UNIVERSITY MEDICAL DISSERTATIONS


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INDICATORS AND PREDICTORS OF SLEEPINESS

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Blessings on him who invented sleep. It covers a man all over, thoughts and all, like a cloak. It is meat for the hungry, drink for the thirsty, heat for the cold and cold for the hot. It makes the shepherd equal to the monarch and the fool to the wise. There is but one evil in it and it is it resembles death, since between a dead man and a sleeping man there is but little differences.

- Miguel de Cervantes (1547-1616)

To Annika, a fantastic woman, and all the kids

Daniel
Emanuel
Jakob
Nils
Simon
Sofie
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ABSTRACT

Sleep is a basic need as important as physical fitness and good nutrition. Without enough sleep, we will create a sleep debt and experience sleepiness. Sleepiness can be defined as the inability to stay awake, a condition that has become a health problem in our 24-hour-7-day-a-week society. Estimates suggest that up to one-third of the population suffers from excessive sleepiness. Among other interactions, sleepiness affects our performance, increasing the risk of being involved in accidents. A considerable portion of work related accidents and injuries are related to sleepiness resulting in large costs for the individuals and society. Professional drivers are one example of workers who are at risk of sleepiness related accidents. Up to 40% of heavy truck accidents could be related to sleepiness. A better knowledge about reliable indicators and predictors of sleepiness is important in preventing sleepiness related accidents.

This thesis investigates both objective and subjective indicators of sleepiness, how these relate to each other, and how their pattern changes over time. The indicators investigated were electroencephalography, heart rate variability, simple reaction time, head movement, and subjective ratings of sleepiness (Study I-IV). In Study V, a questionnaire study was conducted with professional drivers in northern Sweden. This study mainly deals with predictors of sleepiness.

When subjects were sleep deprived both objective and subjective ratings indicated a rapid increase in sleepiness during the first hour of the test followed by a levelling off. This change in pattern was evident for all the indicators except heart rate and heart rate variability. On the other hand, HRV was correlated with the increase of EEG parameters during the post-test sleep period. The changes in pattern of the indicators included in the thesis are analysed in the perspective of temporal patterns and relationships. Of the tested indicators, a subjective rating of sleepiness with CR-10 was considered to be the most reliable indicator of sleepiness.

Of the investigated predictors of sleepiness, prior sleep habits were found to be strongly associated to sleepiness and the sleepiness related symptoms while driving. The influences of driving conditions and individual characteristics on sleepiness while driving were lower.

A multidisciplinary approach when investigating and implementing indicators and predictors of sleepiness is important. In addition to their actual relations to the development of sleepiness, factors such as technical and practical limitations, work, and individual and situational needs must be taken into account.

Key words: Karolinska Sleep Scale (KSS), Category-Ratio Scale (CR-10), sleepiness, sleep, driving, indicator, sleep debt, heart rate variability, electroencephalography (EEG), head movements, performance, truck drivers, sleep habits, predictor
LIST OF ORIGINAL PUBLICATIONS

I. van den Berg J, Neely G, Nilsson L, Knutsson A, Landström U.
Eeg and subjective ratings of sleep deprivation.
Sleep Medicine 2005;6(3):231-240.

II. van den Berg J, Neely G, Wiklund U, Landström U.
Heart rate variability during sedentary work and sleep in normal and
sleep-deprived states.

III. van den Berg J, Neely G.
Performance on a simple reaction time task while sleep deprived.
Perception and Motor Skills 2006; Accepted.

IV. van den Berg J.
Sleepiness and Head movements.
Industrial Health 2006; Accepted.

V. van den Berg J, Landström U.
Symptoms of sleepiness while driving and their relationship to prior
sleep, work and individual characteristics.
Transportation Research 2005;in press.
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<th>Abbreviation</th>
<th>Description</th>
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<tr>
<td>CR-10</td>
<td>category – ratio scale, number of ten</td>
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<tr>
<td>ECG</td>
<td>electrocardiography</td>
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<td>EEG</td>
<td>electroencephalography</td>
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<td>EMG</td>
<td>electromyography</td>
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<td>EOG</td>
<td>electrooculography</td>
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<td>FFI</td>
<td>fatal familial insomnia</td>
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<td>FFT</td>
<td>Fast Fourier Transformation</td>
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<td>HLF</td>
<td>high low frequency</td>
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<td>HR</td>
<td>heart rate</td>
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<td>HRV</td>
<td>heart rate variability</td>
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<td>KSS</td>
<td>Karolinska sleepiness scale</td>
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<td>LF</td>
<td>low frequency</td>
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<td>MSLT</td>
<td>multiple sleep latency test</td>
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<tr>
<td>PERCLOS</td>
<td>percentage of eyelid closure</td>
</tr>
<tr>
<td>P&lt;sub&gt;HF&lt;/sub&gt;</td>
<td>power of the hf competent</td>
</tr>
<tr>
<td>P&lt;sub&gt;LF&lt;/sub&gt;</td>
<td>power of the lf competent</td>
</tr>
<tr>
<td>PSD</td>
<td>partial sleep deprivation</td>
</tr>
<tr>
<td>P&lt;sub&gt;TOT&lt;/sub&gt;</td>
<td>total power, estimated variance</td>
</tr>
<tr>
<td>P&lt;sub&gt;VLF&lt;/sub&gt;</td>
<td>power of the vlf competent</td>
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<td>REM</td>
<td>rapid eye movement</td>
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<td>SCN</td>
<td>suprachiasmaticus nucleus</td>
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<td>SSS</td>
<td>Stanford sleepiness scale</td>
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<td>SWSD</td>
<td>shift work sleep disorders</td>
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<td>TSD</td>
<td>total sleep deprivation</td>
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<td>VAS</td>
<td>visual analogue scale</td>
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<td>VLF</td>
<td>very low frequency</td>
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INTRODUCTION

At some point everyone has experienced being sleepy, longing for a good sleep, being aware of the negative effects of a sleep debt, and feeling how sleepiness affects performance. Certainly, most of us have also taken actions to alleviate sleepiness in order to be able to stay awake longer. The following quotation from the medical field describes sleepiness as a common phenomenon with negative effects and that denying sleepiness is a problem itself.

