

# Fatigued driving: prevalence, risk factors and groups, and the law

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## ABSTRACT

Fatigue and sleepiness are major causes of road traffic accidents. However, precise data is often lacking because a validated and reliable device for detecting the level of sleepiness (cf. the breathalyzer for alcohol levels) does not exist, nor does criteria for the unambiguous detection of fatigue/sleepiness as a contributing factor in accident causation. Therefore, identification of risk factors and groups might not always be easy. Furthermore, it is extremely difficult to incorporate fatigue in operationalized terms into either traffic or criminal law.

The main aims of this thesis were to estimate the prevalence of fatigue problems while driving among the Finnish driving population, to explore how VALT multidisciplinary investigation teams, Finnish police, and courts recognize (and prosecute) fatigue in traffic, to identify risk factors and groups, and finally to explore the application of the Finnish Road Traffic Act (RTA), which explicitly forbids driving while tired in Article 63.

Several different sources of data were used: a computerized database and the original folders of multidisciplinary teams investigating fatal accidents (VALT), the driver records database (AKE), prosecutor and court decisions, a survey of young male military conscripts, and a survey of a representative sample of the Finnish active driving population.

The results show that 8-15% of fatal accidents during 1991-2001 were fatigue related, that every fifth Finnish driver has fallen asleep while driving at some point during his/her driving career, and that the Finnish police and courts punish on average one driver per day on the basis of fatigued driving (based on the data from the years 2004-2005).

The main finding regarding risk factors and risk groups is that during the summer months, especially in the afternoon, the risk of falling asleep while driving is increased. Furthermore, the results indicate that those with a higher risk of falling asleep while driving are men in general, but especially young male drivers including military conscripts and the elderly during the afternoon hours and the summer in particular; professional drivers breaking the rules about duty and rest hours; and drivers with a tendency to fall asleep easily. A time-of-day pattern of sleep-related incidents was repeatedly found.

It was found that VALT teams can be considered relatively reliable when assessing the role of fatigue and sleepiness in accident causation; thus, similar experts might be valuable in the court process as expert witnesses when fatigue or sleepiness are suspected to have a role in an accident's origins. However, the application of Article 63 of the RTA that forbids, among other things, fatigued driving will continue to be an issue that deserves further attention. This should be done in the context of a needed attitude change towards driving while in a state of extreme tiredness (e.g., after being awake for more than 24 hours), which produces performance deterioration comparable to illegal intoxication (BAC around 0.1%). Regarding the well-known interactive effect of increased sleepiness and even small alcohol levels, the relatively high proportion (up to 14.5%) of Finnish drivers owning and using a breathalyzer raises some concern. This concern exists because these drivers are obviously more focused on not breaking the "magic" line of 0.05% BAC than being concerned about

driving impairment, which might be much worse than they realize because of the interactive effects of increased sleepiness and even low alcohol consumption.

In conclusion, there is no doubt that fatigue and sleepiness problems while driving are common among the Finnish driving population. While we wait for the invention of reliable devices for fatigue/sleepiness detection, we should invest more effort in raising public awareness about the dangerousness of fatigued driving and educate drivers about how to recognize and deal with fatigue and sleepiness when they ultimately occur.

**Key words:** Fatigue, sleepiness, fatal motor-vehicle accidents, seasonality, in-depth studies, breathalyzer, alcohol, traffic law.

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## LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following studies, which are referred to in the text by their Roman numerals (I-VI).

- Study I** Radun, I., & Summala, H. (2004). Sleep-related fatal vehicle accidents: Characteristics of decisions made by multidisciplinary investigation teams. *Sleep, 27*, 224-227.
- Study II** Radun, I., & Radun, J.E. (2006). Seasonal variation of falling asleep while driving: An examination of fatal road accidents. *Chronobiology International, 23*, 1053-1064.
- Study III** Radun, I., Radun, J.E., Summala, H., & Sallinen, M. (2007). Fatal road accidents among Finnish military conscripts: Fatigue-impaired driving. *Military Medicine, 172*, 1204-1210.
- Study IV** Radun, I., Ohisalo, J., Radun, J.E., Summala, H., & Tolvanen, M. (2009). Fell asleep and caused a fatal head-on crash? A case study of multidisciplinary in-depth analysis vs. the court. *Traffic Injury Prevention, 10*, 76-83.
- Study V** Radun, I., Summala, H., & Radun, J.E. (2009). Drinking and driving "safely": Who uses a breathalyzer and when. *Transportation Research Part F: Psychology and Behavior, 12*, 155-158.
- Study VI** Radun, I., & Radun, J.E. (in press). Convicted of fatigued driving: Who, why and how? *Accident Analysis and Prevention*.

## ABBREVIATIONS

AKE	Finnish Vehicle Administration
BAC	Blood alcohol concentration
ES	Experience seeking
ESS	Epworth sleepiness scale
MSLT	Multiple sleep latency test
PC	Penal Code
RTA	Road Traffic Act
SSS	Sensation seeking scale
VALT	Traffic Safety Committee of Insurance Companies
N	Number of participants, accidents etc.
t	Value on t-test
d.f.	Degrees of freedom
SD	Standard deviation
M	Mean
CI	Confidence interval
OR	Odds ratio
ref.	Reference category in logistic regression
$\chi^2$	Value on Chi-square test

## **PREFACE**

Almost ten years ago, when I had no idea I would be doing safety research, I had a driving incident that shaped my attitude toward driving while in a state of extreme tiredness. At the time, I had had a driver's license for only four months and had less than 2000 km of driving experience. One summer afternoon, together with my friends, I drove approximately 300 km to a place on the Adriatic coast where we spent the entire night at a summer festival. The following morning I slept about two hours, and I spent the rest of the day on the beach. In the evening, I started driving alone to my hometown 350 km away. I was extremely tired and sleepy but determined to get home by evening that day. To fight my tired state, I played music very loudly, opened the window to let the air blow in, stopped for a short break and rinsed my face with cold water, drank caffeinated drinks, and even talked with my friends on my mobile phone (!). Nothing helped. After drifting dangerously several times to the right side of the road, I pulled over and decided to take a nap. However, I did not take a nap: I had a five-hour long sleep. After that, I continued my drive and happily came home early the next morning. I was lucky. Many drivers covered in this thesis were not.

As the title clearly indicates, this thesis deals with fatigue and sleepiness problems while driving. A comprehensive literature review, starting from a quite broad perspective, is given in chapters 1-4. The aims of the thesis, research questions, and the main rationale for them are set in chapter 5, although there are also hints in the introductory chapters. In chapters 6 and 7 summaries of original publications (Studies I-VI) are given. A general discussion occupies chapter 8, together with critical remarks. Finally, the thesis ends with concluding remarks and some safety recommendations.

# 1 GENERAL INTRODUCTION

## 1.1. Biology and society

**Human beings are diurnal animals.** Throughout evolution, humans have adapted to the natural 24-hour cycle of light and darkness, and consequently, humans need light to function. Generally speaking, we sleep during the night and “live” during the day. However, our sleep-wakefulness cycles are not a simple passive response to environmental light changes; they are driven by an endogenous pacemaker in an approximately similar 24-hour rhythm (Lavie, 2001). Nevertheless, although an internal clock controls this circadian rhythm (from the Latin *circa*, around, and *dies*, day), it can be readjusted by both photic and nonphotic stimuli (Lavie, 2001). According to the currently dominant theory of alertness, the need for sleep is determined not only by the endogenous circadian component but by the exogenous component that depends on the alternation of sleep and wakefulness (Borbely, 1982; Folkard, Åkerstedt, Macdonald, Tucker, & Spencer, 1999). The longer the period of wakefulness, the higher the exogenous need for sleep.

**We live in a 24-hour society.** Because of increased globalization and competition, companies have organized work times more efficiently (and economically) by introducing shift work, night work, and irregular and prolonged working hours (Härmä, 1998). As a result, in addition to traditional 24-hour industries (petrochemical, power etc.) and transportation and health services, an increasing number of new organizations offer their services 24 hours a day, 7 days a week. However, as human beings have a natural tendency to be awake during daylight and to sleep during darkness, the 24-hour society challenges our biological adaptation to the 24-hour cycle of light and darkness (Rajaratnam & Arendt, 2001). Increased stress, poor sleep hygiene, and partial and chronic sleep deprivation all are direct consequences of today’s 24-hour society. On the other hand, the concept of sleep has also dramatically changed in modern times: “time asleep is viewed as wasted time, and spending many hours sleeping is often associated with laziness” (Pandi-Perumal et al., 2006, p. 864). It has been suggested that people are not able to recognize being sleepy since many cannot remember the last time they had a good (restorative) night of sleep (Dement, Hall, & Walsh, 2003; Dinges, 2004).

**Sleep disorders are major public health concern.** Given the prevailing attitudes toward sleeping in modern society and the fact that people might not realize that they have a sleep problem, it is not surprising that many of them do not seek medical help. For example, it has been estimated that 20 million individuals in the US may suffer from sleep apnea, but less than 10% of them have been diagnosed (Rosekind, 2005). Sleep apnea is a sleep disorder characterized by either complete obstruction of the airway (obstructive apnea) or partial obstruction (obstructive hypopnea), and accompanying awakenings. Although the causes of sleep apnea are unclear, obesity, highly prevalent in modern society, is the primary risk factor.

In Finland, sleep disorders are relatively frequent: the prevalence for any DSM IV insomnia is 11.7% and for a diagnosis of primary insomnia 1.6% in the general population (Ohayon & Partinen, 2002); up to 3% of middle-aged men and 2% of middle-aged women have sleep apnea (Laitinen, Anttalainen, Pietinalho, Hämäläinen,

& Koskela, 2003); and 11% of women and 6.7% of men suffer from daytime sleepiness (Hublin, Kaprio, Partinen, Heikkila, & Koskenvuo, 1996). Additionally, as in many other high-latitude countries, there is a high (12%) prevalence of seasonal affective disorder (Saarijärvi, Lauerma, Helenius, & Saarilehto, 1997). Seasonal affective disorder, a so-called winter depression, is characterized by changes in mood, increased tiredness, lack of enjoyment, and sleep changes (longer periods of sleep). As with other Nordic countries, the self-reported sleep quality of the general population is worse in summer (Ohayon & Partinen, 2002).

## **1.2. Sleepiness, alertness, and performance**

Humans, as with other living organisms, have limited resources for both physical and mental activities: rest and sleep are necessary for recuperation between activities. Depending on the task, a certain level of alertness and attention is required for any activity. For some activities we need maximum concentration (e.g., the work of air-controllers); for some others we can operate in a quite relaxed state of mind (e.g., listening to music). Even for highly automatic activity, such as driving (once learned), low alertness and attention are a considerable source of problems.

A causal relation between alertness/sleepiness and performance is usually assumed, although it is not easy to establish precise measures. The main problems are difficulties in measuring real levels of alertness/sleepiness (Curcio, Casagrande, & Bertini, 2001), large interindividual and intraindividual differences (Frey, Badia, & Wright, 2004; Ingre, Åkerstedt, Peters, Anund, & Kecklund, 2006), and the existence of many intervening and confounding variables that are difficult to detect and control for.

Nevertheless, the adverse effects of alertness/sleepiness on human functioning are well documented. In short, following a theory of alertness (Borbely, 1982; Folkard et al., 1999), research has focused on the manipulation of circadian and exogenous components of alertness. “Forced desynchrony protocols can be used to estimate circadian and homeostatic components of performance, alertness, and other physiological measures, as well as their interactions across all circadian phases” (Klerman & Hilaire, 2007, p. 96).

The most often used methodology involves partially or totally restricting subjects from sleeping. In their meta-analysis, Pilcher and Huffcutt (1996, p. 325) showed that sleep deprivation has “a substantial effect on mood and motor and cognitive performance in humans.” Interestingly, they found that mood and performance are more affected after partial sleep deprivation than after either short-term ( $\leq 45$  hours) or long-term ( $> 45$  hours) total deprivation. In general, “under demanding and motivating conditions, sleep deprivation will have little impact on high-level decision making or complex skills” (Harrison & Horne, 2000, p. 237). Nevertheless, some studies show that executive cognitive functions can be severely deteriorated by sleep loss (e.g., Jones & Harrison, 2001; Nilsson et al., 2005).

Psychomotor tests, especially those that are long and monotonous (e.g., reaction time and vigilance task performance) seem to be very sensitive to sleep deprivation. Slower reaction times, higher variability in responses, and lapses in responses are

consequences of increased sleepiness and brief sleep episodes (microsleeps). These microsleeps, lasting from several to 15 seconds, can lead to dangerous outcomes in situations where a person's reactions are needed practically on a second-to-second basis (e.g., while driving).

Relevant to driving, the negative effects of sleepiness on performance have been illustrated by comparing the effects of prolonged wakefulness and alcohol (Dawson & Reid, 1997). For example, 17-19 and 20-25 hours of wakefulness produced performance decrements equivalent to those observed at blood alcohol concentrations (BAC) of 0.05% and 0.1%, respectively (Arnedt, Wilde, Munt, & MacLean, 2000; 2001; Dawson & Reid, 1997; Lamond & Dawson, 1999; Williamson & Feyer, 2000).

### **1.3. Sleep-related accidents**

As Härmä (1998) has pointed out, in today's society it is not acceptable that a bus or train driver or a nuclear power operator works in a drunken state. In contrast, working (and driving) in a state of prolonged wakefulness is not regarded as dangerous. Nevertheless, attitudes are slowly changing, and every day more attention is given to problems associated with fatigue and sleepiness. The reasons for such an attitude change do not come only from growing experimental studies showing that sleepiness impairs performance; they come also from real life situations. Especially dramatic evidence comes from major catastrophes in which low alertness was believed to play a major role (e.g., the nuclear plant catastrophe at Chernobyl in 1986; the chemical plant disaster in Bhopal in 1984, considered the worst industrial disaster to date; and the grounding of the oil tanker Exxon Valdez in Alaska in 1989, which was the largest oil spill in US history).

In addition to such rare catastrophic accidents, the economic consequences of sleep-related accidents have drawn a lot of attention and discussion by the media and politicians. For example, Leger (1994) estimated that 52.5% of all work-related accidents in 1988 in the US were potentially related to sleepiness, leading to economic losses of up to 56 billion dollars. Another estimation is that losses of 14 billion dollars in the US and 80 billion dollars worldwide were direct or indirect consequences of sleep-related accidents (Moore-Ede, 1993 according to Rajaratnam & Arendt, 2001). In Finland, the estimated costs of sleep deprivation and sleep disorders were 0.9 billion euros in 1997 (Hyypä & Kronholm, 1997).

In conclusion, Wylie (2005, p. 196) is absolutely right when he writes: "Policies can be very difficult to change, and advocates of change who claim a logical or scientific foundation need valid, reliable, and convincing data." In that sense, this thesis, among other things, seeks to further elucidate the role of fatigue in driving.

### **1.4. Sleepiness and fatigue: definitions**

Although many terms and phrases (e.g., sleepiness, the need for sleep, alertness, fatigue, drowsiness) mentioned in the foregoing are commonly known and understandable, they require more precise definitions. Unfortunately, the literature is

not very helpful in providing clear and useful definitions, especially concerning the concept of fatigue. McDonald (1989, p. 185) has nicely illustrated this: "Fatigue is one of those concepts which appear quite clear and unambiguous in everyday life but become notoriously elusive when one tries to pin them down in scientific discourse."

Grandjean (1979, p. 175) separates muscular and mental fatigue, the latter being "a diffuse sensation which is accompanied by feelings of indolence and disinclination for any kind of activity." Similarly, Brown (1994, p. 302) defines fatigue as "a subjectively experienced disinclination to continue performing the task at hand." According to Hancock and Verwey (1997, p. 497), fatigue is "an individual's multidimensional physiological-cognitive state associated with stimulus repetition which results in prolonged residence beyond a zone of performance comfort." Regardless of formal definitions, most researchers agree that fatigue is eliminated by a sufficient period of rest (Philip et al., 2005a).

Sleepiness, on the other hand, has a more precise meaning and definition. It refers to the pressure to fall asleep or the probability of falling asleep at a particular time due to circadian and exogenous influences (Johns, 2000; Shen, Barbera, & Shapiro, 2006). It disappears after sleep, but not after rest (Philip et al., 2005a).

Drowsiness is "the intermediate state between wakefulness and sleep as defined electro-physiologically by the pattern of brain waves (EEG), eye movements and muscle activity" (Johns, 2000, p. 242). "At what point drowsiness begins is still uncertain, but it is before the onset of Stage-1 sleep as currently defined, even before Stage-1 occurs very briefly as microsleeps" (Johns, 2000, p. 242).

Although the terms "fatigue" and "sleepiness" are not technically synonymous, they will be used interchangeably in this thesis, unless otherwise clearly stated. This is a common practice in traffic safety research (e.g., Åkerstedt, 2000; Dingus, 1995; Pigeon, Sateia, & Ferguson, 2003). "Sleep-related," "sleepiness-related," and "fatigue-related" accidents will be also used interchangeably; however, "falling-asleep accidents" means that the driver fell asleep, not that there was an accident due to a momentary slip of attention because of increased sleepiness or fatigue.

## 2 SLEEPINESS, FATIGUE, AND DRIVING

### 2.1. Driving and sleep-related road accidents

In today's modern society, driving a motor vehicle is a very common part of human behavior. People are driving more and more, and hence, there are more and more vehicles on the road. Consequently, people are exposed to a higher risk of accidents. Motor vehicle accidents are responsible for a large number of deaths and disabilities. According to the Global Burden of Disease study, traffic injuries were the ninth leading cause of death and disability in the world in 1990, and they are predicted to be the third leading cause by 2020 (Murray & Lopez, 1997). In addition, they have a significant economic impact given the number of (young) victims disabled for life (WHO, 2004). Further economic losses arise from medical and rehabilitation costs, property damage, and numerous losses of working hours.

Driving is a complex task demanding perceptual, cognitive, and psychomotor skills (George, 2003; Shinar, 1978). Although, once learned, driving becomes a highly automatic activity, the sustained and divided attention demands on a driver are considerable (Hancock & Verwey, 1997). Observing and analyzing the traffic situation and choosing and applying the appropriate action often have to be done within seconds (or less). Sleepiness can influence some or all of these processes, and a driver's performance can fall below the level required by the traffic situation. As George (2003, p. 311) pointed out, "sleepy subjects do not have to fall asleep to produce collisions or crashes, rather they need only be inattentive because of sleepiness."

Historically, sleep-related problems while driving have been noticed as early as in the 1920s. According to Horstmann, Hess, Bassetti, Gugger, and Mathis (2000, p. 1), "working and motor vehicle accidents due to sleepiness have been anecdotally reported since 1929"; Horstmann et al. were referring to a paper, "A note of narcolepsy," that Kennedy published in the *British Medical Journal* in 1929. In the same year, Miles (1929, according to Horne & Reyner, 2001a, p. 70) wrote: "a motorist or anyone may actually be asleep, even if the eyes are seen to be open." On the other hand, McCutcheon (1998, p. 306) reported that, already in 1926, the Scottish court considered the legal responsibility of falling asleep behind the wheel in the case of *H.M. Advocate vs. Ritchie* when stating, "A person is obliged to take account of the risk of falling asleep when driving."

