions of wakefulness, the assumption being that "physiological sleepiness" is represented. The latter is, however, only a construct based on inference, and an absolute definition of physiological sleepiness does not exist. Attempts to validate a measurement of physiological sleepiness must therefore use other variables assumed to measure the same property. The most well-established one is eye blink duration (Johns & Tucker, 2005; Wierwille & Ellsworth, 1994). In study V, the relation between the KDS and blink duration was one of a gradual increase in both the mean and the variability. This finding seems to support the notion that the KDS represents physiological sleepiness. However, there seems to be little difference between a KDS of 0% and a KDS of 10%, and there also seems to occur a flattening of the slope at the highest sleepiness level. This finding could mean that sleepiness is saturated at this level, and sleep is taking over, partly eliminating blinking and making blinks more difficult to identify. The close relation between eye blink duration and the KDS seems to suggest that KDS could possibly be improved by the addition of long eye blink durations to the scoring criteria.

Subjective sleepiness (KSS) only showed a trend towards an increase across the KDS levels, which was unexpected. One reason may be the obvious restriction of range caused by the very high level of sleepiness at the start (7.4 units) and the ceiling effect due to the scale's end point being 9. One could conceive of using a higher end point, but it is logically difficult to argue that one can perceive sleepiness to exceed the level when one is "fighting sleep (exerting) in an effort to remain awake". However, in Study II with a scenario with a higher degree of ecological validity the ceiling effect was not seen. One solution may be to reduce the monotony in the scenario. Physiological and behavioural indicators can, logically, be extended considerably further, while a person is fighting a losing battle against an increasing frequency of micro sleep. There were 48 occasions with KDS levels of >50%, but only 13 out of these resulted in lane departures (27%). Thus high levels of physiological sleepiness do not automatically lead to lane departures. This situation could be due to the presence of a stretch of straight road with less risk of lane departure or to the pattern of physiological sleepiness; ten continuous seconds may give more time to depart from the lane than an on–off pattern. We could also speculate that there is a need for the presence of theta activity (indicating sleep) or perhaps slow eye movements or long eye blinks. The relative importance of these indicators has not been established. Hence, this is an important future task.

Effects of age

One purpose of the present study was the relation between age and sleepiness at the wheel. The results from study V showed that sleepiness increased with time on task with higher levels for young drivers than for older drivers and the results indicate that younger age is associated with greater susceptibility to sleepiness at the wheel. The absence of a performance difference could have been due to the difference in sleepiness not being sufficient to affect driving performance. This possibility will have to be determined in future studies.

Study V confirms that young drivers seem more susceptible to sleepiness during night driving. The age effect was pronounced; the young participants were less able to sustain alert, in terms of subjective ratings and KDS. This result was not due to the groups for most of the variables. The results agree with crash data (Åkerstedt & Kecklund, 2001; Corfitsen, 1994; Otmani, Joceline *et al.*, 2005; Pack *et al.*, 1995) and with clinical data which indicate that the multiple sleep latency test shows close to pathological values (around 5 minutes' latency to sleep) for young adolescents (Pack *et al.*, 1995).

In a review focusing on adolescents' driving risks (Dahl, 2008) it is concluded that one major cause that contributed significantly to an increased driving risk in teens is sleep deprivation and the consequences of insufficient sleep (sleepiness, lapses in attention, susceptibility to aggression, and negative synergy with alcohol). One additional explanation for an increased risk is the adolescent brain maturation that indicates that essential parts of the brain regulating emotions (pre-frontal) are not fully developed until the adolescent is above 18 years old. Furthermore, the findings of Dahl apply to real traffic environments, not simulator driving. The explanation suggested by Dahl review may, however, not apply for Study V since all subjects were prepared in the same way regardless of age and no one was under the influence of alcohol.

Duration of driving

Although the effects of the duration of driving were not part of the aims of the thesis, one may consider the effects. Results from other simulator studies show pronounced time-on-task effects on sleepiness (Horne & Reyner, 1996; Otmani, Pebayle *et al.*, 2005). This is in line with the results behind not only study V, but also in Studies I, II, III. A crash study (Hamelin, 1987) showed increased risk of truck crashes with time at the wheel. However, in this type of study it is likely that there are strong effects of time of day as well as effects of circadian rhythm, since driving time spans durations from a few hours up to 10—15 hours.