I have stayed up all night lots of times. I hope and think that I have not made a serious mistake because of it. However, I do know that I felt like a zombie the next day. Every citizen on the globe has probably stayed up all night at some point—they know what it feels like. In assuring them that doctor’s function well when sleep deprived, we are asking them to deny their own experience. It is the Achilles heel of the profession.

—A distinguished senior surgeon (1)

When it comes to sleepiness, one might say it is basically a question of not getting enough good sleep. Sleep is as important as physical fitness and good nutrition (2); however, the knowledge about these two latter needs are more widely available to the general public and health care systems than knowledge of sleep, wakefulness, and sleepiness. For instance, compare the amount of weekly magazines focusing on food/diet or sport/fitness with those magazines focusing on sleep, wakefulness, and sleepiness.

To introduce and guide you through this thesis and to put sleepiness in a context, aspects that surround sleepiness are illustrated Figure 1. This thesis mainly focuses on indicators of sleepiness (orange arrow in Figure 1) and how different indicators measure or indicate the level of sleepiness. Thus the purpose of the thesis is to study objective and subjective indicators of sleepiness and their relationship and pattern over time. However, the thesis also deals with predictors of sleepiness among professional drivers (factors that affect the balance of the scale in Figure 1). In addition, this study examines the factors that increase the risk of being sleepy while driving.
The sleepiness indicator gauges the level of sleepiness (the arc in Figure 1); however, since there is a lack of a clear definition of many of the concepts regarding sleepiness while driving, a discussion about the term used to describe the state of a person at risk of falling asleep is needed. This, as well as a general overview of sleep, will be addressed in the thesis.

What actually causes sleepiness? What changes the balance of the scale leading the indicator to point at higher levels of sleepiness? It has been argued that a boring, monotonous environment, heavy meal, or heat can cause sleepiness. On the other hand, one can state that true reason for your level of sleepiness is caused by all the reasons that create a sleep debt (right bowl in Figure 1). The greater your sleep debt is, the sleepier you will feel and the greater your propensity to fall asleep will be. The indicator points to a higher degree of sleepiness. With no sleep debt at all, you will not fall asleep. In this case the indicator will point to zero sleepiness. Causes of sleepiness will be described in the background section of this thesis. However, the level of sleepiness is not only under the influence of your sleep debt, it is also under the influence the amount of external/internal stimulation (left bowl in Figure 1). With a small sleep debt only a small amount of stimulation will be required to balance the scale and thereby keep you awake. More stimulation is required if your sleep debt is greater. In the literature concerning sleepiness and driving such stimulation is usually referred to as countermeasures. Some of these countermeasures will be described in the background section of this thesis.
In addition to the sleep debt and the amount of external/internal stimulation, sleepiness is also under the influence of your circadian rhythm. Simply speaking, you are usually sleepier at night than during the day. In Figure 1 the circadian rhythm is illustrated by the weight hanging under the scale, which moves sideways depending on the time of day.

With a higher degree of sleepiness the risk of an accident is also increased (the wedge in Figure 1). We know, for an example, that work during the night (the circadian weight moved to the right) often is accompanied by less prior sleep (increased weight in the right bowl). In addition, if the level of stimulation is low (less weight in the left bowl), the work is more risky than stimulating work during the daytime. There are also health effects of sleepiness. This and sleepiness related accidents will be described in the background section.

Thus, on the journey from fully awake to sleep onset, sleepiness will vary under the influence of sleep dept, the circadian rhythm, and the level of stimulation, which together influence when sleep begins. When does sleepiness become dangerous? Feeling sleepy while sitting in a comfortable chair or lying in bed is probably less risky as feeling equally sleepy while driving. Thus the real question is this: When is sleepiness undesired? It may be more enlightening to look at accidents or incidents that occurred because of sleepiness. We could say that sleepiness was dangerous when the accident or the incident had occurred. However, stating the hazards of sleepiness this way seems to be both cowardly and impractical. Thus, a more proper statement would be that the hazards of being sleepy is when you put yourself, somebody else, or your or somebody else’s property at risk. Theoretically speaking, there are only two conditions when you are not able to cause a sleep related incident or accident. That is when you are fully awake or when you are asleep. However, because we typically spend two-thirds of our time awake, we are probably somewhere between these two “end-points” most of the time.

How sleepy can one get before one’s sleepiness becomes a relevant risk factor? An indicator of sleepiness is illustrated by the arrow in Figure 1. This indicator plays an important role in measuring the level sleepiness and thereby increases our ability to gauge when sleepiness becomes dangerous.

The indicator should be able to measure sleepiness correctly, precisely, easily, and rapidly. Both objective and subjective indicators can measure sleepiness, but how these are related and how these indicate sleepiness over time is not completely understood. It is also important to find out what predicts sleepiness. That is, what either increases the weight in the right bowl or decreases/increases the weight in the left bowl (Figure 1) is of interest in preventing accidents or incidents.
AIMS

This thesis studies the pattern of indicators of sleepiness measured both objectively and subjectively over time with regard to prior amount of sleep. In addition, this thesis examines the relationship between physiological and subjective measures of sleepiness. The specific aims are listed below:

To examine the pattern and relationship between the objective indicators alpha and theta power density, obtained by electroencephalography EEG, and subjective sleepiness ratings obtained by Karolinska Sleepiness Scale (KSS) and the category – ratio scale (CR-10) when sleep deprived and rested (Study I);

To examine the pattern and relationship between the objective indicators of heart rate variability components and alpha /theta power densities, obtained by EEG, and how these indicators develop and relate over time when sleep deprived and rested (Study II);

To examine how performance on a simple reaction time task develops over time when sleep deprived and rested, and how the performance relate to objective and subjective indicators of sleepiness (Study III);

To examine the pattern of the objective indicator of head movements over time when sleep deprived and rested, and how head movements relate to subjective and other objective indicators of sleepiness (Study IV); and

To examine prevalence of sleepiness while driving and different aspects sleepy driving; symptoms of sleepiness, countermeasures and contributing factors to sleepiness, and further aspects that predict sleepiness while driving (Study V).
BACKGROUND

SLEEP

Because all of us know how sleep feels, the actual meaning of the word is generally not questioned. Beyond the simple level of recognizing that sleep is different from wakefulness, there are still unanswered questions about the nature of sleep: What happens to us while we sleep? Why do we need to sleep? What are the mechanisms of sleep? (3). Knowledge of normal sleep, sleep physiology, and sleep patterns is essential for the identification, treatment, development of countermeasures, and the understanding of the consequences of sleepiness. Sleep is an omnipresent phenomenon with a biological function that appears to be restorative, protective, energy conservation, and/or instinctive (4, 5). Exactly what is being restored or protected is still elusive, but in a more general term it has been hypothesized that REM–sleep restores the brain and non–REM sleep restores the body (6). Even if not everything is known about why we sleep, it might be more obvious how we sleep. Sleep, a reversible condition that differentiates it from coma or anaesthesia, is characterized by perceptual disengagement from and lack of responsiveness to the environment. It is usually associated with species-specific postures, selections of location, and circadian timing (5, 7). Normal needed sleep time, which varies 10 fold among species, for people is around 8 hours (6, 8). Subjectively, a good sleep quality is associated with sleep continuity, ease of falling asleep, and ability to sleep through the night (9).