After the Second World War, fatigue research intensified, although in the beginning it was mainly unconnected to driving (Milošević, 1997). In the 1960s, much research was inspired by "highway hypnosis" (Williams & Shor, 1973); that is, "a state showing sleepiness signs and attention slip resulting from driving a motor vehicle for a long period in a highly predictable environment with low event occurrence, this being the case with motorways and very familiar roads" (Cerezuela, Tejero, Choliz, Chisvert, & Monteagudo, 2004, p. 1045). Later this state was termed "driving without awareness" (Brown, 1995) or "driving without attention mode" (Kerr, 1991). The explosion of fatigue- and sleepiness-related research took place during the 1990s and continues to grow.



## 2.2. Official statistics

Official statistics from many countries regarding fatigue-related accidents are missing because causal factors are not routinely recorded (Horne & Reyner, 1999). For example, the Finnish police road injury database, which is otherwise information rich, does not provide any information on causal factors except for breathalyzer testing. On the other hand, even when a checklist of accident causes is included on police accident reporting forms, it does not necessarily include fatigue as one of the choices (Knipling & Wang, 1994).

Therefore, only a few countries with official statistics based on police reports are able to provide information on the proportion of fatigue-related accidents. For example, in the US from 1989-1993, 1% of all police-reported accidents and 3.6% of fatal accidents were attributed to driver drowsiness (Knipling & Wang, 1994). Similarly, in Switzerland sleepiness was a causative factor in 1% of traffic accidents that included bodily injury or property damage in excess of 500 Swiss francs (Laube, Seeger, Russi, & Bloch, 1998). In Sweden, from 1994 to 2001, 3% of single vehicle accidents reported to the police were fatigue related (Anund, Kecklund, & Larsson, 2002). In Australia, more than 20% of fatal accidents were attributed to driver fatigue (Roads and Traffic Authority, 2001). However, in this Australian report the decision of whether a particular accident was related to fatigue was not based only on police officer judgment but also on the criteria set afterwards. The criteria included specific driving maneuvers “suggesting loss of concentration due to fatigue” and the exclusion of other possible causes (e.g., speeding). Using such operational definitions of fatigue is quite common in Australia; however, different states have very different definitions (Dobbie, 2002; Queensland Parliamentary Travelsafe Committee, 2005). Reanalyzing and reevaluating police reports is a usual practice when estimating the number of fatigue-related accidents (e.g., Horne & Reyner, 1995).

In general, causative factors are more often investigated and recorded when an accident results in serious injury or fatality. For example, in Finland there is a database of fatal accidents studied in depth by multidisciplinary investigation teams (VALT) that is unique worldwide. This database serves as the main source of data in this thesis (more details in chapter 6.1.1). For now, it should be mentioned that, according to the statistics provided by VALT (for example in 2005), drivers who fell asleep caused 11% of fatal accidents (VALT, 2006).

## 2.3. Prevalence of the fatigue problem

Since data from official statistics are often lacking, much research has relied on drivers' self-reports. Here are several results of such studies from different countries.

- In a telephone survey of a random sample of licensed drivers in New York State, US, 54.6% of the drivers reported driving while drowsy within the preceding year; of these, 22.6% had fallen asleep at the wheel without having a crash, 2.8% had crashed because of falling asleep, and 1.9% had crashed when driving while drowsy (McCartt, Ribner, Pack, & Hammer, 1996).

- In a representative postal survey of British male drivers, 29% reported being close to falling asleep while driving in the past 12 months, and 7% of accident-involved drivers reported tiredness to be an accident-contributing factor (Maycock, 1996; 1997).
- In a telephone survey of a random sample of Canadian drivers, 20% reported that they had nodded off or fallen asleep at least once in the past 12 months (Beirness, Simpson, & Desmond, 2004).
- In a Norwegian sample of accident-involved drivers, 27% reported falling asleep at the wheel at some point during their driving career; for 8.3% this happened during the preceding year, and 3.9% reported that sleep or fatigue contributed to their accident (Sagberg, 1999).
- Face-to-face interviews with a rest area sample of long-distance truck drivers showed that 47.1% of them had fallen asleep at the wheel of a truck, and for 25.4% that had happened in the preceding year (McCartt, Rohrbaugh, Hammer, & Fuller, 2000).
- In a stratified random sample of the adult population of the Finnish town of Tampere, 15% of drivers had dozed off at the wheel and 1.3% had tiredness-related accidents (Martikainen, Hasan, Urponen, Vuori, & Partinen, 1992).

## **2.4. Recognizing an accident as sleep-related**

There is a widespread consensus that sleep-related accidents are underrecognized and underreported (Åkerstedt, 2000). One reason for such a belief is the fact that driver surveys consistently show high proportions of drivers who have experienced falling asleep behind the wheel (e.g., Wilson, Fang, Cooper, & Beirness, 2006). Another reason is connected with the work of police officers investigating accidents; as Lyznicki, Doege, Davis, and Williams (1998, p. 1909) wrote, “Little is known about police training to recognize sleepiness as a cause of crashes or the criteria they use for reporting this factor.”

In addition to the blurred concept of fatigue, the inexistence of a validated and reliable device for detecting the level of sleepiness (cf. the breathalyzer for alcohol levels) aggravates the work of investigating officers. Unfortunately, there is little evidence that such a device will be available in the (near) future. Therefore, investigating officers have to rely on other clues coming from the participants themselves, eyewitnesses, and the characteristics of the crash itself. However, there are no criteria for the unambiguous detection of fatigue/sleepiness as a major or contributing factor in accident causation. Whether the particular accident will be coded into official statistics as sleep related or not depends solely on police officers’ subjective opinions.

When judging whether driver fatigue contributed to an accident, investigating officers, obviously, do not have direct knowledge of a driver’s preaccident condition. However, a driver’s arousal and emotional state change after an accident, and do not necessarily reveal anything about the preaccident condition. Drivers might also have difficulties in recollecting the period prior to the accident and even the accident itself, due to traumatic effects of the accident. In a case where a driver falls asleep and

causes the accident, the recollection might be even poorer. Such an assumption comes from experimental results showing that subjects who fall asleep usually deny having been asleep if woken up within two minutes (Bonnet & Moore, 1982; Horne & Reyner, 1999). On the other hand, in cases where drivers are able to recall information about the causes of the accident, they do not necessarily report it. It might be that some drivers are not willing to admit to falling asleep due to the embarrassment of being labeled a bad driver or concerns about insurance and legal consequences (Corfitsen, 1999; Reyner & Horne 1998).

How police officers attribute the cause of an accident is undoubtedly influenced by current developments in safety research and practices. As Ogden and Moskowitz (2004, p. 186) pointed out, "Police descriptions of crashes are typically assigned to the cause of current interest." These authors offer an example how through the second half of the twentieth century "inattention" became a favored explanation instead of "loss of control" for the same type of crashes at T-intersections. Furthermore, focusing on other aspects of the accident, typically on alcohol involvement, might leave the role of fatigue/sleepiness in accident causation unnoticed (e.g., Corfitsen, 2003). Police officers often use an elimination procedure in their investigation; for example, excluding the alcohol contribution might be a first step. On the other hand, in crashes with a heavy vehicle, accident investigators might first exclude the possibilities of suicide and sudden illness attack. However, this elimination procedure "might overlook the other factors simultaneously operating" (Rajaratman & Jones, 2004, p. 1075).

In Queensland, Australia, as a part of their training process, police officers investigating road accidents receive special instructions about how to recognize the signs of fatigue-related crashes (Queensland Parliamentary Travelsafe Committee, 2005). Such signs include, for example, "the lack of braking or evasive tactics prior to the crash," "a vehicle traveling straight ahead prior to the crash," "the medical history of the drivers, for instance the presence of sleep apnea," etc. However, there is no evidence of how effective this training has been (Queensland Parliamentary Travelsafe Committee, 2005).

The problem of recognizing an accident as sleep related is an issue that practically cannot be avoided in any study dealing with fatigue/sleepiness problems while driving. To a greater or lesser extent, this question has been discussed in most of the original publications of which this thesis consists.

In summary, caution is recommended when analyzing and interpreting official statistics based on police reports. International comparisons might be especially problematic if differences in accident reporting systems are not taken into account.

## **2.5. Driver appraisal of inner state**

Although drivers might not remember or might deny falling asleep, it is likely they can recall being tired or sleepy some time before the accident or can recall some actions (opening a window for fresh air, playing music loudly) that would imply such a state (Horne & Baulk, 2004).

It is quite safe to state that normal, healthy people cannot fall asleep behind the wheel without experiencing a continuous period of increased sleepiness beforehand (Horne & Reyner, 1996; Lisper, Laurell, & Van Loon, 1986; Reyner & Horne, 1998). Unforewarned sleep attacks do not exist, at least not among healthy individuals (Horne & Balk, 2004); they can occur only in rare clinical conditions, such as narcolepsy.

Driving simulator studies show that drivers are aware of sleepiness before any driving incidence (e.g., Horne & Reyner, 1996; Otmani, Pebayle, Roge, & Muzet, 2005; Reyner & Horne, 1998). However, in real life these symptoms of sleepiness are not taken seriously enough (Kaplan, Itoi, & Dement, 2008; Nordbakke & Sagberg, 2007); rather, they are considered trivial (Dinges, 1995). A completely different issue is whether drivers act inappropriately by applying ineffective countermeasures (e.g., Dawson, 2005; Maycock, 1996; Nordbakke & Sagberg, 2007).

In most studies dealing with a driver's awareness of sleepiness while driving – regardless of whether the driving is done using a driving simulator, in a closed circuit, or in real traffic – participants are asked to monitor their sleepiness. Such methodology probably makes the participants more sensitive to any changes in sleepiness (Horne & Balk, 2004). Another often neglected issue concerns participants' expectations and anticipations in experimental situations of long "boring" driving when given instructions to monitor their level of sleepiness. In other words, we can imagine that in such experimental situations some participants might reason in this way: "If they are asking me every five minutes how sleepy I am, they might expect some changes in my responses." As a result, "a good subject effect" is quite possible (Orne, 1962). Similarly, it has been shown that the context of a sleepiness rating affects the outcome of the rating (Åkerstedt, Kecklund & Axelsson, 2008). Nevertheless, at least some experimental studies have shown a relatively good correlation between self-reported and more objective measures of sleepiness (Kaida, Åkerstedt, Kecklund, Nilsson, & Axelsson, 2007; Kecklund & Åkerstedt, 1993; Pizza, Contardi, Mostacci, Mondini, & Cirignotta, 2004). However, subjects may fail to recognize how much of an effect sleepiness has on their driving performance. As Horne and Reyner (2001b) have nicely summarized: "What many sleepy drivers do not appreciate is that sleep itself can ensue more rapidly than they imagine, and that their driving impairment is worse than they realize."

Whether people can apprehend that they are falling asleep behind the wheel is a central question that has relevance to legal implications. From the point of law, it makes a significant difference whether a driver falls asleep without any warning whatsoever or whether a driver consciously decides to continue driving despite the knowledge that such action endangers traffic safety. This issue has been discussed in Study IV.

## **3 SLEEP-RELATED ROAD ACCIDENTS**

### **3.1. Characteristics of sleep-related accidents**

Accidents caused by drivers falling asleep are likely to be fatal or involve serious injuries (e.g., Horne & Reyner, 1999; Pack et al., 1995). This is understandable, because a sleeping driver will not make any corrective actions and the impact speed will be high, and the higher the impact speed, the higher the risk of injury (e.g., Buzeman, Viano, & Lövsund, 1998). Nilsson, Nelson and Carlson (1997, p. 480) nicely pointed out: “Falling asleep is the natural end result of fatigue. Death is frequently the natural end result of falling asleep while driving.”

A motor vehicle not under the control of a sleeping driver will continue moving, at least for some time, and might cross the middle line or drift off the side of the road. If the driver does not wake up, the vehicle will probably end up leaving the road or hitting an oncoming vehicle. It is also possible that the car could hit a stopped car in its lane. Therefore, most of the accidents caused by drivers falling asleep are head-on collisions, running off the road, and less often, rear-end crashes (e.g., Knippling & Wang, 1994; Pack et al., 1995).

If a driver wakes up before a possible impact, he or she might act in panic and, by applying a sudden or hard corrective movement, might lose control of the vehicle (Hancock & Verwey, 1997). As a result, a crash could be inevitable. Similarly, in driving simulator studies, compared to rested drivers, fatigued drivers less often make corrective steering wheel movements, but when they do, the movements are of higher amplitude (Thiffault & Bergeron, 2003a; Verwey & Zaidel, 1999). These larger corrective movements are necessary because fatigued drivers tend to have problems keeping within the lines; that is, there is more line crossing and, in general, a higher standard deviation of lateral position (e.g., Philip et al., 2005a). Such driftings occur more often among fatigued drivers because they lose perceptual sensitivity to small changes and their reactions are slower (Thiffault & Bergeron, 2003b). Therefore, fatigued/sleepy drivers do not need to fall asleep to have an accident; they just may fail to perceive the position of their vehicle on the road and correct it in time. Other characteristics of sleep-related accidents will be discussed in the following chapters dealing with risk factors and risk groups for such accidents.

### **3.2. Causes and factors mediating fatigue and sleepiness**

There are many factors that increase the level of sleepiness and/or fatigue and that contribute to the probability of being in a crash due to falling asleep or sleepiness-related inattention. These factors are listed in the following sections, but not necessarily in order of importance.

### **3.2.1. Time-of-day (circadian) effects**

Circadian variation in alertness is a major cause of sleep-related accidents (e.g., Åkerstedt, 2000). During the night humans experience the highest need for sleep; therefore, this is when many sleep-related accidents occur. However, the number of sleep-related accidents is actually the largest during the day, while the proportion of such accidents remains the highest during the night (e.g., Maycock, 1997; Sagberg, 1999). Many studies have shown a clear time-of-day pattern of sleep-related accidents (e.g., Horne & Reyner, 1995; Pack et al., 1995). However, as Folkard (1997) has shown, circadian effects cannot account for the whole variance of the daily distribution of sleep-related accidents. For example, sleep-related accidents peak at 2.00 (Folkard, 1997), while laboratory studies show that people experience the greatest feeling of sleepiness around 4.00-6.00 (e.g., Horne & Reyner, 2001a). Folkard (1997, p. 424) suggested that “one possibility, given that the start times of road journeys are likely to ‘cluster’ at certain times of day, is that time into journey effects may contribute to the overall time of 24-hour day effects in a fairly systematic manner.” Horne and Reyner (2001a) further explained this departure from the “ideal” circadian curve. According to them, drivers who had an accident around 2.00 had not yet reached the maximum sleepiness level that appears later around 4.00-6.00, but their driving was obviously so impaired that they had an accident at that time of night. On the other hand, drivers having a sleep-related accident around 6.00 have probably started their drive in the previous one or two hours (Horne & Reyner, 2001a). Time-of-day effects were in focus in all studies reported in this thesis.

### **3.2.2. Sleep history**

According to the theory of alertness (see 1.1.), alertness at any point of time is not determined only by circadian factors; it also depends on more variable alternation of sleep and wakefulness. Therefore, it is obvious that the distribution of sleep-related accidents does not have to follow the “ideal” circadian curve. The duration of wakefulness and sleep, time on task, and circadian effects are intertwined.

Short sleep duration in healthy individuals is associated with a greater daytime sleepiness. Acute periods of short sleep are a major cause of sleep-related accidents (e.g., Connor et al., 2002; Fell & Black, 1997; McCartt et al., 1996). Cumulative or chronic sleepiness due to a habitual lack of sleep is as dangerous as acute sleep loss, especially because it impairs perceptions of one’s level of sleepiness (Bonnet & Arand, 1995; Dinges, 2004; Van Dongen, Maislin, Mullington, & Dinges, 2003). As Carter, Major, Wetherall, and Nicholson (2004, p. 454) explained, “Most realize they are sleepy, but many may not realize that they are unusually sleepy. Indeed, long-term sleepiness during the day can lead to loss of a sense of what is an acceptable level of alertness.” Furthermore, following chronic (7 days) sleep restriction it takes several days before the performance level returns to its baseline (Belenky et al., 2003). This indicates that making up for sleep deprivation with a few nights of normal or prolonged sleep (e.g., during the weekend) is not as easy as one might expect.

As already mentioned (section 1.2.), 17-19 hours of wakefulness produce performance decrements equivalent to those observed at 0.05% BAC (Williamson &

Feyer, 2000). This means that drivers driving around midnight, assuming that they woke up at around 7.00, might be as impaired as they would be at a BAC of 0.05%. Longer periods of wakefulness are even more dangerous because the person is then awake at times when normal circadian alertness drops.

Because accidents related to sleep are related to circadian rhythms and to the alternation of sleep and wakefulness, one possibility is that such accidents may be influenced by seasonal changes in the quality and duration of sleep. However, only a few reports have discussed possible seasonal variations in sleep-related road accidents. For example, Langlois, Smolensky, Hsi, and Weir (1985) reported a seasonal pattern in fatigue-related single-vehicle accidents in Texas, with the highest number in May and July and the lowest number in January and February. The results of our previous studies show a seasonal variation of falling-asleep fatal accidents where the number and proportion of such accidents was much higher in summertime (Summala, Karola, Radun, & Couyoumdjian, 2003; Summala & Radun, 2004). The main difference was during the afternoon hours (Summala et al., 2003). Partinen (2004) reported similar findings. This possible seasonal variation of sleep-related accidents has been investigated in Studies II and VI.

### **3.2.3. Health status including sleep disorders**

There is nothing surprising in the hypothesis that people with increased daytime sleepiness, or those who are in general sleepier, might be more likely to fall asleep while driving. The hypothesis might stand regardless of the causes of excessive daytime sleepiness.

Daytime sleepiness is an important sign or criterion for many medical conditions, including sleep apnea, narcolepsy, nocturnal periodic leg movements, circadian rhythm disorders, affective disorders (depression), and idiopathic hypersomnia (Whitney et al., 1998).

To estimate whether daytime sleepiness is connected with the likelihood of falling asleep while driving, two methods are often applied. In the first approach, daytime sleepiness is measured and correlated with accident involvement in a sample of the “total” driving population. The Multiple sleep latency test (MSLT) and the Epworth sleepiness scale (ESS) have been typically used as tools for measuring daytime sleepiness (Carskadon et al., 1986; Johns, 1991). Both have advantages and disadvantages; cheapness and easy applicability are the main advantages of the ESS. Therefore, the ESS is widely used in traffic research. It has been shown that ESS scores correlate with the likelihood of falling asleep while driving (Maycock, 1996, 1997; Powell, Schechtman, Riley, Li, & Guilleminault, 2002). However, there are serious concerns about the usage of ESS; several researchers even share uncertainty about what the construct is that the ESS actually measures (Chervin, 2003; Miletin & Hanly, 2003; Sangal, 2006; Tachibana & Taniguchi, 2007).