Whether real driving is as sensitive to time on task, as simulator driving is not known. In one study (Sagaspe *et al.*, 2008) no effect on involuntary line crossing was seen during 10h of highway driving on the day. However, breaks occurred every second hour, which may have maintained alertness. The same group did, however, show pronounced effects when 2, 4, and 8h of night driving, without breaks, were compared (Sagaspe *et al.*, 2008). This was the first study of real life sleepy driving that controlled for prior amount of sleep, prior time awake and circadian rhythm.

Simulator driving versus driving on real roads; and selection of participants

Four out of five studies included in the thesis have been carried out in a driving simulator. This has special implications. Whereas a simulator comes quite close to real life driving in some ways (Törnros, 1998) it is likely that the fatigue inducing effects may be larger in the simulator and especially with a monotonous scenario as in Studies I, III and V. At least in studies I and V a rapid increase is shown. In study III a significant development over the first five minutes was shown for all variables except blink duration. The reason for the rise may be that driving in the simulator induces sleep and this effect sets in early during the drive, at least as indicated by KDS values and lateral variability. Eye blink durations seem to be more resistant, possibly because difficulties in keeping one's eyes open usually appear only at high levels of sleepiness (Åkerstedt & Gillberg, 1990). Rapid rises of sleepiness have been seen in many other simulator studies of sleepiness (Horne & Reyner, 1996; Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006). It seems a reasonable assumption that impairment and sleepiness in a more complex situation as in Study II or in real driving would be less likely to be due to the higher level of stimulation. Study II did not show a strong initial rise with time on task.

Philip and colleagues (2005) found no immediate rise in lane crossings or KSS across 10h of day driving. However, they concluded in a comparative study that sleepiness can be studied equally well in real and simulated driving conditions and that the main difference is the level rather than changes when driving in alert or sleepiness condition is compared. The effects were almost the same except that the simulator driving comprised more frequent line crossings and road departures than driving in a real environment. Since touching the lane boundaries is an early indication of an incident, it could, however, be possible to run a similar experiment on a test track or on a real road without risk. A disadvantage would still be the need for a vehicle equipped with dual controls and the presence of a supervisor to stop the session if necessary.

Another limitation of simulator studies, especially relevant for study V, is that, after a lane departure, drivers are aware of the fact that lane departure will not trigger a crash, unlike in real driving. Even if some of the drivers experienced several lane departures and only the first five were included in the study, it may be that the situation was too unrealistic. An advantage with the Cox regression used in Study V, however, is that , to some degree, it handles different hazard functions for lane departures, depending on whether a departure is the first, second, third, and so forth.

Even if the scenario was more complex in Study II and hopefully had a higher degree of ecological validity, there was a problem in creating a scenario that made it possible for the drivers to reliably perceive a distance to the car ahead and to oncoming cars. Although the scenario included reference points, the simulator projection - with a resolution of approximately 2 arc minute - could not fully substitute for what the human eye sees in real world driving. This probably affected the subjects' willingness to overtake, both with respect to the frequency and variation. However, all comparisons were made between the two conditions (night sleep - no sleep) and any limitations were present in both.

Clearly, a driving simulator suffers from weaknesses in comparison to real life driving. However, there seem to be no studies investigating to what extent a simulator study leads to erroneous conclusions compared to what would have resulted from a real life study. Still, the simulator provides the opportunity to monitor the driver without any risk, all the way to sleep onset and actual lane departure. The lack of real risk is also a disadvantage. The simulator also offers total control over environmental conditions, which increases the possibility to draw reliable conclusions. The simulator also makes possible cost-efficient use of research subjects and other resources, making larger and more representative samples possible. At present a validation study of the same section of road is being carried out in the simulator and in real life. Still, future studies will need to be carried out in real driving situations to verify key implications resulting from simulator studies.

Limitations

There are other limitations related to the use of participants in the simulator studies that should be mentioned. One is the use of volunteers for the simulator studies. On the other hand the consequences could be that drivers with real problems or specific needs will not be included and, hence, it may not be possible to generalize the results. On the other hand, the volunteers had e been interviewed before and a list of inclusion criteria used in order to find representative persons without major psychological or physiological impairments.

Another limitation is that, in most of the studies included in the thesis, the participants have been shift workers. Shift workers do not by definition have “normal” sleep and wake patterns and they more often than others report problems with sleepiness. On the other hand this is a group that are at risk and therefore of special interest. It could be that they are more used to sleepiness than drivers in general and thus even more trained and experienced of the situation. This may lead to assumptions that underestimate the problems encountered. The major limitation is the fact that in most of the studies there are few participants involved (10-35 participants). Impairments (driving and driver) caused by sleepiness are individual dependent and there will be individual differences (Ingre, Åkerstedt, Peters, Anund, Kecklund *et al.*, 2006; Van Dongen, 2007) that cannot be taken into account for all studies.