A model of sleep regulation

Sleep is not regulated in a specific sleep centre. The brainstem, thalamus, and suprachiasmaticus nucleus (SCN) are some important structures of the central nerve system that are actively involved in the regulation of sleep (10). Several models of how sleep is regulated exist. One widely accepted model is the two-process model of sleep regulation (11, 12). This model describes the changes between sleep and wakefulness in terms of the interaction of the two processes, process S and process C (Figure 2). Process S is the homeostatic process and is determined by prior sleep and wakefulness. That is, it increases exponentially during awake and decreases during sleep (11, 12). The upper sleep-threshold marks the transition from an increase of process S to decrease of process S while the lower sleep termination threshold marks the transition from a decrease of process S to an increase of process S. It is presumed that the two thresholds are under the control of the circadian rhythm, also called the internal body clock (11). This rhythm is an approximately 24 hours, endogenous, and very constant rhythm and is linked to the light/dark cycle (6, 13). The two thresholds vary parallel and together with the circadian rhythm and are referred as process C. For simplicity it can be
said that process S controls the internal needs while process C controls the environmental time. Thus the sleep–wake cycle is prevented from running free. Another regulating factor involved in sleep regulation that has been discussed is the ultraradian rhythm. This rhythm, an extremely short biological rhythm, is the cycle of REM and non–REM sleep, which lasts between 90 and 120 minutes. This rhythm and the homeostatic mechanism seems mutually dependent, whereas deep sleep (see below) declines and REM sleep increases (13).

![Figure 2. Illustration of the interaction between process S, the homeostatic process, and process C, the circadian process. During waking process S increases until sleep onset (represented by threshold 1, T1). During sleep it decreases until it reaches the level of process C and sleep is terminated (represented by threshold 2, T2).](image)

**Sleep EEG and sleep stages**

Sleep behaviour seems to correlate well with physiological measures of sleep (8). The physiological measurement of sleep is typically done by electroencephalography (EEG), isolated or in the combination with electromyography (EMG) and electrooculography (EOG), which also is called polysomnography (5). The measures of EEG are frequency (Hz) and amplitude (µV) of the brainwaves. The pattern of these recordings reveals three different states of vigilance: wakefulness, REM (rapid – eye – movement) sleep or “dream – sleep,” and non-REM sleep. The latter, non–REM sleep, can further be divided into four stages of sleep: 1, 2, 3, and 4 (6). In general, during transition from wakefulness to stage 4 sleep the EEG activity becomes slower and the amplitude of the waves increases. Active wakefulness consist of low-amplitude waves, 10 – 30 µV, with a varying fast frequency, 16 – 25 Hz, whereas relaxed wakefulness with eyes closed has an amplitude of 20 – 40 µV and a frequency of 8 – 12 Hz. This pattern is also referred as the alpha rhythm. In stage 1, further slowing of the frequency is seen and theta rhythm, 4 – 8 Hz, is more noticeable. Slow rolling eye movements appear on EOG and EMG shows moderate to/low activity. During stage 2, intermediate sleep, theta rhythm is established and the EEG pattern also
shows burst of short fast frequency periods (sleep spindles) and biphasic waves with very slow frequency and high amplitude (K-complexes). Eye movements are rare and EMG is low or moderate. Sleep stages 3 and 4, slow wave sleep or quiet sleep, is characterized by predominance of delta rhythm with a frequency of 0.5 – 2 Hz and of high amplitudes, > 75 µV. REM – sleep, distinguished in a tonic and a phasic type, resembles the pattern of stage 1 sleep with a fast and low amplitude rhythm (7, 14). However, saw-tooth waves appear in the EEG and, unlike in stage 1 sleep, the EMG recording shows absent or very low muscle activity and EOG show rapid eye movements. Although the EEG, EOG, and EMG measures can be used to identify state and stage of sleep, state and stage changes do not just switch off and on. Rather, they change gradually, which can make it difficult to separate states. To help distinguish and score sleep stages and REM–sleep from each other, a manual has been established (15). An example of the different sleep stages in an EEG recording is presented in Figure 3.

Sleep cycles
When scoring sleep–EEG, one can find that during a normal night of sleep a person passes throughout all sleep stages and REM–sleep in cycles. There is usually 4 to 6 cycles per night with a length of 90–120 minutes each. REM sleep, which appears for the first time after approximately 90 minutes, comprises about 25% of the total sleep time and has its longest duration in the last sleep cycles. Stage 1 sleep accounts for 5–10% of the sleep time, stage 2 sleep accounts for 45–50%, and stage 3 and 4 sleep accounts for 20–25% of the total sleep time. However, total sleep time and the time spent in each sleep cycle is not only highly age related, it is also very individual. Premature infants and term infants sleep and sleep-EEG are not comparable with adults; they sleep longer, their sleep is widely distributed over the twenty-four hour period, and they spend more time in REM–sleep and less time in deep sleep, stage 3 and 4 (8, 16, 17). Prepubescent children are good sleepers; they fall asleep quickly, sleep through the night, and when awake they function at a high level throughout the day. Teenagers need around 10 hours sleep, but since they often want to go to bed later it might result in sleep deprivation because of the wake-up times needed for school (14). In early adulthood, sleep in stage 3 and 4 becomes less and when getting even older the total sleep time may be reduced due to family obligations, work and social activities. With advanced age, sleep may again become polyphasic, shorter, more fragmented and need for daytime napping appears. It is, however, important to be aware that the need for sleep and sleep characteristics are highly individualized.
SLEEPINESS