In the second approach, researchers instead compare the accident involvement between groups “assumed” to have different levels of daytime sleepiness (e.g., sleep apnea patients vs. “normal” drivers). (More on the results of such studies below in 3.3.3.) However, daytime sleepiness is not the only consequence or sign of some sleep disorders. For example, narcoleptic patients might fall asleep without previous

warnings, i.e., without any signs of increased sleepiness. On the other hand, increased daytime sleepiness and fatigue are not necessarily related to sleep disorders; they might be consequences of frequent sleep interruptions (e.g., nocturia, i.e., getting up during the night in order to urinate) (Chartier-Kastler & Tubaro, 2006).

General physical fitness is an important factor promoting sleep and its quality and quantity (Härmä, 1993; Kubitz, Landers, Petruzzello, & Han, 1996; Taylor & Dorn, 2006). Therefore, regular exercise might protect against driver sleepiness and fatigue. On the other hand, some controversy exists about whether “acute” exercise can alert sleepy drivers (e.g., Horne & Reyner, 1999; Taylor & Dorn, 2006). Although long-distance (truck) drivers, or sleepy drivers in general, are often advised to walk or exercise during a break, this recommendation is not based on strong empirical evidence (Horne & Reyner, 1999).

Study II contains a short discussion about sleep disorders as causes of sleep-related accidents.

### **3.2.4. Driving duration and work history**

Driving duration has been regarded for a long time as one of the most important risk factors for falling asleep behind the wheel. However, driving duration alone does not seem to be a crucial factor; for example, 60% of fatal sleep-related accidents occur within the first hour of driving (Summala & Mikkola, 1994). The effects of driving duration are closely related to time-of-day effects (Folkard, 1997) and the pre-trip levels of fatigue and sleepiness (e.g., Philip et al., 2005b; Williamson, Feyer & Friswell, 1996). For example, twelve hours of real or simulated driving had no effect on driving performance (line crossing), reaction test performance, and subjective sleepiness (Philip et al., 2005a). However, these parameters were strongly affected by partial sleep deprivation (Philip et al., 2005a). Philip et al. (2005b) reported similar results in another study.

Real-life data show that many drivers are sleep restricted (e.g., early awakenings) by their own initiative prior to the start of a long distance summer vacation trip (Philip et al., 1997; Philip, Taillard et al., 1999). Similarly, in an Australian study of professional long distance truck drivers, the pre-trip level of fatigue had a strong influence on later fatigue during a 12-hour drive (Williamson et al., 1996).

The pre-trip level of fatigue or sleepiness is often connected with the work history (e.g., driving home after a long working day) (McDonald, 1989). Driving home after a night shift is the most problematic, especially if it involves monotonous driving for more than 20 minutes (Åkerstedt, Peters, Anund, & Kecklund, 2005; Horne & Reyner, 1999). Work is also a major contributor to driver fatigue in urban areas (Fell & Black, 1997).

Among professional drivers, participation in loading and unloading activities can produce additional fatigue and contribute to a decrease in driving performance (Morrow & Crum, 2004). In one study, this decrease was observed after 12 to 14 hours of duty, although an initial improvement in alertness was reported and explained by a break in driving and exercises (O’Neill, Krueger, Van Hemel, McGowan, & Rogers, 1999).



In summary, it is important to analyze the effects of driving duration in the context of time-of-day effects, sleep and work history, physical fitness, and situational and environmental factors. Driving duration as a predictor of fatigue-related accidents has been investigated in Study I.

### **3.2.5. Situational and environmental factors**

A situational factor often connected with long drives is monotony. The belief that driving in monotonous conditions (e.g., on a motorway) enhances driver fatigue follows the assumption that lower amounts and variation of stimulation lead to lower arousal (Thiffault & Bergeron, 2003a). In a driving simulation study, Thiffault and Bergeron (2003a) showed the possible effects of roadside visual stimuli on driver fatigue.

According to Horne and Reyner (1999, p. 290), only a few sleep-related accidents occur on urban roads “because the driving conditions are relatively stimulating, and usually there is much for the sleepy driver to see and do.” However, Fell and Black (1997) reported that according to official statistics in the State of New South Wales, Australia, 42% of fatigue-related accidents have occurred in a city. In this context, traffic density has been studied as an important mediating factor: for example, the greater the traffic density on a motorway, the lower the proportion of sleep-related accidents (Flatley, Reyner, & Horne, 2003). This finding was explained by the fact that the presence of other vehicles in otherwise monotonous motorway driving may trigger drivers’ attention and keep them more alert (Pandi-Perumal et al., 2006).

It has been argued that together with a monotonous environment and low traffic density, monotonous road geometry and design can produce boredom and increase the likelihood of sleep-related accidents, especially on straight parts of roads (Sagberg, 1999). In line with this, Desmond and Matthews (1996, 1997) reported a faster and larger impairment of simulated driving performance on straight parts of the road than on curves. Similarly, in another simulator study, drivers driving on a straight road showed more often fatigue-related performance decrement compared to those driving on a winding road (Oron-Gilad & Ronen, 2007). An analysis of accident data showed that approximately 80% of fatigued-related crashes occurred in areas of low demand due to the terrain (Smith, Oppenhuis, & Koorey, 2006).

Besides factors outside the vehicle, the situation in a vehicle contributes to drivers’ fatigue/sleepiness. The heat, noise and vibrations (McDonald, 1984), and air quality (Sung, Min, Kim, & Kim, 2005; Utell, Warren, & Sawyer, 1994) in vehicles have been reported as causes of driver fatigue. On the other hand, the comfortable seats and sound reduction that modern cars offer might unintentionally enhance driver sleepiness (Horne & Reyner, 1999).

Having passengers in a car should, at least in most cases, reduce drivers’ boredom and consequent fatigue. Furthermore, a passenger might notice signs of driver fatigue (e.g., facial expressions or drifting of the vehicle) and their seriousness before the driver does. Therefore, having passengers might be regarded as a protective measure against falling asleep behind the wheel. However, if the passengers are asleep, the driver is again on his/her own. On the other hand, the presence of passengers in a car driven by a young adult might even have a counterproductive effect because young

male adults are susceptible to peer pressure and might continue driving despite increased fatigue or sleepiness (Näätänen & Summala, 1976; Rice, Peek-Asa, & Kraus, 2003; Summala & Mikkola, 1994).

### **3.2.6. Personality**

Large interindividual and intraindividual differences can be seen regarding performance (not only driving tasks) under sleep deprivation (Frey et al., 2004; Van Dongen, Baynard, Maislin, & Dinges, 2004). There are also large individual differences “in drivers' susceptibility to becoming drowsy” (Verwey & Zaidel, 2000). Such large individual differences have been observed in most, if not all, experimental studies of fatigue and driving. For example, only 10% of long-haul drivers accounted for 54% of the video-recorded periods of drowsiness during one regular working week (Mitler, Miller, Lipsitz, Walsh, & Wylie, 1997). Similarly, during a 200 km nighttime drive on a highway, some drivers were severely affected by sleepiness and some others coped very well (Philip et al., 2006).

Although these large individual differences in responses to experimental settings inducing fatigue and sleepiness are well documented, little is known about the underlining mechanisms (Ingre et al., 2006).

How people will react in monotonous driving conditions, under sleep deprivation and at a certain time of day or night depends on many different factors. Personality factors that have been identified as mediating precursors to driver fatigue are extraversion, sensation seeking, and field dependence (Thiffault & Bergeron, 2003b). According to Thiffault and Bergeron (2003b, p. 173) “drivers who score high on the ES (Experience seeking) component of the SSS (Sensation seeking scale) and high sensation seeking extraverts may be more sensitive to road monotony and thus more prone to fatigue-related driving errors on low demanding road environments.” Similarly, Matthews, and Desmond (1998) have suggested that multiple traits, rather than “simple trait-state isomorphism,” and situational factors influence driver fatigue. Other personality constructs relevant to driver fatigue include morningness/eveningness types, boredom susceptibility, and locus of control (Verwey & Zaidel, 2000).

Brown (1995, p. 163) has raised an interesting question regarding personality, fatigue, and professional drivers: “One question which remains to be explored, to my knowledge, is the extent to which personality influences the professional driver's choice of career and persistence in the job. For example: are long-distance truck drivers predominantly introvert? If not, is there any strong association between personality and accident liability among this professional group?”

### **3.2.7. Alcohol**

There are also large interindividual differences in response to alcohol consumption. However, regardless of drinking history, the speed of alcohol elimination from the body, etc., alcohol has biphasic effects: stimulatory effects are present at low to moderate doses and as BAC rises to a peak, while sedative effects are present at higher doses and at the descending phase of the BAC curve (Roehrs & Roth, 2001).

Consequently, under the stimulatory effects of alcohol drivers might engage in risky behavior (e.g., overtaking, speeding), while under the sedative effects the likelihood of falling asleep at the wheel increases.

The interactive effects of sleepiness and low alcohol levels have received significant attention only recently. In a driving simulator study, the combination of prolonged wakefulness and alcohol consumption produced greater impairment, although not statistically significant, in driving performance than would have been expected from the additive, separate contributions (Arnedt et al., 2000). The combination of low BAC (0.03%) and extended wakefulness impaired performance (driving simulator and vigilance test) more than a BAC of 0.05% alone (Howard et al., 2007). Alcohol at a legal BAC (0.035%) produced additional decrement in driving simulator performance in a state of partial sleep deprivation (Banks, Catchside, Lack, Grunstein, & McEvoy, 2004). Similar results were found in a series of simulator studies conducted by Horne and his colleagues (e.g., Horne, Reyner, & Barrett, 2003; Barrett, Horne, & Reyner, 2004a,b; 2005).

The additive and interactive effects of sleepiness and small amounts of alcohol are also visible in “normal” daily situations. That is, drivers do not have to be sleep deprived or awake for a long time; it is enough that they consume alcohol during a normal circadian drop in alertness. For example, compared to the early evening, both simulated driving and vigilance test performance were worse during the afternoon among women drinking a small amount of alcohol (Horne & Baumber, 1991; Horne & Gibbons, 1991).

These studies also show that the ability to perceive one's own impairment and the related risk deteriorate with increased sleepiness and intoxication (Horne et al., 2003; Barrett et al., 2004b; Banks et al., 2004). Compared with men, women seem to be more aware of their impaired simulated driving due to sleepiness and low alcohol intake, and better at evaluating the consequent risks (Barrett et al., 2004b).

Alcohol also affects performance through its impact on sleep quality, its residual effects, and hangover effects. Simulated driving was still impaired in the afternoon testing as the BAC approached zero from an initial BAC of 0.05% in the morning (Roehrs, Beare, Zorick, & Roth, 1994). These sedative residual effects of alcohol have also been found in other studies (Roehrs, Claiborne, Knox, & Roth, 1994; Roehrs, Yoon, & Roth, 1991; Roehrs, Zwyghuizendoorenbos, Knox, Moskowitz, & Roth, 1992; Yesavage & Leirer, 1986). Consumption of a moderate amount of alcohol (BAC 0.07%) late at night significantly reduces alertness in the early morning hours for those individuals who are relatively alert (Walsh, Humm, Muehlbach, Sugerma, & Schweitzer, 1991). In general, high doses of alcohol disturb sleep in healthy people (Roehrs & Roth, 2001). A hangover from alcohol also impairs performance (McKinney & Coyle, 2004; Wiese, Shlipak, & Browner, 2000).

Roadside surveys also show a connection between alcohol consumption and increased sleepiness. For example, in a nighttime roadside survey in Denmark, self-reported tiredness was much higher among intoxicated drivers compared with sober drivers (Corfitsen, 1996). In a Canadian roadside survey, legally intoxicated male drivers (BAC <0.05%) more frequently reported being sleepy than those with either higher or zero BAC (Wilson et al., 2006).

Evidence that the combination of alcohol and fatigue represent a safety hazard comes also from accident statistics (e.g., Philip, Vervialle, Le Breton, Taillard, & Horne, 2001).

Study II contains a short discussion about possible residual effect from alcohol consumption and its contribution to the causation of sleep-related accidents. In Study V it was explored whether drivers who use a breathalyzer to avoid illegal blood alcohol levels might be exposed to the risks connected with the additive and interactive effects of small amounts of alcohol and sleepiness.

### **3.2.8. Medication and food**

Besides positive effects, every medication has its own adverse effects that can impair, to a smaller or larger extent, the health and functioning of individuals. It has been recognized for some time now that certain medications reduce a person's fitness to drive. In the context of sleep-related crashes, benzodiazepine anxiolytics, long-acting hypnotics, sedating antihistamines (H1 class), and tricyclic antidepressants have been identified as risk factors (NCSDR/NHTSA Expert Panel on Driver Fatigue and Sleepiness, 1997).

It is well known that eating habits (what, how much, and when) are connected with sleep quality. For example, snoring and sleep apnea are worsened by obesity. It should be noted that, however, in severely obese subjects increased daytime sleepiness was independent of the presence of sleep apnea (Dixon, Dixon, Anderson, Schachter, & O'Brien, 2007). Avoiding eating a heavy meal before going to bed or driving is recommended, although for different reasons. Eating a heavy meal before bedtime can disturb the quality of sleep. On the other hand, eating a heavy meal before driving can produce drowsiness because of a drop in blood glucose levels as a consequence of the body's normal insulin response to a heavy meal. However, as Horne and Baulk (2004, p. 164) stated, the situation is far from clear: "A literature search on the effects of sugar/glucose loading on alertness/sleepiness produced equivocal findings for those studies using participants who were already alert and not previously sleep deprived. On the other hand, there is greater consistency among the few studies of people already sleepy before sugar/glucose intake."

### **3.2.9. Driving exposure and experience**

Drivers that drive more often during the hours when sleep propensity is high (e.g., late night hours), those who often drive when sleep deprived, those who drink and drive (especially during the night and mid-afternoon), etc. are clearly exposed to a higher risk of falling asleep at the wheel. However, it seems that some drivers (e.g., taxi drivers) have adapted well to, for example, night driving (e.g., Corfitsen, 1993; Dalziel & Job, 1997). Experienced professional drivers are in general better at compensating for some fatigue effects (Brown, 1994). For example, in a driving simulator study, inexperienced drivers were worse at performing an additional task, both under normal and sleep-deprived conditions (Lenne, Triggs, & Redman, 1998).

### **3.3. Risk groups**

It is expected that different groups of drivers will be associated with different factors causing and mediating fatigue and sleepiness. Risk groups are mainly based on sex, age, sleep disorders, and work type (professional drivers and shift workers).

#### **3.3.1. Sex: Male drivers at higher risk**

Women cause only a small proportion of sleep-related crashes (e.g., Horne & Reyner, 1995) and less often report falling asleep while driving (e.g., Beirness et al., 2004; Hanning & Welsh, 1996). This might be obvious knowing that men in general drive more, in longer durations, and more often during the night. However, in addition to different exposures to the risk of falling asleep, it seems that women are better at perceiving sleep-related driving impairment and the consequent accident risks (Barrett et al., 2004b). Even when a man recognizes the risk of falling asleep, he might continue driving because, as Nelson (1997, p. 411) pointed out: “Tolerating fatigue while driving can even be the ‘macho’ thing to do.” Considering the interactive effects of alcohol and sleepiness, it should not be forgotten that men also more often drink and drive (e.g., Rajalin, 2004).

#### **3.3.2. Age: Young drivers at higher risk**

Large sex differences in the number of sleep-related accidents are to a large extent due to the high number of such accidents caused by young male drivers. Besides being the most prevalent group of road users at times with the highest sleep propensity (during the night hours), several risk factors are typical for young (male) drivers. They often sleep too little as a part of their lifestyle habits (Carskadon, 1990). This lack of sleep puts them at risk because they are more susceptible to acute sleep loss than are those more advanced in age (Brendel et al., 1990). Because of their driving inexperience, young drivers can also overestimate their capabilities and fall asleep without realizing the risks (Gregersen & Bjurulf, 1996). Furthermore, so-called extra motives (e.g., peer pressure) typical for young people can push them to continue driving despite increased sleepiness (Näätänen & Summala, 1976). The drivers’ age was in focus in almost all the studies included in this thesis. In Study III, the focus of investigation was on one special group of young male drivers, military conscripts.

#### **3.3.3. Drivers with untreated and unrecognized sleep disorders**

Much research shows the association between accident involvement and sleep disorders (e.g., George & Smiley, 1999; Teran-Santos, Jimenez-Gomez, & Cordero-Guevara, 2001). Narcolepsy and especially sleep apnea are among the most studied sleep disorders in connection with driving. In the general population narcolepsy is at least 100 times less frequent than sleep apnea; however, narcoleptics are at an especially high risk of falling asleep while driving. Therefore, as Horne and Reyner (2001a) have reported, narcoleptics are not usually allowed to drive in the UK. On the other hand, there is no conclusive evidence that the most prevalent sleep disorder –

insomnia (difficulties in initiating sleep) – is connected with increased motor-vehicle accident risk (Daley et al., in press; Leger, Massuel, Metlaine, & Grp, 2006).

Although many studies show that sleep apnea sufferers have more accidents than normal controls, some researchers have expressed caution. For example, in their review of 14 studies investigating the relationship between sleep apnea and accident risk, Connor, Whitlock, Norton and Jackson (2001) noted many shortcomings of the methodologies employed (e.g., small sample sizes, no control for many confounding variables such as age, mileage, etc). Even a well-cited case-control study by Teran-Santos et al. (2001) failed to match cases and controls according to driving mileage; on a yearly level, the subjects being treated for sleep apnea drove 50% more than “matched” controls.

Interestingly, most of the research on sleep apnea and driving comes from outside of Europe. For example, Horne and Reyner (2001a, p. 66) wrote, “in the UK there is as yet little evidence to show that sleep apnea makes a significant contribution to sleep-related vehicle accidents.” However, in a very recent comprehensive review a number of sleep researchers (Alonderis et al., 2008, p. 374) recommended that “sleep apnea needs to be included without further delay in the list of medical conditions by the European Union to be a driving risk in all European countries.”

#### **3.3.4. Shift workers**

It is well known that shift work is associated with increased subjective, behavioral, and physiological sleepiness (Åkerstedt, 1988). Many shift workers suffer from disturbed sleep (Åkerstedt, 2003). Workers working irregular and night shifts are especially prone to increased sleepiness, involuntary sleep at work, and increased work-related accident risk (Åkerstedt et al., 2002).

Besides the increased risk of falling asleep at work, shift workers are at high risk of falling asleep behind the wheel, especially when driving home after the night shift. This is illustrated in a driving simulator study where driving performance was significantly impaired in shift workers after the night shift (Åkerstedt et al., 2005). Similar to another driving simulator study (Horne & Reyner, 1999), it seems that following an entire night without sleep, driving performance significantly deteriorates already after 15-20 minutes (Åkerstedt et al., 2005).

In many studies, frequent cases of falling asleep while driving and accident involvement among shift workers have been reported. For example, medical interns reported two times more motor vehicle accidents and five times more near-miss incidents after an extended work shift compared to a nonextended shift (Barger et al., 2005). Similarly, compared to nurses working only day or evening shifts, those working night or rotating shifts reported more than 3 times the odds of nodding-off while driving to or from work in the preceding year (Gold et al., 1992). Almost one-third of industrial 12-hour shift workers reported at least one motor vehicle accident when driving home from work (Budnick, Lerman, Baker, Jones, & Czeisler, 1994).