One more limitation is that in most of the studies included in the thesis only the reactions of drivers of passenger cars are considered. The results are probably not valid for truck drivers, which is another group at risk of sleepiness while driving (Kecklund & Åkerstedt, 1993). The results also indicate that there are large individual differences regarding the capability of resisting sleepiness. This could be exemplified by the results from Study III where 3 out of 35 drivers did not have any lane departures at all while 19 drivers experienced 8 rumble strip hits or more in the sleepy condition. These results are, however, in line with other studies of individual differences in driver sleepiness (Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006) or in behavioural responses to sleep loss in general (Van Dongen, 2007). One consequence of individual differences is that the development of fatigue warning devices needs to take such differences into account. This is most likely valid for driver sleepiness, as for the reactions to warnings.

In experiments like those included in this thesis it is important to have a stable and long enough baseline period (alert). A weakness in for example Study III is that this period was not a really alert condition – the driving followed a night of work. Probably, the results may have been even more pronounced if such a condition had been used. However, the situation was realistic for going home after a night shift that we know for will lead to an increased risk of lane departures.

Preference for countermeasures and related background factors

From a driver theoretical point of view the most promising countermeasures will be those that contribute to the decision not to drive at all when there is a risk of being sleepy (Haddon, 1972). This is an important area but not in focus in this thesis. During the drive there are critical decisions a driver needs to take in order to avoid the risk of a sleep related crash. First of all, the driver has to recognize the sensation of sleepiness. In the next step, the driver must be motivated to take corrective actions, and have knowledge of which countermeasures are effective and lasting. Finally, the driving circumstances should allow the driver to act according to an effective strategy, as shown in Figure 12.

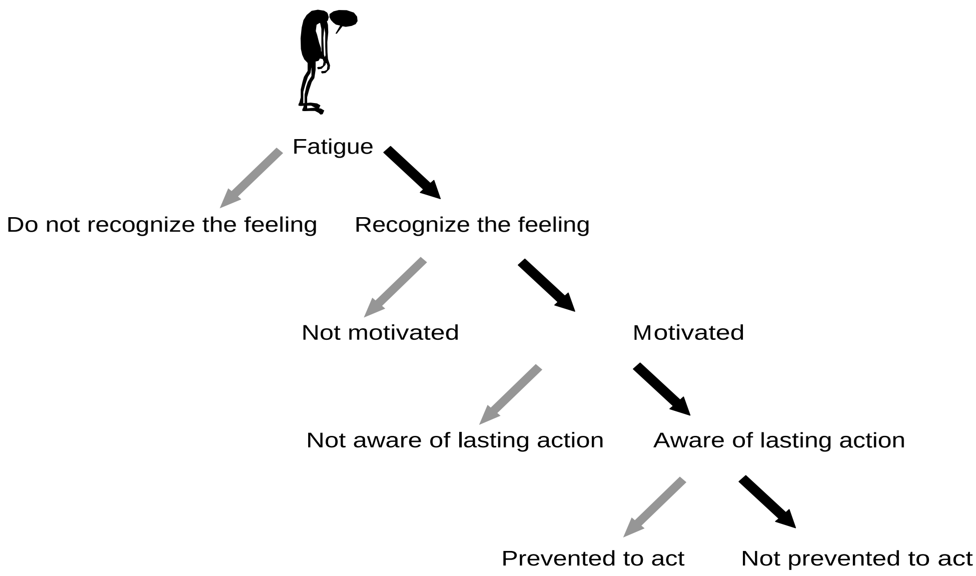

Figure 12 The chain of decisions in order to avoid increased risk of crash when sleepy

The drivers' preference for countermeasure will not only influence the motivation to do something about it, but also the probability of a choice of an effective countermeasure will be influenced.

The results from study IV show that the most common self-administered countermeasures involved stopping for a short walk, turning on the radio/music player, opening a window, and drinking coffee. Thus, one of the two most efficient countermeasures, caffeine intake, was only the fourth most common countermeasure, whereas the second most efficient countermeasure, stopping for sleep, was only practised by 18%. This is a relatively discouraging result but reveals a potential for increased safety within reach by information and educational efforts. However, the amount of research into efficient countermeasures is limited and has mostly been carried out in the laboratory (Horne & Reyner, 1999; Horne & Reyner, 1996).

The dominance of laboratory studies of countermeasures leaves the possibility open that the more stimulating driving context of the real road may result in other countermeasures also becoming efficient. For instance, a matched case-control study showed crash reduction among those using highway rest stops, drinking coffee or playing radio while driving (Cummings *et al.*, 2001). However, such groups may constitute a selection in terms of responsibility and the reduced crash rate may partly be due to this . An experiment with randomized groups is clearly needed.