Definitions

In this thesis, the term sleepiness is defined as the inability to stay awake, a drive to sleep. This definition has been used Åkerstedt and Kecklund (18). Several other terms or definitions have been used to describe the driver who is at risk of falling asleep at the wheel. Many of these are used synonymously. Examples of such terms are hypersomnia, somnolence, sleep propensity, weariness, fatigue, tiredness, the ability to fall asleep, sleep ability, the ability to stay awake, sleepiness, and drowsiness (19). However, it seems that the most commonly used terms in the literature when describing a driver at risk of falling asleep at the wheel is sleepiness, drowsiness, fatigue, and tiredness. It has been stated that sleep itself attracts more attention and effort than sleepiness (20) and that the incorporation of the knowledge of sleep and wakefulness physiology into a multi-disciplinary thinking about driving while sleepy is made difficult by the lack of clear definitions and terms (21). Thus a brief discussion around the different terms is appropriate.

As pointed out in an overview of sleepiness related accidents (22), fatigue and sleepiness are used synonymously to mean sleepiness resulting from the neurobiological regulating circadian rhythm and the drive to sleep. In a more recent consensus statement about fatigue and accidents in transport operations by a group of international scientists (23), the term fatigue was used, but as they also pointed out fatigue was used synonymously with drowsiness, tiredness, and sleepiness. Corfitsen (24) used the term tiredness when studying young male night drivers while drowsiness has been used in other reports (25-27). Brown (28) used the term fatigue in an overview of motor vehicle crashes while sleepiness was used by others in studies dealing with professional drivers or car crashes (29-31). Driver
impairment has been used in a more generalized term to summarize the reasons drivers fall asleep at the wheel (32, 33). Thus there is a lack of a defined concept describing the sleepy, drowsy, tired, or fatigued driver. Merriam-Webster's Collegiate Dictionary defines sleepy as “ready to fall asleep,” tired as “drained of strength and energy”, fatigue as “weariness or exhaustion from labour, exertion, or stress”, drowsy as “inducing or tending to induce sleep,” and impaired as “disabled or functionally defective.” It appears that there are differences in the meaning of the terms. Johns (19, 21) declares that the drowsy driver is in the state of drowsiness, and that this state, occurring at some point before sleep stage 1, is a transitional state between wakefulness and sleep in which the sleep process already has begun and probably will lead to sleep. Furthermore, Johns distinguishes the state of drowsiness from sleepiness by saying that sleepiness is neither a state nor a process. Sleepiness is sleep propensity or the probability of falling asleep at a certain time (19, 21). Others have used a similar definition of sleepiness. For instance, Stutts et al. defined sleepiness as the inclination to sleep (34) and Åkerstedt and Kecklund (18) write that sleepiness is a part of the concept tiredness and describe it as an inability to stay awake, a drive to sleep. Johns (21) stresses further that his definition of sleepiness should be seen as a position along a continuum of arousal states from alert wakefulness to sleep and that it should be distinguished from the presences and intensity of feelings and symptoms that are related to the state of drowsiness, also called subjective sleepiness.

Although fatigue is a recognized concept in driving research (35), conceptually it is easier to separate from drowsiness and sleepiness than drowsiness is from sleepiness. Fatigue can be defined as a psychological state in which individuals declare that they are unable to continue performing the task in question (35), or it can be defined as a subjective experience of tiredness and an inability to continue performing the current task (28). A person can, after a good night sleep followed by a strenuous training session, experience fatigue without experiencing subjective sleepiness. As pointed out by Johns (21), one can doze off for a short period without experiencing fatigue. Definitions of concepts regarding drowsy driving is absent, but as Åkerstedt (20) has stated such diversity is a characteristic for a young research area. Nevertheless, it is important that this multidisciplinary research area develop an unified conceptual framework.

**Prevalence of sleepiness**

During the last centuries many important innovations have been made. Electric lightning, the march of civilization regarding infrastructure of ground and air transportation, and worldwide computerization have contributed to a 24 hour society seven days a week. This is not without disadvantages; curtailment of sleep and sleep disturbance are side effects with negative consequences on social life, family parenting, work performance, medical disorders, nature, and economy. Sleep deprivation is one of the most common health problems today and up to one-third of the population are suffering from excessive sleepiness (36-39). However,
depending on the purpose of the scientific studies carried out, such as age of the subjects and sample size in the study, different estimates of the prevalence of sleepiness are found. For instance, one review reported that about 20% of young adults had pathological sleepiness (40). A Finnish study estimated the prevalence of having daytime sleepiness almost everyday to 11% for women and 7% for men (41). In a Swedish study 12% of the subjects reported insufficient sleep (42). An American report from 1993 concluded that about 40 million Americans suffer from chronic sleep disorder. Another 20 to 30 million suffer from occasional sleep deprivation with a cost of 15.9 billion dollars for direct sleep disorders. As much as $150 billion in sleepiness-related lost workplace productivity, accidents, and deaths have been reported (43). More recent reports from the National Sleep Foundation reveal that a sizable proportion of adults, 37%, report that they are so sleepy during the day that it interferes with their daily activities a few days a month or more; and 16% experience this level of daytime sleepiness a few days per week or more (44). Clearly sleepiness is common, troublesome, and costly.