### 3.3.5. Professional drivers

Professional drivers, obviously, due to the nature of the work, spend most of their working hours driving a motorized vehicle. In addition to long periods of driving, many professional drivers work in shifts, have irregular working hours, and work during the night. Therefore, they are exposed to the risks connected with shift work and time-of-day effects. Additionally, many professional drivers exceed allowed working hours (e.g., Beilock, 1995; Häkkänen & Summala, 2000a, b). For example, 40% of long-haul drivers reported driving more than 10 hours within a 24-hour period, breaking EC Regulation No. 3820/85 (Häkkänen & Summala, 2000a).

Sleep disorders and excessive sleepiness are more prevalent among professional drivers compared to the general population (e.g., Carter, Ulfberg, Nystrom, & Edling, 2003; Howard et al., 2004; Stoohs, Guilleminault, Itoi, & Dement, 1994). Self-reported occurrences of dozing off while driving, near misses, and accidents due to fatigue are also more common among professional drivers compared to non-professionals (e.g., Powell et al., 2007). In an Australian survey of truck drivers, 14% reported nodding off at least occasionally during the previous nine months (Arnold et al., 1997). As mentioned before, 47.1% of long-distance truck drivers had at least once fallen asleep at the wheel of a truck, and for 25.4% that had happened in the preceding year (McCartt et al., 2000). In a Finnish sample of long-haul truck drivers, 40% reported dozing off while driving in the previous three months and 16.4% reported a lifetime accident while driving at work due to dozing off (Häkkänen & Summala, 2000b).

Accident analyses show, for example, that fatigue was involved in 31% of fatal-to-the-driver heavy truck crashes in eight US states (National Transportation and Safety Board, 1990). In New Zealand, 17.6% of truck accidents were found to be fatigue related (Gander, Marshall, James, & Le Quesne, 2006).

Although a high proportion of truck drivers believes that fatigue is a problem for the industry, a significantly smaller proportion finds it to be a personal problem (Arnold et al., 1997; Baas, Charlton, & Bastin, 2000; Feyer & Williamson, 1995). Similarly, company representatives considered fatigue to be a problem for drivers other than those of their company (Arnold et al., 1997).

Nevertheless, it seems that many professional drivers do adapt over time and somehow learn to cope with fatigue-related problems (e.g., McDonald, 1989). A self-selection process, typical for all kinds of shift work, also plays a role in eliminating problems of fatigue (McDonald, 1989).

## 4 COUNTERMEASURES FOR DRIVER FATIGUE

In general, two types of countermeasures can be separated, those applied by drivers themselves and those designed and created by industry and society. Of course, drivers' actions include taking advantage of the countermeasures introduced by industry and society.

### 4.1. Drivers' countermeasures

It is practically impossible to find a driver that at some point in his driving career has not faced some level of fatigue and tried to fight it in one way or another. Most of the countermeasures self-reported by surveyed drivers are those taken inside the car without actually stopping driving. Such actions include opening the window for fresh air, (loudly) listening to the radio, talking to a passenger, singing, putting the seat upright, drinking caffeinated beverages, smoking cigarettes, etc. (e.g., Anund, Kecklund, Peters, & Åkerstedt, 2008; Maycock, 1996; van den Berg & Landström, 2006). In cases when drivers decide to stop, they stop just to have a short break or to engage in different activities such as walking, exercising, drinking a caffeinated drink, etc. (Stutts, Wilkins, & Vaughn, 1999). Completely stopping driving to take a nap or to sleep is rarely reported by non-professional drivers (e.g., Lucidi, Devoto, Bertini, Braibanti, & Violani, 2002; Nordbakke & Sagberg, 2007), although it is rated among the most effective countermeasures both by professional and non-professional drivers (Arnold et al., 1997; Nordbakke & Sagberg, 2007). However, in general, it seems that misconceptions about countermeasures for fatigue are widespread regardless of country and driver status (e.g., Dawson 2005; Maycock, 1996; Nordbakke & Sagberg, 2007). Even when drivers have the appropriate knowledge, their actions are not necessarily in line with it (e.g., Fell, 1995).

Besides the fact that experimental research has shown that most in-car countermeasures often taken by drivers are ineffective or short lasting (Reyner & Horne, 1998), it is worrying that some drivers engage in actions that can even be counterproductive. Driving faster (Perez-Chada et al., 2005), overtaking (Nordbakke & Sagberg, 2007), talking on a mobile phone (Häkkinen & Summala, 2000b; Nordbakke & Sagberg, 2007), and even drinking alcohol (Arnold et al., 1997) or smoking cannabis (Maldonado, Mitchell, Taylor, & Driver, 2002) are actions that bring additional safety risks to already fatigued drivers.

It is obvious that completely stopping driving and going to sleep is the most effective countermeasure; however, opportunities for such actions are limited. In contrast, stopping the vehicle and taking a nap is possible in most driving circumstances. The combination of a caffeinated drink (150 mg of caffeine, about two cups of coffee) and a short nap (<15 minutes) seems to be a very effective countermeasure for sleepiness (Horne & Reyner, 1996; Reyner & Horne, 1997).

On the other hand, preventive measures applied before starting a drive are also very effective. Not starting a drive, especially a long one, at all while tired/sleepy is of course the best preventive measure. Detailed trip planning, having a good night's sleep before departure, avoiding alcohol, and drinking caffeinated drinks are



countermeasures reported in various drivers' surveys (Nordbakke & Sagberg, 2007; Stutts, Wilkins, & Vaughn, 1999).

Interestingly, and ironically as Philip et al. (1996) put it, traffic campaigns advising drivers to avoid peak hours during holiday weekends or seasons can place many fatigued drivers on the roads. As many as 47% of acutely sleep-deprived drivers on a long vacation trip on a major European highway had restricted their sleep prior to departure following such campaigns promoting a "safe trip." Starting a drive in the late evening or early morning may help to avoid traffic jams but adds to the risk of falling asleep behind the wheel, especially for drivers not used to driving at that time of the day or the long distances typical for vacation trips.

## **4.2. Society and industry**

Although the exact proportions of sleep-related road accidents are unknown, it is widely recognized that they represent a significant safety problem, and therefore, effective countermeasures have to be developed and applied to prevent them. Such countermeasures include safety campaigns, environmental interventions, in-vehicle technologies, and legal approaches (Fletcher, McCulloch, Baulk, & Dawson, 2005).

### **4.2.1. Safety campaigns**

Great misconceptions about fatigue countermeasures are a clear sign that many drivers should be educated that sleepiness leads to sleep and that sleep can come faster than they may apprehend. In a summary of their comprehensive review, Horne and Reyner (1999, p. 294) "advocate heightened public awareness, greater employer responsibility, and better education of drivers about sleep-related vehicle accidents, which cause numerous road casualties each year."

Educating and changing attitudes is a first step in an attempt to reduce the number of sleep-related accidents; however, the ultimate goal of changed behavior cannot be achieved easily. As Donovan, Jalleh, and Henley (1999, p. 243) pointed out: "The general conclusion is that mass media supported road safety campaigns can change knowledge and attitudes, but there is little evidence that they change behavior in the absence of accompanying enforcement." In the case of fatigued driving, enforcement is very difficult to accomplish, with the exception of professional drivers (e.g., checking the driving logs). Nevertheless, there are some promising results on driver training as a fatigue countermeasure (Gander, Marshall, Bolger, & Girling, 2005).

Despite unknown effectiveness, many safety campaigns, some of which are practically continuous, have been conducted around the world. For example, the National Sleep Foundation's program "Drive Alert...Arrive Alive" active in the US since 1993 and the "Think Campaign" in the UK are among the most cited examples of such campaigns (Drobnich, 2005; Fletcher et al., 2005). In their "survey of public education literature regarding driver sleepiness" Flatley and Reyner (2000, p. 21) classified three approaches:

- “Education of the general public about the dangers, and to gain general disapproval of driving whilst sleepy
- Education of ‘high risk’ population groups using appropriate material
- Education of other opinion formers using appropriate material”

Furthermore, organizations of road accident victims (e.g., in the US, the organizations Parents against Tired Truckers and Victims of Irresponsible Drowsy Drivers) participate in raising public awareness about the hazards of fatigued driving (Dement, 1997).

#### **4.2.2. Environmental interventions**

The idea that roads should be designed in such a way to prevent sleep-related accidents is not new. As early as in 1970, Shor and Thackray (1970, according to Thiffault & Bergeron, 2003a) proposed that highways should be built “so as to induce mild stress and perceptual novelty in order to help ward off drowsiness.” Kenny (1995) proposed some measures in road design that would not reduce the induction of fatigue but rather the likelihood of fatigue-related accidents (e.g., “provide a wide ‘clear zone’ adjacent to the road so that the fatigued driver has time to correct an error before colliding with an object”). Building such “a more forgiving” environment to reduce the number of fatigue-related crashes is indeed one of the recommendations in Queensland, Australia (Queensland Parliamentary Travelsafe Committee, 2005).

Building rest areas along motorways provides an opportunity for fatigued drivers to stop and rest before continuing their trip. However, if drivers do not feel safe in such rest areas, it is unlikely they will stop and, for example, take a nap in their car. Such personal safety reasons for not stopping are typical for women drivers (Anund et al., 2008). It is quite common that many shipping and transport operators have a black list of rest areas. In a recent EU report, more than 20% of surveyed companies even reported being forced by insurance companies or shippers to avoid certain parking areas (Visser & van den Engel, 2007). Furthermore, many internet forums and traveling portals also list rest areas with a high prevalence of various criminal activities, including robberies, vandalism, and aggressive begging.

Popular and relatively cheap road intervention, at least in comparison to guardrails, is a rumble strip barrier. Installed on the centerline or sideline, rumble strips when crossed alert drivers by creating a loud noise and vibrations. Therefore, their purpose is to reduce unintentional crossing to the opposite lane and running off the road. Since most sleep-related accidents are head-on crashes or running-off accidents, rumble strips are also meant to reduce the possibility of such accidents. However, as Lyznicki et al. (1998, p. 1911) state, “because rumble strips do not prevent sleepiness, there is concern that their use may awaken drivers only temporarily and may not prevent them from falling asleep further down the road.” It is still unclear how effective rumble strips are, but some promising reports exist showing a significant reduction in either general accident rates (e.g., Persaud, Retting, & Lyon, 2004) or specifically sleep-related, running off of the road, fatal crashes (McConnell, Bretz, & Dwyer, 2003) following the installation of rumble strips.

### **4.2.3. Technology-based interventions**

In recent years, much effort has been put into developing methods for assessing on-road driver sleepiness and fatigue. According to Dingus and Mallis (1998), there are four classes of fatigue detection and prediction technology:

1. Readiness-to-perform and fitness-for-duty technologies (e.g., the PVT-Psychomotor Vigilance Test);
2. Mathematical models of alertness dynamics joined with ambulatory technologies (e.g., Fatigue Audit InterDyne system);
3. Vehicle-based performance technologies (e.g., steering and braking movements);
4. In-vehicle, on-line, operator status monitoring technologies (e.g., eyelid closures, physiological measures).

These categories can be roughly grouped into technologies aiming at detecting fatigue in real time and those technologies aiming at predicting fatigue in the future based on past work and rest (Hartley, Horberry, Mabbott, & Krueger, 2000).

In-vehicle real-time devices, besides detecting fatigue/sleepiness, should obviously provide some feedback to the driver; in more advanced concepts such devices should even take a control of the vehicle (Hancock & Verwey, 1997; Verwey & Zaidel, 1999).

Although some commercial alerting devices are already available, there are many concerns about their validity, reliability, sensitivity, and acceptability (Hartley et al., 2000; Wright, Stone, Horberry, & Reed, 2007). Even if all these parameters are met in a satisfactory manner, there is still the more problematic issue of usability (Brown, 1997; Lisper et al., 1986). As Lisper et al. (1986, p. 450) pointed out, "What is the use of alerting a driver already aware of the fact that he is close to sleep but who still continues to drive?" Horne and Reyner (2000, p. 18) expressed even more concern, "Such devices may encourage sleepy drivers simply to take further risks and continue to drive, believing that the device will alert them when the situation becomes particularly dangerous."

### **4.2.4. Regulations, traffic law, and criminal law**

In every country, there are a number of acts and decrees covering road safety. Recommendations, regulations, and traffic and criminal law all to a greater or lesser extent may cover fatigued driving. However, legislation for professional drivers seems to be the only type that is easily applicable because of tachographs installed in the vehicles. These devices record various operating characteristics of a vehicle, for example, details of vehicle speed, distance covered, and driver duty and rest during a 24-hour period. Therefore, the enforcement of regulations on working and rest hours is possible. Despite this, many drivers do not obey the rules, and some of them even falsify their log books (McCartt et al., 2000).

Another approach to direct prevention is stopping drivers at a high risk of falling asleep behind the wheel from driving at all. For example, in Australia, professional drivers suffering from sleep apnea might lose the right to drive until the illness is

successfully treated (McEvoy, 2003). In this context, the Finnish parliament recently passed a new law obliging doctors to notify police if a patient could be a threat to himself or others while driving due to poor health. The law applies mainly to patients in long-term care or with chronic illnesses. As stated in a Finnish Ministry of Social Affairs and Health publication (2004) “in most cases where the medical condition of license holders’ is likely to impair their ability to drive there is clear acceptance of medical advice about giving up driving. The new ruling is aimed at stopping people driving who ignore such advice.” Insomnia, sleep apnea, and other sleep disturbances are listed on the form for doctors to report on driving ability. Doctors are supposed to detect such problems and estimate their influence on driving ability.

This controversial law was adopted against the advice of Finland’s doctors’ union. The main reason for the doctors’ reluctance was the belief that the new law puts patient-doctor relations in jeopardy. Furthermore, doctors’ representatives expressed concerns about possible problems that could be created by the new law. For example, some patients eager to continue driving may not be willing to report certain medical problems or may even decide not to seek medical help. It is also reasonable to predict that different social groups would be affected in different ways. For example, people living in rural areas depend more on personal motor vehicle usage than those living in urban or metropolitan areas that have extensive public transport.

Preventing fatigued driving among the “normal” driving population is extremely difficult. As we have seen, a validated and reliable device for detecting the level of sleepiness (cf. the breathalyzer for alcohol levels) is not available. Therefore, it is practically impossible to enforce any law that forbids driving while fatigued. Police officers cannot reliably detect “too fatigued” drivers on the road and fine them. Sometimes a police officer will stop a driver because of unusual driving (drifting) and suspected intoxication, only to discover that the driver seems only very tired (personal communication). However, further police actions are mainly based on actual “wrong” driving, not only on the basis of the suspected level of fatigue.

The Finnish Road Traffic Act (RTA) explicitly forbids driving while tired in Article 63 (3.8.1990/676), which addresses a driver’s fitness to drive: A person that does not meet the requirements for driving because of illness or tiredness or another similar reason or whose health condition no longer fulfills the requirements needed for granting a driver’s license must not drive a vehicle (unofficial translation). It is unknown how many drivers are charged under this article because of fatigued driving and what the actual consequences are of such fatigued driving. This issue has been investigated in Study VI.

Incorporating fatigued driving together with an accident as its consequence into the law has been done in the state of New Jersey, USA, with the introduction of “Maggie’s Law.” Under this law a driver who causes an accident after being awake for more than 24 consecutive hours can be convicted of second-degree vehicular homicide, sentenced to up to 10 years in prison, and fined a maximum of \$100,000.

Many current discussions are taking place worldwide on how falling asleep at the wheel and fatigued driving can be more explicitly incorporated into traffic and criminal law. This kind of in-depth debate was recently conducted in Australia (Victorian Government, 2004; Tasmania Law Reform Institute, 2007), the UK (House of Commons, 2006), and the US (e.g., “Maggie’s Law”).

## 5 AIMS OF THE DISSERTATION

The complex nature of fatigue and sleepiness has attracted plenty of multidisciplinary and interdisciplinary studies with various methodologies and study designs. Sleep researchers, traffic psychologists, physiologists, engineers, and ergonomists all have contributed from their points of expertise and with their own particular methods. Experimental and laboratory studies, including driving simulator studies, on-road studies, questionnaires, analyses of accident statistics, and accidents, have provided a wide range of valuable results. A variety of subjects have been used in these studies: professional drivers, sleep disorder patients, representative samples of “normal” driving populations, shift workers, young and inexperienced drivers, elderly and health-impaired drivers, etc. In this thesis several sources of data were used.

As in any other scientific research, especially in those with clear application (safety) goals, this thesis follows these (simplified) basic steps: defining the problem, explaining it, and controlling the problem. In the context of fatigued driving, these steps would mean establishing the extent of the fatigue-related problems while driving, identifying risk factors and groups, and finally finding ways to reduce these problems.

How to correctly recognize an accident as sleep-related is a one of the central problems when dealing with fatigue and sleepiness problems while driving. Although risk factors and groups can be identified in experimental settings, and countermeasures can be set accordingly, the lack of precise accident statistics makes the evaluation of applied countermeasures very difficult. The lack of validated and reliable devices for detecting the level of sleepiness/fatigue, and the inexistence of ambiguous criteria for recognizing an accident as sleep related result in unreliable estimations of the role of fatigue in accident statistics.

Two issues were crucial to be able to study this problem in this thesis: the existence of a globally unique fatal accident database (VALT) in Finland and the nature of Finnish traffic law, which forbids driving while tired. Multidisciplinary investigation teams (VALT) investigating all fatal accidents in depth should by default provide more reliable identification of the contribution of fatigue in accident causation, and therefore this method should result in a more accurate estimation of fatigue-related accidents. These teams should also provide more detailed information about risk factors and, naturally, risk groups. On the other hand, Finnish traffic law, which explicitly forbids driving while tired, allowed us to examine the circumstances of fatigue driving offenses, including the identification of risk factors and risk groups.

These two sets of data allowed us also to examine the possibility of the seasonal variation of fatigue/sleepiness problems while driving and to examine whether Finnish military conscripts are at high risk of fatigue-related accidents. Finally, to our knowledge, for the first time we raised the safety implications of increased breathalyzer usage in the context of fatigued driving.

More specifically, this dissertation has four main aims with several more focused research questions:

### **1. To estimate the prevalence of fatigue/sleepiness problems while driving**

- How many fatal accidents are caused by drivers falling asleep according to VALT multidisciplinary investigation teams (Studies I & IV)?
- How many drivers are punished on the basis of fatigued driving (Study VI)?

### **2. To explore the recognition of fatigue/sleepiness problems while driving**

- What variables in the computerized database explain VALT teams' decisions of whether an accident was sleep related or not (Study I)?
- Is previously observed seasonal variation in the proportion of falling-asleep accidents a real phenomenon, or does it reflect a possible bias in the analyses and conclusions of the VALT investigation teams (Study II)?
  - What are the factors leading to falling asleep behind the wheel according to the VALT teams (Studies II, III, and IV)?
  - Are there differences in the discussions and conclusions between the courts and VALT in-depth investigation teams regarding the contribution of fatigue to accident causation (Study IV)?
  - When do Finnish courts find drivers guilty of fatigued driving (Study VI)?