The pattern of countermeasure usage in study IV seems logical. Most clusters included some sort of activity at the wheel, presumed to be alertness promoting. Very likely, the reason is that an activity that can be carried out while still driving is less intrusive than stopping or taking a nap during a stop, and will therefore be easier to apply. One would then expect a combination of activity while driving as a first line of defence, followed by stopping, and then combined with caffeine intake. Having a nap would be a less prevalent means, possibly related to exposure to sleepiness, as discussed below.

Interestingly, the use of presumably efficient countermeasures clearly differed between groups. Among the clearest result was the importance of having had a sleep related crash or experience of sleepiness while driving. This was predictive in identifying a nap as an efficient countermeasure. The importance of having had experience of sleepy driving probably explains the relatively low prevalence (18%) observed above. Note that being a professional driver or being older (up to the retirement age criterion) will add explanatory power. Both seem to represent other aspects of experience that would lead one to have a nap. This may be related to increasing caution with increasing knowledge of the dangers of driving.

The increase in preference for efficient countermeasures with increasing age is interesting from the standpoint of the lower risk of sleepiness related crashes in higher age groups (Åkerstedt & Kecklund, 2001; Pack *et al.*, 1995). Also, being male was associated with a preference for a nap. The reason for this is not immediately obvious. However, the results from the pre-discussion within focus groups (Anund *et al.*, 2002) suggested that females can be afraid of stopping for reasons of personal security. Interestingly, having disturbed sleep, being a snorer or being a shift worker were not related to identifying a nap as important, despite the fact that such individuals should have ample experience of sleepiness (Philip and Akerstedt, 2006).

When caffeine intake was used as the dependent variable, being a male, being a professional driver, being aged over 25 years and having experience of driving under severe sleepiness were again significant predictors. Having had a sleepiness related crash did not enter into the regression. The reason for the latter is unclear, but clearly caffeine intake is more common as a countermeasure than taking a nap, and caffeine intake is also widespread and a relatively easily administered countermeasure. Thus, caffeine intake countermeasures may demand less experience of critical situations, such as sleep related crashes, to be applied as a countermeasure.

With regard to information to drivers about sleepiness, the one most accepted was clearly feedback of driving behaviour. This is similar to what has been found in a field study on this topic (Dinges *et al.*, 2005). More passive information (signs, other information) was less credible as a countermeasure. Clearly again, experience of sleepy driving was an important predictor. However, professional drivers and women were not positive. The former may believe that their professional skill and experience do not need external information on driving performance, but the reason for the negative attitude of women is more difficult to understand. One may perhaps speculate that there is lower interest in technical gadgets among women compared to men, and therefore trust in such devices may be lower in women. This remains to be demonstrated, however.

Another feedback to the driver could be information about the driver's physiological state (alertness level). With regard to such a system there was less difference between driver groups. Thus, a positive view was seen among those with experience of sleepy driving or drivers among those with problems with snoring, but also among drivers aged 26-45 years. The reason for the difference in preference between systems based on impaired driving behaviour and drivers' physiological state remains unclear.

It should be kept in mind that the results from study IV are based on the drivers' own reports. This means a certain risk of poor recall or of social desirability. Still, the questionnaire was based on the results from focus groups and the correspondence between those results and questionnaires was good. Another limitation is that the countermeasures applied will depend on the context. There will probably be a difference due to time on task, circadian, environmental or other external factors. The response rate differed between the age groups and the lowest response rate was observed among young drivers. This is normally the case in questionnaires in Sweden. However, also here the results for the young group were similar to the results from the discussion with focus groups with young drivers.

In study IV, 10 predictors were used in two separate univariate analyses. Assuming independence, one may expect one predictor to show a significant beta weight. On the other hand the results show many more significant results and interpretable patterns. Thus, there seems to be no need to correct for the number of variables used but rather for caution that one of the significant beta weights may be spurious.

Practical implications

From a practical point of view the studies in this thesis include a number of observations and conclusions that may have implications.

One of these concerns is driving home after night work as indicated in studies I, II and III. Physiological, behavioural and subjective sleepiness is greatly increased and there is a considerable risk of losing control of the vehicle. The problem is the same when driving *during* a night shift. Obviously, driving home under such conditions should be avoided both when the situation is monotonous and more complex. It is also of great importance to use efficient countermeasures. One may also consider the lack of awareness of sleepiness inducing factors in the legal provisions for professional driving, as well as the same absence in the systematic investigation of road crash causes.