Sleep deprivation
We all have different daily sleep requirements, which for adults on average is about eight hours a night. We spend approximately one-third of our life asleep. The well-regulated timing and durations of sleep is an indicator of how important sleep is to an individual (11). If we don’t obtain the amount of sleep we require, a sleep debt is created. The only way this debt be reduced is by obtaining extra sleep above the daily requirement. Sleep debt or lack of sleep is in the scientific literature often referred to as sleep deprivation and it will be more prominent as wakefulness continues. Sleep deprivation is commonly divided into total and partial sleep deprivation, but selective sleep deprivation (lack of specific sleep stages) and sleep fragmentation (arousal during sleep) have also been described (38). Total sleep deprivation (TSD) has been defined as the length of time since the end of the last sleep period (45). The degree of TSD can be described in terms of loss of sleep, lack of sleep for at least 24 hours (46, 47), or further subdivided into short-term TSD (< 45 hours lack of sleep) and long-term TSD (> 45 hours lack of sleep) (48). Partial sleep deprivation (PSD) can be defined in both the reduction of total sleep time and the length of PSD period (45). PSD can be acute, one or two days reduced sleep time, or chronic, several days a week of reduced sleep time for an extended period (38, 39). Research on sleep deprivation is extensive (over 1000 studies during the past 100 years). However, modern sleep research can be limited to research done after 1950 (3). Several authors conclude that the effects seen in sleep deprived studies are minor and reversible with recovery sleep (38). However, they also point out that the results from different studies are conflicting (38, 47, 49-53). For example, cortisol has been shown to increase post-sleep deprivation (54), decrease post-sleep deprivation (55), or be unaffected (56). Even if the function and meaning of sleep and the short-term effects of sleep deprivation still might be elusive, the long-term effect of total sleep deprivation is fatal. This has been shown
in animal studies (57) and for humans it can be exemplified by the fatal disease fatal familial insomnia (FFI), a rare disease where the thalamus becomes atrophied. The most common symptom in this disease is progressive insomnia that develops further to a total lack of sleep followed by death within 7 to 36 months (58, 59). Furthermore, even if physiological effects of short-term sleep deprivation are reversible by sleeping, other effects of short-term sleep deprivation are more serious, such as traffic accidents.

THE CIRCADIAN RHYTHM

A fundamental property in higher life forms is the ability to keep track of time (60). One part of these time keeping systems is the circadian pacemaker, also called the biological clock (61). The circadian pacemaker, which is located in suprachiasmatic nucleus in the brain, generates the circadian rhythm with three characteristics; the rhythm is endogenous and robust rhythm, its rhythm is roughly 24 hours (circadian, from the Latin circa and dies, meaning literally "around a day"), and the rhythm is in phase relative to the time of day (61). This circadian pacemaker regulates the sleep and wake pattern as well as other behavioural, physiological, and biochemical rhythms, promoting being awake during the day time and sleep during night time (61, 62).

The circadian rhythm is primarily synchronized and entrained by the light-dark cycle with the function of adjusting life to a diurnal rhythm (61). Other external clues that have been suggested to influence the circadian rhythm are exercise, social interaction, and sleep-wake schedules; however, these factors do not influence the circadian rhythm as significantly as light (61).
THE SLEEP DEBT

There are many causes that contribute to sleep debt, ranging from just going to bed too late the previous night to the disease fatal familial insomnia. Because the causes, disorders, or reasons related to sleep debt and sleepiness are presented differently, it can be hard to develop a general view of all the reasons that cause sleepiness. However, one way to get a grasp of the causes to sleepiness is by studying the classification of sleep disorders using The International Classification of Sleep Disorders: Diagnostic and Coding Manual (63). In an overview of this classification (64), 84 sleep disorders are included (Table 1). These disorders are divided into four major groups: dyssomnias, parasomnias, medicopsychiatric, and proposed sleep disorders. Dyssomnias, disorders that produce either insomnia or excessive sleepiness, are either intrinsic (for instance narcolepsy, obstructive sleep apnea syndrome), extrinsic (for instance inadequate sleep hygiene, high noise, caffeine), or result from a disrupted circadian rhythm (for instance shift work, jet lag). Parasomnias refer to disorders that are not abnormalities related to the sleep/awake states but rather to phenomena that often occur during sleep, such as sleep walking or sleep talking, which in turn can result in arousal or disturbing one’s bed partner (64). Medicopsychiatric sleep disorders are, as the name suggests, disorders of medical or psychiatric origin that cause disturbed sleep. Names for these sleep disorders are short or long sleepers (sleep shorter or longer than normal without pathological sleep). To describe all of these disorders is beyond this thesis; however, a brief description of shift work sleep disorder (group 1: C: 2 in Table 1) is appropriate since professional driving often involves shift work.

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<th>The International Classification of Sleep Disorders</th>
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<td><strong>1. Dyssomnias</strong></td>
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<td>A. Intrinsic Sleep Disorders</td>
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Shift work and sleepiness

The 24-hour-7-day society that we have approached requires organizations and arrangements where time constraints no longer limit human activities. Shift work can be defended as work hours arranged in schedules with two or more shifts (65, 66). Working permanent night is considered as shift work. In the literature (66-70) estimates of how many workers that are engaged in shift work varies from 16 to 22%, a large proportion of these are in healthcare settings or in the transport industries (68). Shift workers in general report more sleep disturbances than day workers, especially those working in three-shift schedules (71, 72). Complaints associated with sleepiness can be related to the shift and/or between shifts. However, there are individual differences regarding sleep disturbance in shift work. There are individuals whose sleep pattern or quality are not essentially impaired by rotating schedules or night schedules; however, some people are more affected while on schedules that interfere with the circadian sleep-awake cycle (73, 74). A distinction between shift workers with independent sleep disturbance and those for whom shift work is the contributing factor to sleep disturbance is important. Criteria for shift work sleep disorders (SWSD) includes the primary symptoms of insomnia or excessive sleepiness that is temporally associated with a work period that occurs during the usual sleep phase (63, 70). The prevalence of SWSD among shift workers is sparsely investigated, but one report estimates that 10% of those working nights and on rotating shifts meet the criteria of SWSD (70). There are at least two major causes to sleepiness related to shift work: one is sleep loss and the other is the conflict between the displaced work hours and the circadian rhythm (65). For instance, before the first night shift there is less sleep resulting in an extended period of wakefulness. Day sleep after night shift is reported to be shorter and the loss affects REM-sleep more than stage-4 sleep and the percentage of deep sleep is increased (65, 75). As the circadian rhythm promotes sleep, work obligations force the shift worker to stay awake. A gradual phase shift of the circadian rhythm can occur over successive nights of shift work; however, in contrast to jet-lag, a complete phase shift in the shift-lag will in general not be reached due to light exposure during early morning that counteracts the adjustment for shift workers (74, 75).
THE COUNTERMEASURES

Sleepiness at work is associated with an increased risk of accidents and the most obvious countermeasures would be good scheduling of work hours and proper sleep hygiene (76, 77). However, other obligations in life outside working hours might influence the effects of those countermeasures. Employing countermeasures during work hours or while driving may be helpful to prevent sleepiness related accidents. Countermeasures can either be those taken by the driver or of a technological character. Another way to divide countermeasures is into preventive strategies and operational countermeasures (78). They can also be categorised into sleep as countermeasure, drugs and food as countermeasures, environmental stimulation as countermeasure, and behavioural countermeasures (76, 79). Below the discussion will follow the latter approach, beginning with those that work best.