### **3. To identify risk factors and driver groups at risk of falling asleep behind the wheel**

- Is the seasonality of sleep-related fatal accidents related to different populations at risk, to changes in lifestyle factors including sleep habits, or to both (Study II)?
- What is the role of fatigue in fatal road accidents caused by military conscripts (Study III)?
- Are drivers who use a breathalyzer to avoid illegal blood alcohol levels exposed to the risks connected with the additive and interactive effects of small amounts of alcohol and sleepiness (Study V)?
- Who are the drivers punished of fatigued driving (Study VI)?
- Is there a time-of-day and seasonal pattern of fatigue-related driving offenses (Study VI)?

### **4. To analyze the application of the position of fatigued driving in the Finnish legal system**

- Is there a need for a reform of the Finnish legal system regarding fatigued driving, and if so, how it can be done (Studies IV and VI)?

## **6 METHODS**

### **6.1. Data sources**

Five main sources of data were used: the computerized database and the original folders of the multidisciplinary investigation teams (VALT), a survey collected from Finnish military conscripts, the Finnish Vehicle Administration (AKE) driver record database, Finnish prosecutor and court decisions, and a survey of a representative sample of Finnish drivers.

#### **6.1.1. The VALT method**

The VALT method is a road accident in-depth investigation system with a long tradition that is unique worldwide. The first permanent team was established in 1968, and since the early 1970s every road accident involving one or more fatalities has been studied in depth by one of 14 multidisciplinary investigation teams stationed across Finland (Hantula, 1992). (Nowadays, there are 20 teams with about 270 members (Salo, Parkkari, Sulander, & Keskinen, 2006)). Every team consists of a police officer, a vehicle engineer, a traffic engineer, a physician, and (in certain cases) a psychologist. It is important to note that the police officer on this team is not involved in an official accident investigation that will potentially lead to criminal proceedings. Alerted immediately after the crash, the team members arrive at the scene to collect all available information: they interview the survivors and eyewitnesses, carry out alcohol and drug tests, and analyze the vehicle positions, the damage caused, the road geometry, and the signage. A preliminary reconstruction of the accident is done on the spot. Afterwards the team collects data from national driver records and health-care centers, and in cases involving a driver's death it obtains an autopsy statement and interviews the deceased's relatives in order to establish any relevant background factors. All members fill in their own standardized data sheets. At their final meeting they exchange opinions about possible causes of the accident based on all the data that they have collected. As a result, the team produces a final statement in the form of an explicit decision as to the primary cause, called the key event (the event triggering the course of events that deviated from normal driving, such as falling asleep). The team also lists the risk factors that contributed to the accident (fatigue, for example). All the original documents are stored in files that are available to researchers, and some 300 variables concerning the participants, the vehicles involved, the traffic situation, and the road and weather conditions among other factors are imported into the VALT computerized database. More information on this method and on the work of the investigation teams is given in Hantula (1992) and Salo et al. (2006). The VALT database from 1991 to 2001 lists 2,980 fatal accidents studied in depth, and selected samples were used in several studies included in this thesis.

### **6.1.2. Conscript survey**

A survey was carried out at one garrison in Southeastern Finland of 259 young male conscripts (mean age=19.52, SD=1.1, range 18-29) holding a valid driver's license. This sample of conscripts represents the Finnish population of 19- and 20-year-old men very well. At the time of testing in October 2005, the conscripts had served about four months. The data collection was done by a research assistant in a lecture room, but was also supervised by army personnel, who guaranteed the conscripts' attendance. The questionnaire included a wide range of questions (e.g., driving behavior, lifestyle and personality scales, questions on alcohol consumption, driving exposure, etc.). The questions regarding the use of a personal vehicle for holiday trips were of special interest.

### **6.1.3. The Finnish Vehicle Administration (AKE) driver record database**

The Finnish Vehicle Administration (AKE) maintains the Vehicular and Driver Data Register "for the purposes of improving road safety, reducing environmental nuisances caused by road traffic and managing tasks related to road traffic taxation and to motor vehicle mortgages" (Vehicular and Driver Data Register Act, 859/2005). This data is available for scientific research purposes. We extracted all drivers (N=784) punished under Article 63 of the RTA from 2004-2005.

### **6.1.4. Court decisions**

Court decisions in Finland are available to the public, and obtaining them for research purposes is free of charge. A prosecutor decision includes a short description of the offense, including the time and place, the vehicles involved, and in most cases an explanation of the offense and the basis for the charge. The accused has to sign the completed form and by doing so accepts what is written there; however, the accused has the possibility to give a statement providing his view of the incident, which can be contrary to the information provided by the investigating police officer. If the accused officially contests the notification, a charge might be brought in a district court. Compared to prosecutor decisions, district court and court of appeal decisions have significantly more text and information available. They are written by the court and include the final decision, the reasoning and the grounds on which it was based, and a summary of the court process. On two different occasions, a number of court decisions were requested from prosecutor offices, district courts, and courts of appeal (Studies IV and VI). Parts of the law relevant to the present research are listed in the following paragraphs.

There are a number of acts and decrees covering road safety in Finland, of which the Road Traffic Act (267/1981) is the most important. The Road Traffic Act (RTA) and the Penal Code (PC) define penalties for traffic crimes, but only the PC defines crimes leading to imprisonment. It should be noted here that fixed fines are used only for minor traffic offenses (e.g., slightly exceeding the speed limit); while day-fines (from 1 to 120 days) are the predominant form of punishment. The actual sum of a day-fine depends of the monthly income and the assets of the offender (Joutsen, Lahti,



& Pölonen, 2001). This day-fine system has been used in Finland as form of punishment for all kinds of offenses (not only traffic offenses) since its introduction in 1921. Traffic crimes relevant to this research include Endangering Traffic Safety (RTA Art. 98; PC Ch. 23, Sec. 1) and Grossly Endangering Traffic Safety (RTA Art. 99; PC Ch. 23, Sec. 2). Additionally, the PC (578/1995) defines sanctions for homicide and bodily injuries which are also potentially applicable to the cases discussed. More details follow.

**Endangering Traffic Safety – Causing a traffic hazard** (RTA Art. 98, PC Ch. 23, Sec. 1): A road user who deliberately or negligently breaches the Road Traffic Act (267/1981) or the Vehicle Act (1090/2002) or the regulations or orders issued on the basis thereof, in a manner conducive to causing a hazard to others, shall be sentenced for *endangering the traffic safety* to a fine or to imprisonment for at most six months.

**Grossly Endangering Traffic Safety - Causing a serious traffic hazard** (RTA Art. 99, PC Ch. 23, Sec. 2): If in the causing of a traffic hazard, the driver of a motor-driven vehicle or tram deliberately or grossly negligently (1) significantly exceeds the maximum speed limit; (2) starts to overtake while the visibility is insufficient for safe overtaking or while overtaking is otherwise not allowed; (3) fails to heed the duty to stop or give way required by traffic safety; or (4) in another comparable manner breaches the traffic regulations, so that the act is conducive to causing serious danger to another's health or safety, the offender shall be sentenced for *gross endangering the traffic safety* to at least 30 day-fines or to imprisonment for at most two years.

**Negligent Homicide** (PC Ch. 21, Sec. 8): A person who through negligence causes the death of another shall be sentenced for *negligent homicide* to a fine or to imprisonment for at most two years.

**Grossly Negligent Homicide** (PC Ch. 21, Sec. 9): If in the negligent homicide the death of another is caused through gross negligence, and the offense is aggravated also when assessed as a whole, the offender shall be sentenced for *grossly negligent homicide* to imprisonment for at least four months and at most six years.

**Negligent Bodily Injury** (PC Ch. 21, Sec. 10): A person who through negligence inflicts not insignificant bodily injury or illness on another shall be sentenced for *negligent bodily injury* to a fine or to imprisonment for at most six months.

**Grossly Negligent Bodily Injury** (PC Ch. 21, Sec. 11): If in the negligent bodily injury the bodily injury or illness is inflicted through gross negligence, and the offense is aggravated also when assessed as a whole, the offender shall be sentenced for *grossly negligent bodily injury* to a fine or to imprisonment for at most two years.

### 6.1.5. Drivers' survey

The data came from the yearly driver survey of *Liikenneturva* (the Central Organization for Traffic Safety in Finland). The main content of the survey is always about the traffic climate, while an additional topic differs from year to year; in the autumn 2007 survey, the additional topic was related to driver fatigue. A full report on fatigue-related issues has been recently published (Radun & Radun, 2008). The data collection was carried out by a professional marketing research company, TNS Gallup, Finland. The participants were interviewed face-to-face. The sample is representative of the Finnish active driving population; it was stratified according to

age, sex, and municipality. Altogether 1563 people were initially contacted, and inclusion was based on whether the person drives a motor vehicle at least occasionally. After the exclusion, 1126 participants were eligible for the study. An additional five subjects were excluded due to missing values. The final sample therefore consisted of 1121 drivers who at least occasionally drove a motor vehicle. Additionally, all major breathalyzer importers in Finland were contacted and asked to estimate how many devices they delivered to retailers in the year 2006.

## 6.2. Procedure

### 6.2.1. Study I

In study I, a VALT computerized database was used to answer the research question: What variables in the computerized database explain teams' decision of whether an accident was sleep related or not?

We focused on “pure” fatigue cases by excluding drivers who were under the influence of alcohol or drugs. Furthermore, professional drivers (truck, bus, taxi, and delivery drivers) were excluded because their driving tasks and fatigue coping skills significantly differ from those of the “normal” driving population. In other words, we avoided controlling for or taking into account driver status in our statistical analysis. Finally, we excluded drivers who had never had a driver's license and cases in which a car's technical fault had a major role.

Starting from the 2,980 fatal accidents studied in depth listed in the VALT database from 1991 to 2001, in the end there were 1,464 cases for the final analysis (Figure 1). Logistic analysis was used as a main statistical tool.

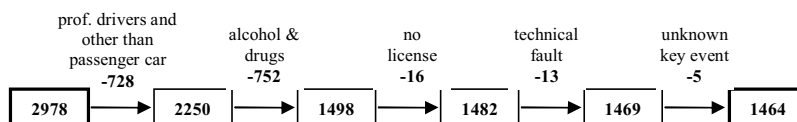


Figure 1. The sample selection procedure in Study I.

### 6.2.2. Study II

In this study, a computerized VALT database and a sample of the original folders were used to answer the two following research questions. Is previously observed seasonal variation in the proportion of falling-asleep accidents a real phenomenon, or does it reflect a possible bias in the analyses and conclusions of the investigation teams? Is the seasonality of sleep-related accidents related to different populations at risk, to changes in lifestyle factors including sleep habits, or to both?

**To answer the first question**, a sample of original folders was selected from the sample used in Study I according to the following criteria: to control for responsibility (in head-on and running-off-road accidents, as in most of these cases,

the responsibility for the accident is not shared) and task difficulty (dry road conditions). The sample was further restricted to afternoon fatal driver accidents (14.00-18.00), as the previous finding that the increase of falling-asleep accidents during the summer mostly comes from an increase in afternoon events (Summala et al., 2003). Given these criteria, the sample consisted of 107 cases. In all, 101 original folders were analyzed, as six were not available. The year was roughly divided into summer (April–September) and winter (October–March).

Since behavioral scientists are not present in every team or for every investigation, a principal researcher-traffic psychologist evaluated the original folders and judged whether the investigation teams provided enough information to state the cause of the accident (key event) conclusively. After the analysis, each case was classified as *clear*, *probably a good decision*, or *unclear*. According to the hypothesis, unclear cases were further classified as biased or not biased. The criteria used included the availability of information, the progress of the accident (e.g., preventive action), the current condition of the driver at the time of the accident (e.g., time being awake, duration of driving), and background factors (e.g., health history, mental problems, sleep disorders). If all available information seemed to support the decision of the investigation team and no contradictory information was noted, the decision was classified as a *clear* or *probably good decision*. The main difference between these two categories was the amount of information provided that supported the final decision of the investigation team. On the other hand, *unclear cases* suffered from either insufficient or contradictory information.

**To answer the second question**, two data sets were used: the same computerized sample used in Study I. and 101 original folders (selection explained above).

To the computerized sample, a hierarchical log-linear analysis was applied. Due to the small number of falling-asleep cases for women (4 of 204 in winter and 20 of 144 in summer), only the men's data was analyzed. The variables included were accident type (falling asleep or not falling asleep), age (six categories), and season (summer vs. winter). Both backward elimination and forward selection procedures were used to obtain the best-fitting model. A log-likelihood ratio goodness-of-fit statistic (G2) was used to evaluate the adequacy of the model.

In the analysis of original folders the focus was only on the summer cases because drivers who fell asleep were involved in only three fatal accidents in the winter, and thus, any comparison between summer and winter cases would not make any sense.

### 6.2.3. Study III

To answer the question “What is the role of fatigue in fatal road accidents caused by military conscripts?” we analyzed original VALT folders for the accidents caused by conscripts and a survey collected on 259 young male conscripts.

After all accidents caused by conscripts were identified in the VALT computerized database, the corresponding original folders were requested. This was necessary since it was not possible to find out the purpose of the conscripts' trips from the computerized database. According to the purpose of the trip, the accidents were classified as army related (driving on duty or to or from the garrison) or army unrelated (on leave driving). It should be stressed that *army related* in this definition

does not imply that the accident is service related or that the army is responsible for the accident.

From the conscripts' survey, only the responses to four open questions regarding the use of a personal vehicle for holiday trips were analyzed and reported. We asked the conscripts how many times they had driven their car between home and the garrison in the preceding two months and in how many instances they were fatigued. In addition, we asked them whether they had traveled as a passenger in a vehicle driven by a fellow conscript. Finally, the conscripts were asked to estimate the distance between their home and the garrison. A t-test and descriptive statistics were used when analyzing the survey data.

#### 6.2.4. Study IV

The main aim of this study was to explore how Finnish courts deal with drivers that according to a VALT team had fallen asleep and caused the death of another person. The VALT database from 1991 to 2001 lists 2,980\* fatal accidents studied in depth, and in ten of these cases the key event remained undecided. In 247 cases (8.32%) the driver had fallen asleep and in 57 (23.1%) of these cases had survived. In the analysis, we included only head-on crashes (participants do not share responsibility) in which the fatality was in the oncoming vehicle (of the non-guilty driver). We also excluded crashes in which the other driver was under the influence of alcohol and those involving more than two vehicles. The final sample consisted of ten cases, although we obtained nine district court decisions (Figure 2).

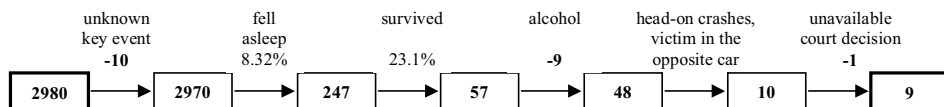


Figure 2. The sample selection procedure for Study IV.

#### 6.2.5. Study V

The main question in the survey was whether a respondent or somebody else in the household owns a breathalyzer. Age and sex were used as predictors (in logistic regression) of the ownership and usage of breathalyzers. The circumstances of breathalyzer usage were also examined.

#### 6.2.6. Study VI

This study was done to investigate the circumstances of fatigue driving offenses. From the Finnish Vehicle Administration driver record database we extracted all drivers (N=784) convicted under Article 63 of the RTA from 2004 to 2005. Of these drivers, 632 received a punishment directly from the prosecutors, 139 from the district

\* Please note that in Study IV were two more accidents compared to Study I (2980 vs. 2978); this is due to corrections made in the database.

courts, and 13 from the courts of appeal. We obtained altogether 776 cases (99%): 628 (99.4%) prosecutor decisions, 137 (98.6%) district court decisions, and 11 (84.6%) courts of appeal decisions. For the eight cases that went to the court appeal, a district court decision was also available; therefore the number of unique cases was 768. Although Article 63 of the RTA lists not only fatigue, but also sickness and other factors concerning a driver's fitness to drive, most (90.5%) of the drivers convicted under this article committed a fatigue-related traffic offense. These cases were the focus of the analysis.

### **6.2.7. Statistical analyses**

All quantitative data was imported into an IBM-compatible computer and analyzed with the statistical package SPSS (SPSS Inc, Chicago IL) for Windows. During the work on this thesis different versions of SPSS were used. In addition to the descriptive statistics present in each study, a wide range of different parametric and non-parametric tests were used. These include logistic regression (Studies I, V, and VI), a hierarchical log-linear analysis (Study II and VI), the t-test (Studies III and VI), and the chi-square test (Studies V and VI).

### **6.2.8. Ethical considerations**

No problematic issues were predicted or detected in terms of ethical considerations; therefore, no special requests were sent to the Ethical Committee of the Department of Psychology, University of Helsinki. On several occasions (Studies I-IV), permission to use VALT data has been requested. The Finnish Vehicle Administration (AKE) has given permission to use the driver record data in Study VI.

## 7 RESULTS

### 7.1. The prevalence of fatigue/sleepiness while driving

The results of study I show that during 1991-2001 in a selected sample of fatal accidents caused by nonprofessional nonintoxicated drivers, 10.1% of the drivers fell asleep, while fatigue was a contributing factor in an additional 5.2% of the cases.

In study IV, the percentage of drivers who fell asleep and caused a fatal accident was somewhat lower – 8.3%. However, this estimation was based on the whole data set that included also the professional and intoxicated drivers (Figure 3).

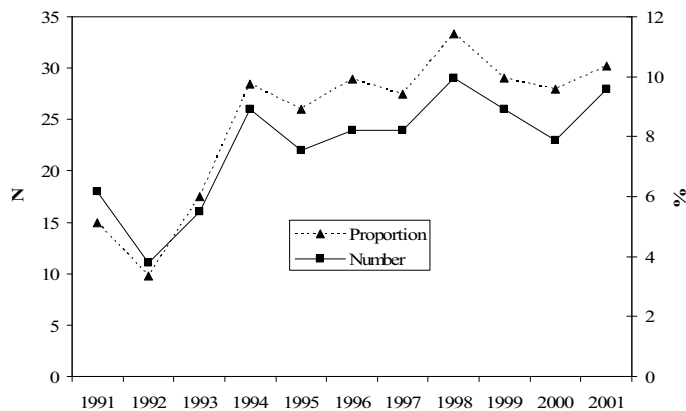


Figure 3. Yearly number and proportion of falling-asleep fatal accidents.

In Study VI, it was reported that in the years 2004 and 2005, the number of drivers convicted of fatigued driving was 321 and 373, respectively. In 92.5% of these cases, the fatigued driver was involved in some kind of accident, mostly a single vehicle accident (81%). In 17.1 of the accidents (N=110), someone was slightly or seriously injured, and eight (1.2%) accidents were fatal.

### 7.2. Recognizing fatigue/sleepiness in traffic

#### 7.2.1. What variables in the computerized database explain a team's decision of whether an accident was sleep related or not (Study I)?

##### Missing values analysis

There was a high variation in the proportion of missing values for different variables, ranging from 0 to 44%. The variables for the time and place of the accidents were free of missing values. Information about weather conditions, road type and conditions,

and vehicle conditions was rarely lacking, averaging around 1%. In contrast, driver-centered variables suffered from missing values much more often. Among the variables indicating driving experience, lifetime mileage was missing in 33.5% of cases, current annual mileage in 33.1%, the driver's experience (in mileage) with the present vehicle in 31.1%, and the extent of driving on the current road or in the area in 14.9%. Similarly, the driver record data was lacking quite often: former traffic accidents in 23% of cases and traffic offenses in 13% of cases. Finally, the background characteristics and the current status of the driver had a high percentage of missing values. Marital status was lacking in 7.4% of cases, the main purpose of the trip in 11%, sleeping time the previous night in 44.1%, time awake in 39.5%, total driving time before impact in 20%, breaks during driving in 32%, driving since the last break in 33.5%, the most important action taken to prevent the crash in 32%, and whether the participant felt tired in 35.2%.