A second observation across several studies is that the effect of driving time is important and should be considered in planning trips.

A third observation, made in study III, is that rumble strips serve as an effective countermeasure against sleepy driving, but it has to be kept in mind that the effects are very temporary.

A fourth observation, based on the results from study IV is that driver support systems based on sleepiness monitoring are, from the drivers' point of view, the most preferred solutions in relation to driver support. The results from Study II also support that there is a potential in using in-vehicle information about temporary critical situations, even if the driver is under the influence of sleepiness. The implication from Study V is that a warning system should be activated no later than at a KDS (combined scoring of EOG and EEG measurements) level of 20%. At this level signs related to a decrease in driving performance and a risk of lane departure are prevalent.

A fifth observation is that exposing learner drivers to sleepy driving may be a way of raising awareness. Information addressed to learning drivers about effective/not effective countermeasures and how to be prepared before leaving may influence the drivers to plan and take lasting countermeasures. This is also supported by the results of Study V which show that the young drivers are more susceptible than old drivers to sleepiness when driving.

A sixth observation is that young age groups have an increased susceptibility to sleepiness during driving. This should at least be a topic for focused information in driving classes. There may also be a need for a restriction for novice drivers at night as has been implemented in New Zeeland, Australia and in some parts of the US (Engström, Gregersen, Hernetkoski, Keskinen, & Nyberg, 2003). There is one major difference in those countries compared to Sweden and that is that one is permitted to take a driving licence before the age of 18 in some of those countries.

Finally, a driver under the influence of sleepiness has an increased risk of incident and crash. This holds true even if the roads are equipped with milled rumble strips since it has been shown that this is only a short lived effect. The most promising countermeasures are information and education in order to avoid sleepy driving at all, but also to teach drivers about the risk of driving under the influence of sleepiness and what is a lasting countermeasure.

5 CONCLUSION

The general aim of the thesis was to explore the relation between driver sleepiness and driver impairment and the changes that precede a crash or a similar event, but also what constitutes good reliable behavioural / physiological measurements of sleepiness. A second question concerned particular groups and situations – is post-night shift driving characterized by increased sleepiness, is more complex driving also affected by sleepiness, and are younger drivers more affected by sleepiness behind the wheel than older drivers? A third question concerned countermeasures. What are the preferred self-administered countermeasures and what are the effects of the structural countermeasure called rumble strips?

In conclusion the results show that a combined scoring of EOG and EEG measurement, the so called KDS scoring, is a promising method for estimating physiological sleepiness under conditions of driving. At KDS level 30 % (meaning sleepiness signs 30% of the time within a given time frame) the risk of lane departure is 2.6 times higher; at KDS 40% the risk of lane departure is more than 6 times higher. The relation between KDS and variability of blink duration shows that at KDS 30% the variability has changed from 0.04 second to 0.07 second . Moreover, at KDS level 30% the average subjective sleepiness level, rated by KSS, is 8 out of 9.

Moreover, the results showed that driving home from the night shift was associated with an increased number of incidents (2 wheels outside the lane marking, from 2.4 to 7.6 times). There were a decreased time to first crash, increased lateral deviation (from 18 to 43cm), increased eye closure duration (0.102 to 0.143sec), and increased subjective sleepiness. Moreover, a night of prior sleep loss increased levels of established indicators of sleepiness behind the wheel even if the driving situation requires frequent interactions with other cars on the road. However, blink duration (mean and variability) was shorter during overtaking compared to other situations even when going home after night shift. Sleepiness increased with time on task with higher levels for young drivers than for older drivers and the results indicate that younger age is associated with greater susceptibility to sleepiness behind the wheel.

The thesis has also shown the importance of taking into account the type of driver group when working with countermeasures against sleepiness related crashes. The most common countermeasures among drivers were to stop to take a walk, turn on the radio/stereo, open a window, drink coffee and to ask passengers to engage in conversation. None of them have so far been proven to be effective. Counteracting sleepiness with a nap (a presumably efficient method) was practised 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 years, and the most endorsed means of information to the driver about sleepiness was in-car monitoring of driving performance. This preference was related to experience of sleepy driving, not being a professional driver or being a male. Another promising countermeasure is the milled rumble strip. A sleepy driver leaving the lane and hitting the rumble strip will be awakened and show an improved driving behaviour. However, the sleepiness sign returned 5 minutes after the rumble strip was hit. It was concluded that various aspects of sleepiness are increased before hitting a rumble strip and that the effect is very short.

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