Sleep, naps, or break as a countermeasure
Åkerstedt and Landström (76) concluded that napping was the most effective countermeasure against sleepiness. In particular, they noted found that naps of 0.5 – 2 h counteract the fall in alertness around the circadian low point during early morning. In an intervention study on the effect of napping among police driving during night shift concluded that napping is an effective countermeasure to decreased alertness and poor performance in driving tasks (80). Napping in the afternoon among a group of long-haul drivers has been shown to have positive effects on subjective sleepiness ratings, reactions times, and psychomotor performance measured during the night time (81). Other studies have found that 15-minute naps during the night or early morning counteract sleepiness significantly (82, 83) while just taking a break was ineffective. Landström et al. (84) found that truck drivers’ EEG patterns showed a more alter state after a break in driving. In a flight simulator study, the effect of 5 short breaks spaced hourly during a 6-hour flight was compared with a control group who had 1 break in the middle of the flight. The experimental group showed significant reductions for 15 minutes post-break in physiological parameters as well as in alertness for up to 25 minutes post-break, indicating positive effects of short-duration breaks (85). Nevertheless, while evidence of just taking a break may be elusive, there is strong evidence that sleep at work or naps before or during work is an effective, probably the most effective, countermeasure against sleepiness (76). Thus, discussing sleep/naps as a countermeasure in terms of Figure 1 in the introduction, sleep/naps counteract sleepiness by decreasing sleep debt and thereby lighten the weight in the left bowl. This result is in contrast to the measures that will be described below.

Drugs and food as countermeasures
There are studies that have investigated the effect of caffeine with or without a combination of a nap. Caffeine, corresponding to 2 – 3 cups of coffee, reduced lane drifting significantly for the first 30 minutes and subjective sleepiness in a group of
sleep deprived subject in the early morning (86). When combining caffeine and a nap for a group of sleep deprived subjects, it was shown that the combination was more effective than either of the countermeasures in reducing line drifting and subjective sleepiness and the effect could be maintained up to 2 hours (82, 83).

Few studies have examined the effects of food and drinks as countermeasures. One study indicated that intake of fructose or glucose had a similar stimulating effect on wakefulness immediately after intake, while the intake of fructose could lead to a delay in the development of drowsiness (87). The effect of energy drink given to sleepy subjects driving in a simulator showed an improvement in performance as measured by line drifting and reaction time (88).

Environmental stimulation as countermeasure
Sudden noise has an arousing effect and thus a potential countermeasure against sleepiness. This has been shown in both laboratory and field studies (89, 90). The influence of a waking sound that enhances wakefulness was studied in a laboratory setting, measured by EEG. The subjective ratings and results found that the waking effect increased when sound varied in duration and frequency (90). In a field study, a waking sound system was tested and the waking effect of the sound was analysed through subjective ratings. Exposure to the sounds was correlated to improvements of the immediate as well as the long-term self-reported changes in wakefulness (89). In no case did the drivers find the sound to be annoying although the sound was disharmonic (90). Nevertheless it could be experienced as unpleasant. A more common sound in cars and trucks come from the radio. Listening to the radio when driving, in laboratory settings, has been shown to reduce subjective sleepiness and a trend to reduce lane drifting incidents (91); however, it can also distract drivers from being aware of their sleepiness.

Because the circadian phase is closely linked to light, bright light seems to be a logical countermeasure to sleepiness. However, in a field study with professional drivers trying a self-administered 30-minute light treatment in the middle of a night drive showed no significant effect (92). Another study tested whether 30 minutes of exposure to a bright light would reduce subjective sleepiness and EEG indicators of sleepiness, alpha and theta power density. Analysis showed that exposure to bright light significantly reduced subjective sleepiness but had no effects on alpha or theta power density. This suggests that a short exposure may not counteract sleepiness for a longer period following the exposure (93).

An optimal comfort temperature is around 25°C for sedentary work such as long distance driving (76). A laboratory study investigating altering air temperature as a countermeasure to sleepiness showed that reductions of the air temperature by 10 degrees in repeated sequences significantly increased wakefulness measured with EEG and subjective ratings (94). The effect of cold air as an “in-car” countermeasure to driver sleepiness, measured with EEGs and subjective rating of sleepiness, showed no overall effects on incidents or line drifting (91).
However, it was suggested that it could be used to temporarily reduce sleepiness and provide the driver time to find a suitable place to stop.

**Behavioural countermeasures**

The effect of exercise as a countermeasure is under investigation. Strenuous exercise 6 hours before bedtime can intervene with sleep due to physiological activation. Therefore, it is advisable to plan exercise to minimize its interference with needed sleep (78). Exercise as a countermeasure for the sleepy driver is limited and has only a short term effect (95).

In a multinational questionnaire study, licensed drivers were ask questions regarding what behaviours they used as countermeasures to prevent drowsiness while driving (79). Among the most frequently used behaviours were turning up volume of radio, drinking caffeinated beverages, rolling down window, and slapping and pinching self. Other reported behaviours were trying not to stare at the division line, driving over rumble strips, chewing gum, smoking, conversing with someone, screaming, rotating drivers or playing games in the car. There is a lack of scientific evidence to support all or some of these behaviours, although they may work for the individual giving him or her enough time to find a place to stop. Most people, regardless of their occupation, level of education, and any other demographic characteristics agree that there is no substitute for sleep (79).

**INDICATORS OF SLEEPINESS**

This section describes both objective and subjective indicators that measure sleepiness. This approach is a more general approach compared to the more detailed description in the method section.

**Objective measures**

**Electroencephalography, EEG.**

Measurement of sleepiness with EEG has been used extensively in laboratory and clinical settings and shown to correlate with sleepiness (95-97). EEG parameters can be summarized in patterns and spectral characteristics. Spectral analysis of a sleepy person’s EEG often involves power density of alpha and theta activity. Alpha power density has been shown to increase in night workers compared to afternoon workers (98). Other studies of night workers have shown an increase in alpha and theta activity as well as increases in self ratings of sleepiness during long night shifts (96, 99). This can be referred to as instantaneous measure of sleep propensity according to Johns (21). Horne and Reyner (82, 83) have concluded that the combination of alpha and theta activity gives more consistent EEG results than if they are evaluated separately. Even if the interpretation of EEG signals is standardised, there is no standardised way to evaluate sleepiness using the EEG.
technique. Moreover, EEG measurements require a fair amount of expertise to record and to analyse. Currently it seems impractical to use EEG as a routine method for analysing sleepiness among truck drivers.