**Table 1.** Percentage of missing values in fatigue-related variables by the injury severity of the driver responsible for the accident.

	Not injured	Light injury	Serious injury	Died	Total
Time awake	4.3%	11.5%	21.9%	50.0%	39.5%
Sleeping time	6.9%	11.5%	24.8%	55.8%	44.1%
Lifetime mileage	8.6%	11.5%	19.0%	41.5%	33.5%
Number of cases	116	183	105	1060	1464

To reveal possible sources of missing values, logistic regression models were computed for the most important sleep-related background factors (sleeping time the previous night, time awake since sleep) and driving experience (lifetime mileage). The severity of driver injury, as might be expected, had a big influence on missing values (Table 1 and 2). Sex, age, and marital status were also significant predictors of missing values; the information was more often available for women, younger, and married participants. There were also some differences between teams that may indicate different levels of activity, although such an interpretation should be taken with caution. On the other hand, it is clear that a general yearly trend in the teams' activity exists: in the year 1991, just after a change of accident investigation method in 1990, there were fewer missing values compared to the following years. This might indicate more carefulness in data collection during the first year of the introduction of the new method and the adoption of routine procedures afterwards.

**Table 2.** Logistic regression models for predicting missing values in the variables time awake, sleeping time, and lifetime mileage (This table was not published in Study I).

	Time awake Odds Ratio (CI)	Sleeping time Odds Ratio (CI)	Lifetime mileage Odds Ratio (CI)
<b>INJURY</b> (ref. Not injured)	p<0.001	P<0.001	p<0.001
Light injury	2.69 (0.95-7.57)	1.58 (0.66-3.83)	1.18 (0.50-2.78)
Serious injury	6.07 (2.13-17.29)***	4.38 (1.81-10.57)***	2.36 (0.97-5.74)
Died	25.05 (9.85-63.69)***	19.18 (8.97-41.00)***	7.44 (3.63-15.23)***
<b>SEX</b> (ref. Female)	1.74 (1.29-2.36)***	1.71 (1.27-2.29)***	1.48 (1.08-2.01)*
<b>AGE</b> (ref. ≤25)	p<0.001	P<0.001	p<0.001
26-35	4.26 (2.72-6.68)***	3.46 (2.22)***	3.35 (2.11-5.32)***
36-45	2.32 (1.49-3.62)***	2.25 (1.45-3.49)***	2.41 (1.51-3.83)***
46-55	1.95 (1.26-3.01)**	1.91 (1.24-2.92)**	2.51 (1.59-3.95)***
56-65	3.25 (1.99-5.29)***	2.42 (1.50-3.90)***	2.24 (1.34-3.74)**
≥66	2.59 (1.73-3.89)***	2.67 (1.79-3.99)***	3.14 (2.05-4.82)***
<b>MARITAL STATUS</b> (ref. Married)	2.81 (2.12-3.74)***	2.91 (2.20-3.85)***	1.73 (1.30-2.30)*
<b>YEAR</b> (ref. 1991)	p<0.05	p>0.05	p<0.001
1992	1.90 (1.08-3.36)*		1.58 (0.85-2.96)
1993	1.32 (0.72-2.41)		1.46 (0.76-2.83)
1994	2.27 (1.25-4.09)**		2.11 (1.11-4.01)*
1995	2.05 (1.11-3.79)*		1.81 (0.92-3.55)
1996	1.47 (0.80-2.71)		3.32 (1.74-6.36)***
1997	2.16 (1.19-3.92)*		2.21 (1.15-4.26)*
1998	2.99 (1.65-5.45)***		3.39 (2.07-7.47)***
1999	1.96 (1.07-3.57)*		3.36 (1.77-6.39)***
2000	2.53 (1.39-4.61)**		3.08 (1.63-5.82)***
2001	2.12 (1.17-3.83)*		4.36 (2.31-8.23)***
<b>PROVINCE</b> (ref. Uusimaa)	p<0.001	P<0.001	p<0.001
Ahvenanmaa	8.59 (0.55-134.68)	6.62 (0.39-110.87)	18.25 (1.26-264.65)*
Häme	0.48 (0.31-0.74)***	0.46 (0.30-0.70)***	0.63 (0.39-1.01)
Central Finland	1.05 (0.60-1.84)*	0.77 (0.44-1.34)	2.06 (1.16-3.63)*
Kuopio	0.5 (0.27-0.93)*	0.43 (0.24-0.79)**	0.73 (0.37-1.42)
Kymi	2.53 (1.55-4.11)***	2.32 (1.42-3.82)***	6.53 (3.99-10.69)***
Lappi	0.70 (0.37-1.33)	1.00 (0.53-1.88)	2.64 (1.40-4.97)**
Mikkeli	1.86 (0.90-3.85)	1.19 (0.58-2.44)	2.06 (0.97-4.38)
Oulu	0.50 (0.32-0.82)**	0.48 (0.30-0.77)**	1.43 (0.87-2.34)
Pohjois-Karjala	1.52 (0.69-3.33)	0.93 (0.43-2.03)	2.05 (0.93-4.56)
Turku	0.33 (0.19-0.57)***	0.24 (0.14-0.41)***	0.55 (0.31-0.98)*
Vaasa	0.67 (0.40-1.10)	0.61 (0.37-1.00)*	0.88 (0.51-1.51)
Helsinki	1.75 (0.50-6.12)	1.47 (0.43-5.04)	6.55 (1.86-23.01)**
Pori	0.76 (0.45-1.30)	0.54 (0.32-0.91)*	4.40 (2.56-7.56)***

\* p<0.05, \*\* p<0.01, \*\*\* p<0.001

### Explaining falling-asleep accidents

A series of logistic regression models were computed to explain falling-asleep accidents in this data, or rather, the investigating team's decision that the major causal factor was falling asleep (Table 3). By gradually adding sleep-related variables, the sample size decreased due to missing values such that the third model included a subsample of 591 cases (40.4%), those having all values on major sleep-related variables (sleeping time last night, time awake, preaccident preventive action, and tiredness anamnesis, which refers to a physician's report of a driver's previous exhaustion or frequent tiredness). This procedure was aimed at explaining the teams' decisions first by means of fairly objective (and complete) data and, second, to test whether specific (and less reliable) sleep-related information influenced the sleep-related attributions.



**Table 3.** Logistic regression models for predicting falling-asleep accidents with an increasing number of fatigue-related predictors (Models 1 to 3). Unidimensional distributions of cases in each variable are also given.

	MODEL 1		MODEL 2		MODEL 3	
	%	Odds ratio (95% CI)	%	Odds ratio (95% CI)	%	Odds ratio (95% CI)
<b>DAY OF ACCIDENT</b> (ref. Thursday)	14.3	p<0.05		p>0.05		p>0.05
Friday	16.7	3.17 (1.41-7.11)**				
Saturday	11.6	2.19 (0.92-5.25)				
Sunday	13.1	2.69 (1.19-6.11)*				
Monday	15.6	2.08 (0.91-4.75)				
Tuesday	14.5	1.85 (0.79-4.31)				
Wednesday	14.1	0.96 (0.38-2.44)				
<b>SEX</b> (ref. Female)	23.7	p>0.05	26.5	p>0.05	24.9	p>0.05
Male	76.3	1.58 (0.93-2.67)	73.5		75.1	
<b>AGE</b> (ref. ≤25)	23.9	p<0.05	28.0	p=0.052	27.4	p>0.05
26-35	14.0	0.59 (0.30-1.17)	12.1	0.40 (0.13-1.20)	11.5	
36-45	15.2	0.86 (0.44-1.69)	16.3	0.98 (0.39-2.48)	17.1	
46-55	15.8	1.54 (0.84-2.81)	16.4	1.74 (0.75-4.04)	15.7	
56-65	10.5	1.26 (0.62-2.58)	9.9	2.18 (0.78-6.14)	10.3	
≥66	20.6	0.59 (0.29-1.23)	17.5	0.58 (0.19-1.72)	17.9	
<b>TIME OF ACCIDENT</b> (ref. 11:01-14:00)	18.5	p<0.001	17.4	p>0.05	18.1	p>0.05
14:01-17:00	24.0	2.58 (1.27-5.23) **	24.9	1.70 (0.67-4.31)	26.9	
17:01-20:00	15.8	2.72 (1.27-5.78)*	16.4	1.38 (0.48-3.94)	16.1	
20:01-23:00	9.4	0.64 (0.19-2.15)	8.7	0.24 (0.04-1.44)	8.8	
23:01-02:00	4.4	3.51 (1.25-9.91)*	4.3	2.38 (0.57-10.04)	3.7	
02:01-05:00	2.7	7.36 (2.62-20.63)***	2.1	4.12 (0.72-23.73)	2.2	
05:01-08:00	9.3	5.64 (2.43-13.06)***	11.0	1.32 (0.39-4.43)	9.5	
08:01-11:00	16.0	1.66 (0.71-3.90)	15.3	1.48 (0.48-4.58)	14.7	
<b>ROAD TYPE</b> (ref. Street)	9.4	p<0.001	9.9	p<0.01	10.5	p>0.05
Main road	48.6	17.51 (2.29-133.96)**	45.3	8.75 (1.05-72.73)*	42.5	
Main connecting road	10.9	11.84 (1.44-97.30)*	10.8	5.70 (0.61-53.02)	11.0	
Other highway	19.8	7.67 (0.97-60.86)	20.8	2.18 (0.24-19.62)	21.7	
Other	11.4	3.15 (0.32-30.76)	13.2	0.60 (0.04-8.50)	14.4	
<b>ACCIDENT TYPE</b> (ref. Other)	15.7	p<0.001	18.8	p<0.001	19.6	p<0.05
Head-on	43.5	12.46 (4.77-32.58)***	42.0	8.25 (2.80-24.28)***	38.1	6.84 (1.87-24.84)**
Intersection	19.0	0.005 (0.000-157633)	18.8	0.004 (0.00-2.6x10 <sup>7</sup> )	19.5	0.001 (0.000-7x10 <sup>8</sup> )
Running-off	21.8	12.43 (4.59-33.63)***	20.3	11.43 (3.60-36.24)***	22.8	5.50 (1.48-20.31)**
<b>ROAD CONDITION</b> (ref. Snow, Ice, Other)	35.4	p<0.001	14.9	p<0.001	15.6	p<0.01
Dry	48.8	15.43 (7.41-32.09)***	44.7	24.31 (8.63-68.46)***	46.2	24.12 (4.57-127.25)***
Wet	15.8	9.25 (4.06-21.10)***	15.0	16.74 (5.24-53.53)***	14.0	13.13 (2.14-80.66)***
<b>SLEEPING TIME</b> (ref. 7-8h)		NOT INCLUDED	22.3	p<0.001	21.2	p<0.01
Under 6h			8.4	10.37 (3.98-26.99)***	8.0	4.11 (1.18-14.26)*
6-7h			9.0	1.30 (0.49-3.58)	9.8	0.79 (0.22-2.83)
Over 8h			60.3	0.73 (0.34-1.57)	61.1	0.50 (0.18-1.40)
<b>PREVENTIVE ACTION</b> (ref. Yes)		NOT INCLUDED		NOT INCLUDED	48.7	p<0.001
No					51.3	5.13 (2.02-13.04)
<b>TIME AWAKE</b> (ref. Under 8h)		NOT INCLUDED		NOT INCLUDED	51.6	p<0.01
8-16h					43.7	2.21 (0.97-5.06)
Over 16h					4.7	8.05 (2.10-30.90)**
<b>TIREDDNESS</b>						
<b>ANAMNESIS</b> (ref. Not reported)		NOT INCLUDED		NOT INCLUDED	94.1	p<0.001
Reported					5.9	25.78 (8.22-80.83)
Number of cases		1452 (99.2%)		812 (55.5%)		591 (40.4%)
Number of falling asleep		148 (10.2%)		86 (10.6%)		61 (10.3%)
Model Specificity		98.4%		98.5%		98.3%
Model Sensitivity		30.4%		41.9%		55.7%
Model overall prediction		91.5%		92.5%		93.9%

\* p<0.05, \*\* p<0.01, \*\*\* p<0.001

In model 1, using the objective data, the highest odds ratios for falling asleep accidents were in the early morning (7.36 times higher than in the early afternoon), on main roads with reference to streets (17.51), in head-on (12.46) and running-off accidents (12.4) with reference to other types, and on dry (15.3) and wet road pavement (9.25) with reference to snowy, icy, and other difficult conditions. Including the variable of sleeping time the previous night into the regression model (Model 2) had a strong effect for under 6 hours (10.37 times higher than for a sleep duration of 7 to 8 hours), while time-of-day effect no longer reached significance. In Model 3, the variables preaccident preventive action, time awake, and tiredness anamnesis were significant predictors.

It is important to note that although the sensitivity (correct prediction of falling-asleep cases) was improved from Model 1 to 3, the percentage of falling-asleep cases remained approximately the same in each model (about 10% of all cases). This means that the teams' attribution of sleep-related causes was independent of the existence of specific sleep-related information in the computerized database.

### 7.2.2. Seasonal variation of falling-asleep accidents: a real phenomenon or teams' bias (Study II)

The full research question was: Is previously observed seasonal variation in the proportion of falling-asleep accidents a real phenomenon, or does it reflect a possible bias in the analyses and conclusions of the investigation teams?

The evaluation of the sample of the original investigation folders (N=101) showed that multidisciplinary investigation VALT teams are reliable when assessing the role of fatigue and sleepiness in fatal road accidents. In 84.1% of the accident cases, sufficient information was found to support the decisions made by the investigation teams (Table 4). In other words, the investigation teams adequately documented their decisions. According to the hypothesis, in 5 of the 16 unclear cases, some bias was suspected. For three of the summer cases, the teams noted falling asleep as the key event; however, for two of them, there was not much information, and in the other, it was very difficult to determine whether the cause of the accident was falling asleep or a sudden illness. For two of the winter cases, the teams noted faulty driving as the key event, although there also was enough information to suggest that falling asleep might have been the key event. In some of the cases, the teams expressed difficulty in determining the cause of the accident because an autopsy was impossible due to the severity of bodily injury, and consequently information about the possibility of an attack of sudden illness was lacking.

**Table 4.** Evaluation of the investigation teams' decisions.

	Clear	Probably good	Unclear	Total
Summer	36 (46.8%)	30 (38.9%)	11 (14.3%)	77
Winter	11 (45.8%)	8 (33.3%)	5 (20.8%)	24
<b>Total</b>	<b>47 (46.5%)</b>	<b>38 (37.6%)</b>	<b>16 (15.8%)</b>	<b>101</b>

### **7.2.3. Factors leading to falling asleep behind the wheel according to the teams (Studies II, III, and IV)**

This issue was in focus in all four studies using the VALT data, although the most attention was given to it in Studies II and IV.

According to the multidisciplinary teams original folders (N=101) the following risk factors contributed to 41 drivers falling asleep during the summer: long driving times, unusual physical activities, and partying and consuming alcohol on the night preceding the accident even though the drivers' BAC was zero at the time of the accident (Study II). For 13 drivers, the investigation teams reported recent problems of tiredness (four cases) or chronic problems with sleepiness (nine). Short-term tiredness was caused by too much work (two), stress (one), or the flu (one). All nine drivers with chronic problems of sleepiness had a tendency to fall asleep easily. For example, one driver had a history of falling asleep in the middle of a conversation. The other driver with similar problems had usually not been allowed by his wife to drive alone, although he was driving alone at the time of his accident, as were all the others.

In Study III, dealing with conscripts' accidents (N=47), risk factors included acute and residual fatigue due to military exercises, the flu, long driving times, short sleep durations, and the interaction between alcohol and sleepiness.

In the original folders (N=9) studied in Study IV, the following risk factors were found: short sleep duration, time-of-day effects, prolonged wakefulness, long driving times, long working day, a heavy meal before the trip, the level of warmth in the car, medicine taken for depression with sedative effects, and all passengers being asleep at the time of accident. Interestingly, in one case team members noted that the driver's lack of recollection of the accident supported the conclusion that he had fallen asleep.

### **7.2.4. Differences in discussions and conclusions between district courts and VALT in-depth investigation teams about whether a driver fell asleep or not (Study IV)**

The analysis of the original VALT folders showed that during the in-depth accident investigation process only two of the nine defendants accepted the possibility that they had fallen asleep and caused the accident; however, one of them denied this at a later stage of the investigation. In one case there was no information about the defendant's testimony concerning the possible cause of the accident, and in three cases the defendants could not remember anything. In two cases the defendants could not remember the accident, but were of the opinion that they had not fallen asleep. One defendant explicitly denied being tired prior to the accident.

The investigation teams were not always absolutely sure about the primary cause (key event) of the accident, and in some cases they rather listed a few possible causes and risk factors. Nevertheless, given the progress of the accident (e.g., no preventive action in any of the cases), the condition of the driver at the time of the accident (e.g., number of hours awake, duration of driving), the background factors (e.g., health history, mental problems, sleep disorders), the explanations, and the reasoning of the

investigation teams, we concluded that falling asleep was the most probable main cause of all nine accidents.

On the other hand, in the courts' summaries and decisions, falling asleep as a cause was not mentioned at all in four cases. In another four cases, there was extensive discussion of that possibility, but only one driver was charged under Article 63 of the RTA, which forbids driving while tired. In that case the court explicitly concluded that the defendant had negligently fallen asleep at the wheel and had caused the collision. Finally, in one case the court concluded that although the exact cause of the collision was undecided, it would not have made a difference with regard to the charge. The defendant was found not guilty in only one case, while all the other defendants were found guilty and given 60-80 day-fines. Only one defendant, who had caused an accident with six fatalities, received a suspended six-month prison sentence.

It is also interesting to note a difference in the "reasoning" between the VALT investigation team and the court decision in the example of case 5 in Study IV. The court reasoning and conclusion was that the defendant could have fallen asleep, since he had been awake for 20 hours before the crash, but on the other hand, this was not considered highly likely since he stopped and got out of the car at a petrol station only 8.5 kilometers before, and there were four passengers in the car. However, the VALT investigation team noted and stressed that all the passengers in the car were asleep. Obviously, it is unlikely that passengers who are asleep would prevent the driver from falling asleep in any way.

### 7.2.5. When Finnish courts find drivers guilty of fatigued driving (Study VI)

Two main issues are relevant here: the type of the incident and the driver's testimony. Driving incidents were predominantly accidents (92.5%), although some drivers (4.9%) were found guilty of fatigued driving because their vehicle was drifting on the road and endangering road safety (Table 5). Most of the drivers admitted the charge of fatigued driving by accepting the charge as a whole or a more specific charge of fatigued driving. Only 3.1% of the punished drivers officially denied being tired or falling asleep; however, four of the eight drivers that caused a fatal accident did so (Table 6).

**Table 5.** Type of fatigue-related offense.

	<i>N</i>	%
Single accident	562	81.0%
Head-on accident	41	5.9%
Rear-end accident	14	2.0%
Other accidents	25	3.6%
Drifting	34	4.9%
Fell asleep in a stopped car in the crossing	3	0.4%
Other driving incident	13	1.9%
Unknown	2	0.3%
<b>Total</b>	<b>694</b>	<b>100.0%</b>

**Table 6.** Drivers' testimony regarding the charge of fatigued driving.

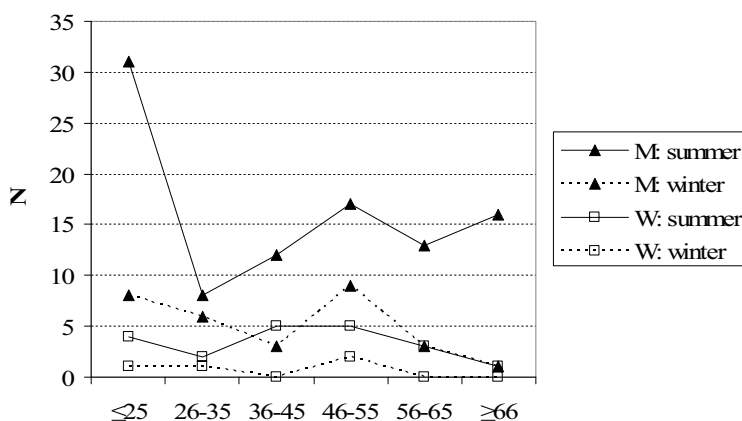
	<i>N</i>	%
Accepts the charge/decision by signing it (prosecutor)	469	67.6%
Admits the charge generally or specifically (district court or court of appeal)	85	12.2%
Admits to having fallen asleep	68	9.8%
Admits to being tired/drowsy/having a lack of sleep	44	6.3%
Denies falling asleep/being tired	15	2.2%
Admitted then denied	6	0.9%
No information (district court )	7	1.0%
<b>Total</b>	<b>694</b>	<b>100.0%</b>

### 7.3. Risk factors and driver groups at risk of falling asleep behind the wheel

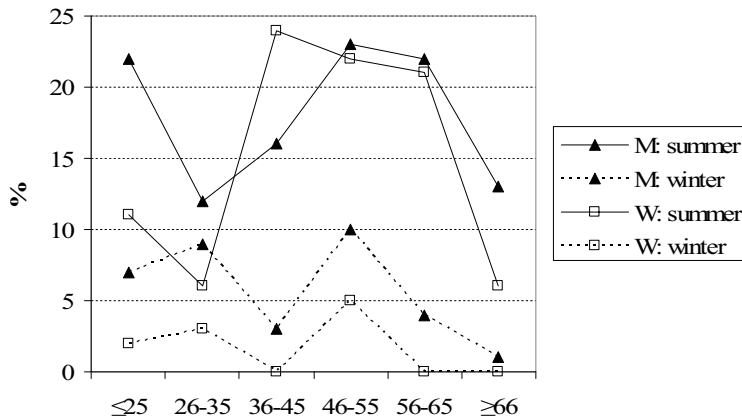
#### 7.3.1. Seasonal variation of falling-asleep fatal accidents: different driving populations at risk and changes in lifestyle factors (Study II)

The full research question was: Is the seasonality of sleep-related accidents related to different populations at risk, to changes in lifestyle factors including sleep habits, or to both?

With the exception of 26-35 year olds, men of all other age groups had a notable absolute and relative increase of sleep-related accidents in the summer (Figure 4 and 5). Young male drivers ( $\leq 25$  yrs), followed by the oldest group ( $\geq 66$  yrs), had the highest increase in the absolute number of sleep-related accidents between the summer and winter months, while the relative change was the highest for ages 56-65. Women showed similar trends. These results were supported by the results of a hierarchical log-linear analysis. A detailed analysis of 44 cases of summer afternoon falling-asleep accidents revealed that many drivers were engaged in unusual activities the day or night before the accident.



**Figure 4.** Number of falling-asleep accidents by season and by age, and sex (M=men; W=women) of drivers (N=1464).



**Figure 5.** Proportion of falling-asleep accidents by season and by age, and sex (M = men; W = women) of drivers (N=1464)

### 7.3.2. Military conscripts and the risk of fatigue-related accidents (Study III)

The questionnaire data showed that about one-third (35.9%) of conscripts had used personal cars to travel to or from the garrisons in the preceding two months. More than half of them reported driving while fatigued (a majority reported several occasions of such driving). The driving distance between the conscripts' homes and the garrison was shorter (t-test,  $t=3.198$ ,  $d.f.=242$ ,  $p<0.01$ ) for those using a personal vehicle ( $M=140.9$  km,  $SD=78.4$ km) than for those not using one ( $M=173.1$ km,  $SD=73.7$ ). However, there was no statistically significant difference in driving distance (from home to the garrison) between those who reported driving while fatigued and those who did not report such problems. In addition to those driving themselves, 41.6% of the conscripts rode at least occasionally as a passenger in a car driven by a fellow conscript.

Analysis of the fatality data showed that during 1991-2004, 137 conscripts were involved in 58 different fatal accidents leading to the death of 60 conscripts and to serious injury for 13 conscripts. Although the conscripts were responsible for 46 accidents (79.3%), 95% of all the conscripts' fatalities occurred in such accidents. In addition to the 57 dead conscripts, 12 other civilians died, increasing the overall number of fatalities to 69 in accidents caused by conscripts.

More than half (31 of 60) of the conscripts died in army-related accidents, with one-third (20 of 60) killed while traveling from the garrisons. Falling asleep is a major cause of the conscripts' accidents, regardless of whether the driving was army related (34.8%) or occurred on leave (36.4%). Haste, which is typically accompanied by speeding, is the second largest factor behind army-related accidents (26.1%), while drunk driving (22.7%) and suicides (18.2%) are typical of accidents occurring on leave. The conscripts were the most likely to fall asleep when traveling home from the garrison (42.9%). On the other hand, according to the investigation teams, in three

cases drivers' army-related fatigue contributed to causing an accident, although the accidents actually occurred while the conscripts were on leave.

Most of the on leave accidents occurred over the weekends (81.8%), while 42.9% of the accidents occurring on the way from the garrison happened on Fridays. On leave accidents in which the conscript fell asleep occurred mostly between 0.00-6.00 (62.5%). On the other hand, while driving from the garrison in the afternoon, the conscripts fell asleep quite often. The accidents caused by falling asleep were either head-on or single accidents.

### 7.3.3. Drivers using a breathalyzer (Study V)

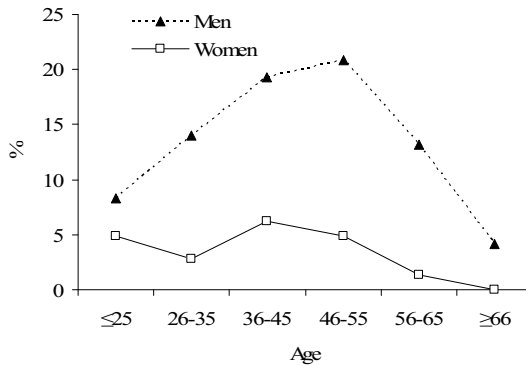
According to the result of the drivers' survey, up to 14.5% of Finnish households have a breathalyzer: 11.5% (N=129) of the respondents in this study own a breathalyzer, and an additional 3% reported that somebody else in the household owns it.

Not only do fewer women own a breathalyzer compared to men, when they do own one they also use it less often than men (Table 7). Age is also a significant predictor of breathalyzer ownership and usage (Table 7). Men aged 36-56 are the group with the highest proportion of breathalyzer ownership and usage (Figure 6). Overall, 24% of drivers owning a breathalyzer do not use it.

**Table 7.** Logistic regression models predicting the ownership and usage of breathalyzers. (This table has not been published in Study V).

	Ownership (129 of 1121)		Usage out of those who own one (98 of 129)	
	% of 1121		% of 129	
<b>SEX</b> (ref. Women)	46.6	<b>p&lt;0.001</b>	24.0	<b>p&lt;0.01</b>
Men	53.4	3.25 (2.12-4.99)	76.0	4.22 (1.51-11.77)
<b>AGE</b> (ref. ≥66)	13.6	<b>p&lt;0.01</b>	5.4	<b>P&lt;0.05</b>
≤25	17.8	2.32 (0.93-5.79)	13.2	4.50 (0.60-33.65)
26-35	18.5	2.81 (1.16-6.86)*	16.3	4.48 (0.64-31.40)
36-45	16.1	4.38 (1.83-10.50)**	20.2	5.75 (0.83-39.65)
46-55	16.3	4.42 (1.87-10.49)**	22.5	5.88 (0.87-39.67)
56-65	17.8	3.76 (1.59-8.89)**	22.5	1.01 (0.18-5.61)

Of those who reported using a breathalyzer, 78.6% use it the following day/morning after an evening/night when they were drinking. That is much more common than using a breathalyzer after acute drinking: just after drinking a few portions of alcohol (18.4%) or when driving back home after being out in the evening (6.1%). Compared to the rest, middle-age (36-56) men use a breathalyzer more often (32% vs. 14%) after acute drinking ( $\chi^2=3.89$ , d.f.=1,  $p<0.05$ ).

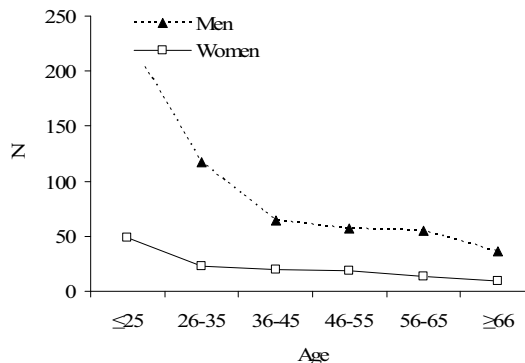


**Figure 6.** Percentage of drivers who own and use a breathalyzer by age and sex.

Additionally, all nine importers that were contacted responded to our inquiry. The estimated number of devices delivered during 2006 in Finland was almost 50,000, equaling appr. one percent of the population and one and a half percent of driver's license holders (Statistics Finland, 2007).

### 7.3.4. Drivers punished of fatigued driving (Study VI)

The drivers were predominantly men (80.7%) and of young age; men 35 years old and younger represented 50% of all convicted drivers (Figure 7). In the available documentation, there was a large variability in reporting details about the profession of the drivers. For 5% of the drivers, the profession was unknown. Of the rest, we managed to identify the following large distinct groups: 17.7% of the drivers were students, 8.8% were professional drivers, 7.1% were retired, and 2.1% were military conscripts. The rest were difficult to classify, but roughly 40% of the drivers had low education. At least 41 (70.1%) of the 58 professional drivers were driving on duty; nine truck drivers had broken the rules about duty and rest hours.



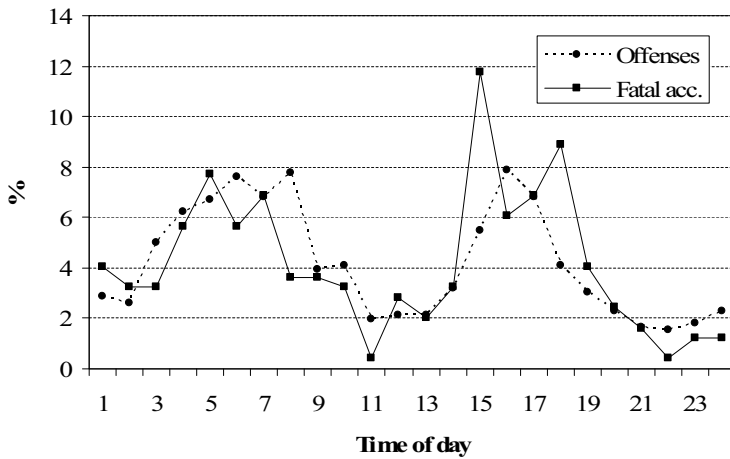
**Figure 7.** Number of fatigue-related offenses by sex and age of drivers (N=694).



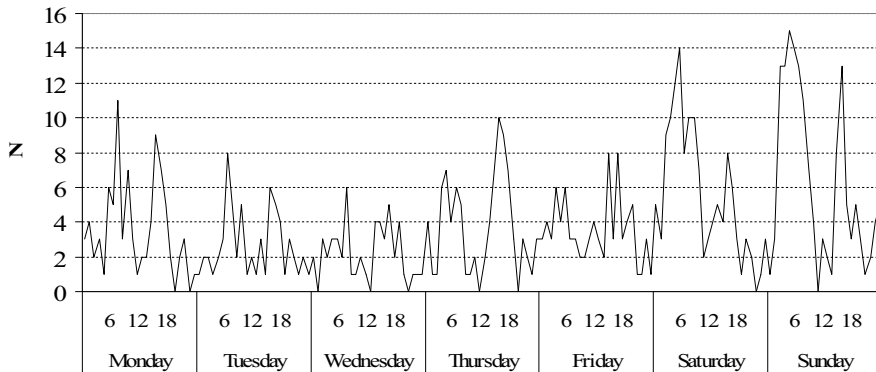
### 7.3.5. Time-of-day and seasonal pattern of fatigue-related driving offenses (Study VI)

A clear overall time-of-day effect can be seen in Figure 8, while a distinct time-of-day and weekday pattern is depicted in Figure 9. The youngest drivers had their fatigue-related incidents predominantly at night, especially during weekends: 62.5% of the incidents for drivers up to 25 years old occurred between Friday and Sunday.

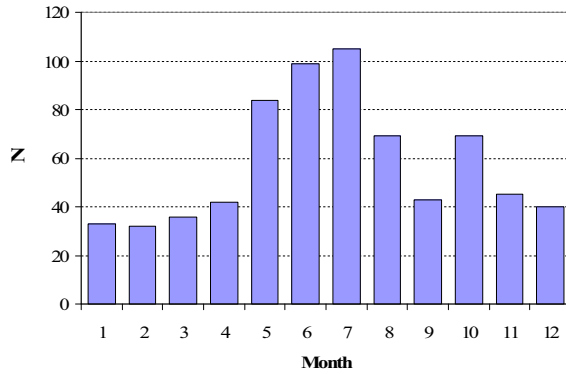
The data also shows a clear seasonal effect (Figure 10). After a sharp rise from April to May, the peak of fatigue-related offenses is reached in July. Although this seasonality is more or less visible in each age group, a summer increase in the youngest drivers' ( $\leq 25$  yrs) offenses is evidently responsible for the clear seasonality of the whole data set.



**Figure 8.** Time of day proportions of fatigue-related offenses (N=658, years 2004-2005, Study VI) and falling-asleep fatal accidents (N=247, years 1991-2001, VALT).



**Figure 9.** Time of day distribution of fatigue-related offenses (N=658).



**Figure 10.** Monthly distribution of fatigue-related offenses (N=694).

## 7.4. Finnish courts and fatigued driving

Studies IV and VI describe the application of the part of the Finnish traffic law that forbids driving while tired.

The results of Study IV show that although VALT multidisciplinary investigation teams concluded that all nine drivers fell asleep and caused an accident, in court falling asleep as a cause was not mentioned at all in four cases. However, the ruling in one case was very indicative for understanding how the article that forbids driving while tired can be interpreted in practice. This particular court concluded that although the exact cause of the collision was undecided, it would not have made a difference with regard to the charge. In other words, proving that the driver fell asleep would not make any difference to the charge of causing the accident, i.e., endangering traffic safety.

Similarly, in Study VI, the results indicate that in the case of an accident or drifting, a charge of fatigued driving can be rather seen as an explanation for the action than as a more serious charge.

## 8 GENERAL DISCUSSION

### 8.1. The prevalence of fatigue/sleepiness while driving

There is not much information about the prevalence of the problem of fatigue and sleepiness and its contribution to accident causation among the Finnish car driving population. There are some previous studies in Finland, but concerning only fatal crashes (Partinen, 1999; Partinen & Sulander, 1999; Summala & Mikkola, 1994), professional drivers (Häkkinen & Summala, 2000a, b), and in some studies the topic was only partly accessed (Martikainen et al., 1992; Sallinen, Härmä, Kalimo, & Hakanen, 2000) or the study was done a long time ago (Häkkinen & Jääskeläinen, 1970). Further problems arise from the fact that the only database that provides information about the causes of the accidents is the database of fatal road accidents studied in depth (VALT). For example, the national Finnish road accident database of injury accidents (based on police investigation reports) does not contain information about the causes of the accidents, only the results of alcohol testing.

According to VALT multidisciplinary investigation teams, 8.3% of all fatal accidents from 1991 to 2001 were caused by drivers falling asleep (Study II). In a sample of nonprofessional nonintoxicated drivers, 10.1% of the drivers fell asleep and caused a fatal accident, while fatigue was a contributing factor in an additional 5.2% of the cases (Study I). This is a slightly higher proportion compared with VALT data from 1984 to 1989 showing that 6.2% of nonintoxicated car drivers fell asleep, while fatigue was a contributing factor in an additional 2% of cases (Summala & Mikkola, 1994). A similar increasing trend from 1991 to 2001 can be seen in Figure 3. However, this increase does not necessarily mean an increase in exposure to fatigue while driving or even in the prevalence of fatigue in fatal crashes. It is possible that VALT teams are giving more attention to fatigue due to increased discussion and research in this area.

Study VI, to our knowledge, is the first study that analyzes the circumstances of fatigue-related traffic offenses from a large set of data. Previous studies reported only on a single accident (Rajaratnam & Jones, 2004) or a few cases (Desai, Ellis, Wheatley, & Grunstein, 2003). The strength of the data is that the contribution of fatigue to accident causation has been “confirmed” on several levels: police officer investigation, court rulings, and driver testimony. Only 3.1% of the convicted drivers in our study officially denied being tired or falling asleep. In 2004 and 2005 the total number of drivers convicted because of a fatigue-related accident involving personal injury, as identified in the present study, was 118. Given that the number of accidents involving personal injuries in 2004 was 6,767 and in 2005 was 7,002 (Statistics Finland, 2007), a rough estimation is that less than 1% of injury accidents were related to fatigue. This is obviously an underestimation. However, this is still a respectable proportion given that these drivers were actually punished on the basis of fatigued driving, in contrast to official statistics from other countries based on checklists of accident causes included on police accident reporting forms.

Additionally, results from recent (non-peer-reviewed) study (Radun & Radun, 2008), using the same survey data as in Study V show that 19.5% of the surveyed

drivers had fallen asleep while driving at some point during their driving career. A slightly smaller proportion of the drivers (15.9%) reported being close to falling asleep or having difficulties staying awake while driving during the last 12 months.

Several different types of data were reported in this thesis, including data from in-depth investigations of fatal accidents, fatigue-related traffic offenses, and drivers' surveys. When these results are taken together with previous research on professional drivers, it is more than clear that fatigue/sleepiness problems while driving are common among the Finnish driving population. To get a better picture, however, it would be highly valuable to have information on causal factors for injury accidents investigated by police imported into the national Finnish road accident database of injury accidents. We are not fully aware of the reasons why the Finnish traffic police do not have a checklist of accident causes on police accident reporting forms. Unfortunately, this is a common situation within the EU (Horne & Reyner, 1999).