Multiple sleep latency test, MSLT
This is a commonly used method to evaluate daytime sleepiness and is also a measure of instantaneous sleep propensity. This test is based on the assumption that the faster an individual falls asleep, the sleepier he or she must have been prior to sleeping. The speed with which the individual falls asleep, sleep latency, can be used to evaluate propensity of falling a sleep, i.e., sleepiness (19, 100, 101). The test is performed in a laboratory setting and under standardized conditions. The MSLT is beneficial when diagnosing narcolepsy and it is claimed that false-positive results are theoretically minimal (100). On the other hand, it might be less sensitive if the person suffers from excessive daytime sleepiness with repeatedly low latencies, i.e., a floor effect (102). False-negative results are possible because it takes a longer time for the subject to fall asleep than it usually does. Drawbacks of MSLT have been raised. First, it does not take into account how the wires that are attached to the subject affect the ability to fall asleep. Second, being in the laboratory settings is not a daily life situation (19). MSLT has been studied in association with driving. A driving simulation study with sleep deprived subjects showed that MSLT correlated with performance as well as to the subjective sleepiness rating but to a lesser degree (103).

Heart rate, heart rate variability
Heart rate (HR) and heart rate variability (HRV) provide information about the autonomic nervous system (ANS). Analysis of HRV is a non-invasive technique that has been used to investigate the effects on cardiovascular autonomic regulation of work-related stresses.

HR has been used in studies as a possible indicator for driving fatigue. HR has been shown to decrease during prolonged and monotonous driving (104). A fatigue related decrease in HR has also been confirmed in laboratory studies (97). In a field study, heart rates measured before and after a trip showed an increase while driving. In another field study (105), no changes in HR related to fatigue could be observed, but another study found an increase in heart rate in prolonged truck driving (106). Egelund (105) also analyzed HRV (spectral analysis) on subjects 12 times during an approximately 4 hour drive and found a relationship between distance driven and low-frequency HRV. Apparies (106) concluded that heart rate is more sensitive than HRV in indexing driver fatigue after measuring HRV using parameters such as respiratory sinus at two different time points during a professional driver’s 8 to 10 hour drive. In another study, HRV was investigated in six long distance truck drivers. It was found that some HRV indices were higher during morning driving (8 a.m. to 12 p.m.) hours than during the afternoon (12 p.m. to 4 p.m.) (107). Because the drivers also had different work assignments and
napping periods, it is hard to interpret these results in terms of how sleepiness changes during long monotonous drives.

**Performance test**
There is strong evidence for the statement that sleepy people have impaired performance (38). The methods used in studies can be divided into psychomotor tasks (simple reaction time task) or cognitive tasks (memory tasks) (102). A study was carried out on young and old subjects that either had a full night’s rest or were kept awake for one night. In the study, it was shown that while older participants performed worse in both conditions, sleep deprivation significantly affected the younger participants while not significantly affecting the older participants’ performance. Tasks that demand continuous and frequent responding, such as simulated driving (29) or reaction time (108, 109), may cause general slowing and be evident nearly immediately. Vigilance tasks usually require the monitoring of a system with infrequent responding. Early results from such tasks (110, 111) suggested that a task needed to be approximately 30 minutes or longer to show effects from one night’s sleep deprivation. More recently, however, others have demonstrated that a single night’s sleep loss affected performance already from the first response on a 34-minute vigilance task requiring infrequent responding (112).

**Head movements**
Researchers have not studied carefully enough the role of head movement as it relates to sleepiness. Although head movement can be measured with an inclinometer (113) or with a video camera system (114), there are few studies dealing with this issue. Ji and Yang (114) noted that head position can reflect a person’s level of sleepiness. Because alert drivers normally look straight ahead, if a driver frequently looks in other directions for an extended time, the driver is either fatigued or inattentive. In an aviation study, head movements were measured among pilots (115). During work head movement is active, but when the pilots fell asleep, no head movements were recorded. Popieul, Simon, and Loslever (116) measured head movement among voluntary drivers who were not sleep deprived in a driving simulator. They found that the increased head movement appeared clearly after 150 km of a 300 km simulated monotonous driving.

**Eye, eyelid, and pupil measures**
Changes of the pupil, eyelid, or eye blink frequencies are suggested as indicators of sleepiness. When sleepy and falling asleep, the pupils constrict and become unstable due to changes in the autonomic nervous system. This phenomena has been used to measure sleepiness (100). Although pupillography have been used to measure sleepiness, it can be impractical to use while driving (117). Changes in eyelids have been studied using a real time detection system (PERCLOS measures the percentage of eyelid closure). This study showed good correlations with vigilance tests (118, 119). A study of eye blink duration as a measure of sleepiness during on-road driving revealed that average blink duration was significantly
longer for bus drivers with OSAS (Obstructive Sleep Apnea Syndrome) before treatment than afterwards. One conclusion was that eye blink duration could be an indicator of sleepiness.

**Subjective measures**

**Symptoms of sleepiness**

Symptoms of sleepiness (eye problems, yawning, difficulties staying alert, and task focused) are well known and have been investigated. Kecklund and Åkerstedt (96) used symptoms of sleepiness such as tired eyes, heavy eyelids, difficulties focusing one’s eyes, and feeling irresistible sleepiness. Mloušević (120) studied long-distance drivers and dump truck drivers by ranking their symptoms of fatigue. Their most common symptoms were back/leg pain, drowsiness/fatigue, bad mood, slowed-down activity, and pain/other eye problems. Nilsson et al. (121) showed in a simulator study that the most salient changes of symptoms over time were sore feet, tired eyes, and feeling drowsy.