## **8.2. Recognizing fatigue/sleepiness problems in traffic**

Recognizing an accident as sleep related is a central problem when dealing with fatigue and sleepiness problems while driving. An adequate identification of the risk factors and risk groups is necessary to be able to conduct safety campaigns aiming at the reduction of sleep-related accidents. Prosecuting drivers on the basis of tiredness/sleepiness also depends on the validity and reliability of the accident investigation process. The work of VALT multidisciplinary investigation teams investigating fatal accidents was in focus in a series of studies included in this thesis. The results show that these teams can be considered reliable when assessing the role of fatigue and sleepiness in accident causation. Despite facing considerable difficulties when investigating fatal accidents, the teams collect a considerable amount of information and in most cases provide a sufficient explanation as to why certain risk and causal factors were considered important or crucial.

VALT investigation teams' decisions about sleep-related accidents could be explained (predicted) by well-known factors identified in earlier experimental and accident studies, such as time of the accident, sleeping time prior to the accident, time awake prior to the accident, and no signs of any preventive action to avoid the accident (Study I). Although in this study certain reservations about the teams' work were expressed, especially regarding the attribution of causal factors during favorable driving conditions, the important finding was that the teams' attribution of sleep-related causes was independent of the availability of specific sleep-related information in the computerized database. This suggests that teams had collected possible important sleep-related information regardless of whether they considered fatigue/sleepiness as a possible cause in the investigation process. This is indeed as it should be: "All sections in the forms are filled regardless of whether the item in question has an effect on the origin of the accident or its consequences. This secures the baseline comparison data for further research" (Salo et al., 2006, p. 31).

In Study II, a hypothesis that the teams' attribution of sleep-related factors might be biased when they investigate fatal accidents that happened during favorable driving conditions was explicitly tested. It was hypothesized that the teams might be more

likely to assume and thus search for external causes in wintertime accidents (when road and weather conditions are very often adverse) as opposed to summer accidents (when road conditions are good, it may follow that fatigue or falling asleep is the favored explanation). Although the employed methodology cannot be regarded as fully reliable, the fact that we discarded our hypothesis shows a possible lack of bias. The results suggest that the investigation teams adequately documented and explained their decisions concerning falling-asleep accidents that happened during favorable driving conditions and that previously observed seasonality is a real phenomenon, not a result of a bias of the teams. Furthermore, investigation teams employ reasonable risk factors and explanations when attributing the cause of the accident to falling asleep (Studies II, III, and IV).

Although we had some reservations in the beginning about the work of the investigation teams, we did not find sufficient evidence to allow strong criticism. The teams passed a test of independent re-evaluation of falling-asleep cases, as they did the re-evaluation of suicide cases (Ohberg, Penttilä, & Lonnqvist, 1997). Of course, this does not imply that further research will not identify possible shortcomings in the teams' work. Focusing on the decision-making processes of these teams might provide valuable information.

The results of Study IV show clear differences between VALT teams and Finnish district courts in discussions on the fatigue contribution to a fatal accident. Since VALT teams investigate fatal accidents for safety purposes only, they obviously have more freedom than the courts when deciding, for example, whether a particular driver fell asleep or not. Therefore, the courts' discussions and conclusions have to be more cautious and based on facts rather than on circumstantial evidence. However, since there is no "fatigue/sleepiness detector" that would reliably show that a driver fell asleep and as it is unlikely that an eyewitness would have actually seen the driver asleep, the case against a defendant has to be built around circumstantial evidence and background information. Such evidence would, for example, include possible pre-accident drifting, a history of sleep problems, a recent lack of sleep, and accident characteristics typical for sleep-related accidents (e.g., no preventive action). Most of the time this type of evidence is not easy to obtain, especially because there is no reason for a defendant to provide information that would be of a self-incriminatory nature (e.g., being without sleep for 24 hours). However, a driver is more likely to report such information to a VALT team, knowing that such information is not going to be used against him in court. On the other hand, drivers punished on the basis of fatigued driving seldom actually object to such an accusation and conviction simply because the final punishment remains quite similar (Study VI). Only in more serious accident cases do defendants more often deny falling asleep or being tired, possibly because in doing so they avoid taking the responsibility for harming other people. It is of course easier to admit to falling asleep when your car goes off the road and nobody is hurt than when your car drifts into the opposite lane, crashes into another vehicle, and somebody is seriously injured or even dies. Nevertheless, some drivers might admit to falling asleep just after the accident while they are in shock and are not thinking about possible legal consequences; however, they might deny this later in court (Studies IV and VI).

In summary, it is indeed very difficult to obtain strong evidence showing that a driver fell asleep or that he was impaired due to fatigue. Defendants are not under any obligation to provide self-incriminatory information that might be crucial to making such a decision. In a case when an investigating police officer suspects that the driver has fallen asleep, it is crucial that all important information is collected in the early investigation phase.

### **8.3. Risk factors and risk groups**

The main finding regarding risk factors and risk groups is that during the summer months, especially during the afternoon, the risk of falling asleep while driving is increased (Studies II and VI). The absolute and relative increases in sleep-related fatal accidents during the summer months cannot be explained only by different amounts of driving between seasons. Although accidents in general are more frequent during the summer months, the summer peak of all injury accidents in Finland is not as obvious as for cases of fatigue driving (Radun & Radun, 2008). Therefore, it is unlikely that the increase in fatigue-related incidents and accidents occurs only because of the general increase in all accidents.

Following the detailed analysis of the VALT investigation folders, it was proposed that lifestyle factors, including driving and sleeping habits, play an important role in the origin of this seasonality (Study II). More frequent activities during the summer months, such as long periods of driving, unusual physical activities, partying, and short sleep duration, all contribute to increased tiredness and sleepiness. Age and sex differences are also notable. This seasonal pattern was also evident in fatigue-related traffic offenses (Study VI), especially among the youngest drivers ( $\leq 25$  yrs). A similar seasonal trend in self-reported instances of falling asleep while driving was recently reported (Radun & Radun, 2008).

In conclusion, any safety campaign aiming at reducing sleep-related accidents should take into account the season-related risks for that kind of accident. Although in Study II this seasonality of sleep-related accidents was also discussed in the context of the seasonality of the reported sleep dissatisfaction of the general Finnish population, the data unfortunately did not allow an examination of any direct relationships between seasonal changes in day length (daylight hours), increased sleepiness, and higher accident risk. Only future studies combining self-reported sleep quality across the year, detailed driving exposure, and involvement in non-fatal accidents (or near misses due to increased sleepiness) will provide more insight concerning the seasonality of sleep-related accidents.

In Study I, information about drivers' recent chronic problems with fatigue/sleepiness was the best predictor (OR=25.78) of investigation teams' decisions that falling asleep was the main cause of the accident. However, certain circular reasoning might exist here, i.e., it is difficult to know whether that particular factor contributed to falling asleep or whether the teams simply concluded that the driver fell asleep because of his/her recent problems with sleepiness/fatigue. Nevertheless, a detailed analysis of the sample of the teams' original folders in Study II revealed that the nine drivers with chronic sleepiness problems all had had a tendency to fall asleep

easily. Obviously, they were aware of their condition and probably had previously experienced sleepiness-related problems while driving. As noted before, one of these nine drivers had usually been restricted by his wife from driving alone. In line with this, as Powel et al. (2007) have shown, the number of self-reported sleepy near-miss accidents predicts the occurrence of an actual accident. As hypothesized in Study II, it may be that drivers who are aware of their problems with sleepiness avoid driving at night and during darker winter afternoons when they feel more endangered, and more often drive in brighter and clearer summer afternoons when they feel safer. To my knowledge, no study has been reported on the detailed driving exposure of drivers with long-term sleepiness problems. Obtaining their detailed driving exposure, countermeasures, and coping skills would be of great interest.

The results of Studies III and VI suggest that Finnish military conscripts are at high risk of fatigue-related accidents. Driving home from the garrison after a tough military training session is especially dangerous. Even if the average driving distance between conscripts' homes and the garrison (140 km) cannot be considered as highly fatigue inducing as such, it is, however, sufficiently long for already fatigued conscripts to fall asleep. For them, the combination of the pre-trip level of fatigue, time-of-day effects, and driving duration unfortunately proved fatal. Therefore, regardless of the driving distance conscripts should not be allowed to leave the garrison and start driving in a state of increased fatigue/sleepiness, which is typical after the forest camps. On the other hand, conscripts should be educated that while on leave overactivity (e.g., partying, heavy drinking) in an attempt to compensate for the time spent on duty can result in an additional sleep debt and increase the risk of falling asleep while driving. They should also be informed that even moderate drinking while on leave together with their residual army-related fatigue or accumulated sleep debt can be an extremely dangerous combination in traffic.

In Study V, the additive and interactive effects of increased sleepiness and even small amounts of consumed alcohol were discussed in the context of drivers using a breathalyzer. A relatively high number of drivers owning and using a breathalyzer indicates that many drivers are obviously more focused on not breaking the "magic" line of 0.05% BAC than being concerned about driving impairment. Obviously the safety message "do not drink and drive" is "translated" by these drivers as "I can drink and drive if I make sure I do not break the law." This is especially true for drivers who use a breathalyzer just after acute drinking when they can forget, if they knew in the first place, about the dangerous combination of sleepiness and even low BAC. On the other hand, drivers using a breathalyzer in the morning after a night of heavy drinking might also disregard the residual sedative effects of alcohol. Similarly, in Study II, eight out of 41 drivers who fell asleep and caused a fatal accident during a summer afternoon had been partying and consuming alcohol on the night preceding the accident, although their BAC was zero at the time. Therefore, it is recommendable to raise public awareness about the additive and interactive effects of even low BAC and sleepiness, as well as about the residual effects of alcohol.

In this thesis, as in many previous studies, the age and sex of drivers were repeatedly identified as predictors of fatigued driving. Women are less often (both absolutely and relatively) involved in sleep-related fatal accidents (Studies I and II) and have less fatigue-related offenses (Study VI). Data from our recent study also

shows that men report falling asleep while driving 2.5 times more often than women (Radun & Radun, 2008). Unsurprisingly, young male drivers proved to be one of the riskiest groups for falling asleep while driving. They are absolute leaders in number of the sleep-related fatal accidents and fatigue-related traffic offenses. As mentioned before (section 3.3.2.), several, especially lifestyle, factors are typical of young male drivers. The possible relation between involvement in fatigue-related driving incidents and season-related lifestyle changes needs further research attention.

The time-of-day pattern of fatigue-related incidents while driving is clear in the data presented in the thesis. There is a striking similarity in time-of-day distribution between falling-asleep fatal accidents investigated by VALT multidisciplinary investigation teams and fatigue-related road traffic offenses prosecuted by police and the courts (Figure 8).

## **8.4. Fatigue and the law**

If there were a reliable device capable of detecting the “true” level of fatigue/sleepiness, legislators worldwide would, without any doubt, make fatigued driving a criminal offense. Despite many methodological problems, including the inexistence of such a fatigue/sleepiness “detector,” scientific evidence strongly suggests a causal relation between sleepiness and human performance. The effects of sleepiness on performance, including driving performance, have been effectively shown by comparing the effects of prolonged wakefulness and alcohol (e.g., Dawson & Reid, 1997).

Given that fatigue and sleepiness effects are often compared with alcohol, here is a similar comparison, although it might be considered somewhat controversial. It is well known that when intoxicated, some individuals might do things that they would never do while sober (it is irrelevant here whether this happens because of alcohol-related chemical reactions in the brain or because of the strong belief, present in European cultures, that alcohol acts as a general disinhibitor). Some individuals might, for example, become overconfident in their skills and underestimate risks, and thus attempt various dangerous acts; driving a vehicle might seem a “piece of cake” for such people. Despite having impaired judgment, drunk drivers are harshly punished on the basis of prior fault. On the other hand, drivers in a state of extreme fatigue/sleepiness maintain a sufficient level of decision-making skills and are able to estimate the risks of continuing to drive in such a state. Compared with drunk drivers, fatigued drivers receive significantly lower penalties. Summarizing this comparison, “voluntarism” in risk taking between drunk and fatigued drivers seems disproportionately sanctioned by law. Why? In my opinion, going back to the beginning of this chapter, it is simply because we have a breathalyzer for detecting BAC and no equivalent instrument for detecting the level of fatigue/sleepiness. From the point of view of science and the controversial moral comparison mentioned above, someone might ask whether drivers who fall asleep while driving deserve to be punished equally, if not more harshly, to drunk drivers.

How, then, without a fatigue/sleepiness “detector” can we detect fatigued drivers and sanction them appropriately? In Study IV, it was examined on what basis



multidisciplinary investigation teams concluded that the nine fatal accidents selected were caused by drivers falling asleep. From the point of view of previous scientific research, it seems that teams base their decision that falling asleep was the main cause of an accident on reasonable risk factors and explanations. Despite the fact that these teams investigate fatal accidents for safety purposes only, similar experts might provide valuable information for the court when discussing similar cases. Using such “expert evidence on the level of fatigue” at trial has already been suggested (Jones, Dorrian, & Dawson, 2003). For example, in the UK, in the *R vs. Gary Neil Hart* case a sleep expert “presented evidence concerning criteria that the jury could use to assist them in determining whether Hart fell asleep or not” (Rajaratnam & Jones, 2004).

However, there is an obvious problem of the cost effectiveness of using such multidisciplinary teams or experts. It is completely out of the question that such teams would investigate any but the most serious (fatal) accidents. Otherwise this would be enormously expensive and practically impossible; however, investigating only fatal accidents would leave many drivers responsible for non-fatal accidents unprosecuted. Nevertheless, if only fatal accidents are investigated by such teams, falling asleep might be taken as an aggravating circumstance. This approach is similar to Maggie’s law, which incorporates fatigue in connection with fatal accidents. However, in this case, many would argue that such a law would have only the purpose of punishment; it would not have any preventive purpose because it is very unlikely that drivers would avoid fatigued driving because of the possibility that fatigue could be taken as an aggravating circumstance if they happened to cause a fatal accident. Especially from the perspective of traffic safety, the law should have primarily a preventive role.

In conclusion, it seems that evidence provided by multidisciplinary teams or similar experts might be valuable in court when discussing a possible fatigue/sleepiness contribution to accident causation, but there are many practical and legal issues that might be too difficult or even impossible to implement. While we wait for the invention of reliable metrics and instruments for fatigue/sleepiness detection, more effort should be invested in raising public awareness about the dangerousness of fatigued driving and educate drivers on how to recognize and deal with fatigue and sleepiness when they ultimately occur.

## **8.5. Limitations of the studies**

Before offering concluding thoughts and some practical countermeasures, I would like to point out the limitations of the present thesis that I am aware of. Some of them are a direct consequence of the materials used, others originated from inadequate methodology. Some interpretations and conclusions therefore may face some criticism.

In several studies (I-IV) we used the original investigation folders of multidisciplinary teams (VALT); however, it is difficult to know whether the teams collected and recorded all relevant information. In particular, there is no guarantee that all available information from the original folders was imported into the VALT computerized database, which was also used in the same studies. Nevertheless, the VALT data has been widely used “in research, education, training, reporting,

statements, policy making and in other traffic safety work in Finland” (Salo et al., 2006, p. 36). Many peer-reviewed publications based on the VALT data give a certain level of credibility of the VALT method and collected data. Various topics and drivers’ groups were investigated using this data. For example, studies on older drivers (Hakamies-Blomqvist, 1993), young drivers (Laapotti & Keskinen, 1998), suicide cases (Hernetkoski & Keskinen, 1998; Ohberg et al., 1997), studies focused on accidents involving bicyclists (Räsänen & Summala, 1998) or truck drivers (Häkkinen & Summala, 2001), and finally studies examining risk factors such as medical conditions (Rainio, Sulander, Hantula, Nuutinen & Karkola, 2007; Tervo et al., 2008) or fatigue (e.g., Summala & Mikkola, 1994).

Similarly, it is unknown whether the summaries of the district courts and courts of appeal always reflected the whole court process in sufficient detail (Studies IV and VI). Nevertheless, it can be assumed that the most important information on which the final decision was based was adequately recorded in the court documentation. On the other hand, some prosecutor decisions included no proper explanation about why the drivers were punished of fatigued driving (Study VI). The main problematic issue in Study VI is that the number of drivers who have been charged but not punished on the basis of fatigue is unknown.

In Study II, only one principal researcher (a traffic psychologist) re-evaluated the investigation teams’ decisions. Obviously, this cannot be regarded as a fully reliable scientific method. Nevertheless, as noted before, the fact that we discarded our hypothesis shows that, possibly, we were not biased in our analysis.

Study IV is a case study with a qualitative rather than quantitative analysis, which raises issues of the generalizability of the findings. However, in this case, I believe such an approach has brought valuable findings and raised new questions, especially when considering them in the context of the results obtained on a large sample of drivers convicted of fatigued driving (Study VI).

When planning Study V, we failed to predict that so many Finnish drivers own a breathalyzer. Because a small number of such drivers was expected, this issue had a minor part in the survey, which had a limited number of related questions. After the data collection and preliminary results it became clear that this issue deserves much more attention. Nevertheless, the value of this study remains since it is, to our knowledge, the first study that raises the possible safety implications of increased breathalyzer use.

## **8.6. Concluding remarks and (safety) recommendations**

There is no doubt that fatigue and sleepiness problems while driving are common among the Finnish driving population. Data from several different sources confirms that.

Despite difficulties in recognizing fatigue-impaired drivers and the fatigue/sleepiness contribution to accident causation, the Finnish police and courts somehow manage to punish on average one driver per day under the article that forbids driving while tired. However, as we previously discussed, the application of such a law probably has only a symbolic value since, in our view, it is mostly used as

an explanation for the action (accident, drifting) rather than as an additional or more serious charge. Therefore, one may ask how large a preventive role this specific part of the law has.

On the other hand, I am quite skeptical about the effectiveness of the in-car fatigue detection and alerting devices which are slowly coming on the market. If such devices leave the final decision of whether to continue driving or not to the driver, they might even be counterproductive, as Horne and Reyner (2000) correctly recognized. In cases where such devices take control of the car away from the “fatigued” driver, the possibility of false detections must be minimal (read: zero). Unfortunately, in my opinion, we are far away from developing such devices, even if they are taking real driving performance (e.g., drifting) into account.

It seems that education and safety campaigns are the only available countermeasures, especially for non-professional drivers. I completely agree with Horne and Reyner (1999, p. 294), who called for heightening “public awareness, greater employer responsibility, and better education of drivers about sleep-related vehicle accidents.”

Educating high-risk driver groups is the obvious choice. In this thesis, several such groups are identified: men in general, especially young male drivers, including military conscripts; the elderly, who are at risk especially during afternoon hours and the summer; those drivers who drive during the late night and early morning hours; professional drivers who break the rules about duty and rest hours; drivers with a tendency to fall asleep easily; and possibly drivers who use a breathalyzer.

Creating broad public disapproval of fatigued driving (Flatley & Reyner, 2000) is extremely important for the prevention of such incidents and accidents. Yes, we do have a law that forbids fatigued driving but, in my opinion, many drivers are either not aware of it or they intentionally or unintentionally break it on a daily basis. We should help them to help themselves.

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