**Ratings scales**

In research it is sometimes important to assess various subjective symptoms, complaints, or annoyances using rating scales. Some of these rating scales are designed for general use and can be used to rate several symptoms, while others are designed to measure a specific symptom, feeling, or phenomena. Measuring subjective sleepiness with rating scales have been used extensively on both general scales or specific scales (33, 122). They are often easy to use and require little expertise in administration and interpretation of results. Rating of fatigue has also been studied. Nilsson et al. (121) used a check list of terms with a Likert-type of scale. The literature on sleepiness often cites specific sleepiness scales such as Karolinska Sleepiness Scale (KSS), Stanford Sleepiness Scale (SSS), and the Epworth Sleepiness Scale, (ESS). Each scale measures different characteristics. Other more general scales are the Visual Analogue Scale (VAS) and the category ratio scale (CR-10 scale).

*Karolinska Sleepiness Scale, KSS*

The Karolinska Sleepiness Scale has been used frequently (122, 123). This scale uses nine steps of categories to cover the entire wakeful/sleepy continuum, making it a bipolar scale. Thus, only a few categories and scale values on the upper end of these scales are available for ratings in sleepy subjects. To study of long distance truck drivers KSS was used to rate subjective sleepiness. Night drivers rated there sleepiness higher and had increased alpha and theta activity (96). There was also an individual correlation between KSS ratings and the alpha activity. In a study dealing with countermeasures, KSS was used to measure the effects of radio and cold air on sleepiness among drivers who had their sleep restricted (91). KSS scores were significantly lower when the radio was playing; however, EEG showed no significant effects.
Stanford Sleepiness Scale, SSS
This rating scale consists of seven descriptive statements to describe the feelings a person may feel at the time of scale administration (124). The statements on the scale are bipolar, ranging from “feeling active and vital, alert, wide awake”. SSS has been used to measure sleepiness among drivers. In a study with professional truck drivers under different types of driving regimes, SSS was used to evaluate the drivers’ level of fatigue (125). Results showed that drivers fatigue during driving was more related to pre-trip fatigue rather than to any of the regimes. In another study using a driving simulation task, SSS did not correlate as well as MSLT did to performance among the sleep deprived subjects (103).

Epworth Sleepiness Scale, ESS
ESS is a simple questionnaire that measures the subject’s general level of daytime sleepiness (126). ESS consists of eight different common situations in which the subjects rate their chances that they would doze off or fall asleep. One can refer to it as measuring average sleep propensity according to definition set by Johns (21). It correlates with MSLT and during overnight polysomnography. ESS has been used in a survey of truck drivers that showed that a higher level of daytime sleepiness as rated by ESS was related to more frequent drowsy driving. In another study of truck drivers, the ESS scale estimated sleep problems rather than finding a certain level of sleepiness that resulted in the drivers stopping (31).

Visual Analogue Scale, VAS
The VAS scale is useful for measuring several subjective phenomena and is most commonly used in the assessment of pain. It is usually a 10 cm line with end anchors labelled with the extremes of the phenomena to be measured. Subjects can indicate their level of the phenomena being measured by making a mark on the line (101, 127). It can be used either as an unipolar scale, not sleepy to very much sleepy, or as a bipolar scale, very alert to very sleepy (102). The unipolar scale version was used in a study of young adult drivers investigating the relationship between perceived sleepiness while driving and a sleep model (128).

Category ratio scale, CR-10
The CR-10, also called the Borg-scale, combines level-anchored judgement aspects of a category scale with the growth rate determination possibilities of a ratio scale by using verbal labels on an open-ended number scale. CR-10 is a general scale that can be applied to various situations. Because it has a greater discrimination than KSS and SSS, it is easier to differentiate the rated symptoms, particularly at the lower end of the scale but also at a higher level of intensity (129). CR-10 has, to the author’s knowledge, not been previously used to specifically measure sleepiness. It has been used frequently when studying perceived exertion during exercise (130, 131); however, it has also been used when measuring perceived fatigue after mental work (132).
RISK OF AN ACCIDENT

Sleepiness related accidents in general
Work-related accidents can be defined as an incident during work that occurs during a short period leading to a personal injury or death (133). Work-related accidents vary depending on occupation, industry, lifestyle, and workplace factors, but they are also responsible for a significant proportion of worker absenteeism, disability, and costs (22, 134). Human errors in a workplace are the most frequently identified root cause to serious incidents and occupational accidents and are related to several different factors, including disturbed sleep (22, 135). It has been suggested that 52.5% of all work related accidents and injuries are related to sleepiness (136). Hsiaso and Simenov (137) devised three categories of risk factors – work environment, task related factors, and personal factors – related to falls from roof accidents in a model that can be applied to occupational accidents in general. Fatigue was classified as a task related factor, implying that performing a task at a given intensity and duration can lead to fatigue. This in turn can lead to a worker being less observant and resulting in accidents. Fatigue can decrease the ability to process information about a hazardous situation as well as decrease the ability to adequately respond to a dangerous situation. It is not clear whether fatigue is an independent risk factor or becomes a risk factor due to working conditions. In a recent study, it was concluded that fatigue and the need of recovery were two independent risk factors for being injured at work (134).

Major accidents such as the nuclear disasters at Three Mile Island (1979) and Chernobyl (1986), the oil spill due to the Exxon Valdez crash (1989), and the poisonous gas leak from a pesticide factory in Bhopal, India (1984) have been linked to sleepiness (22, 138). Besides these “headline” disasters, sleepiness as a cause to incidents and accidents are frequently reported in the transport industry and to a lesser degree in health care settings (26, 139-143). This is somewhat strange since continuous duty and long work hours for healthcare personnel to a much greater extent are allowed than for those in transportation. Results from studies of effects of sleepiness among medical personnel on clinical performance differ. On the one hand, in a study where interns’ weekly work hours were reduced from in average 85 hours to an average of 65 hours, the doctors in the intervention group had significantly less attention failures during night work hours (143). On the other hand, in a study among anaesthesiologists working on simulated patient after either being totally sleep deprived for at least 25 hours compared with after having had extended sleep periods for four consecutive days showed no differences in clinical performance. This despite the fact that after being sleep deprived they had more sleepy behaviour and impaired psychomotor performance (144). There is no consensus on the effects of sleepiness among medical personal and its consequences on the patient. The health care systems have a tradition of long work hours, altered schedules, and on-call periods in the same manner as in other occupational settings (145). In the USA, the National Transportation Safety Board,
when investigating accidents, can formally identify sleepiness as contributing to an accident if the sleep–wakefulness histories and circadian timing of crewmembers that have been involved in accidents suggest that fatigue was present. If the same analysis were applied to accidents involving the care of patients in teaching hospitals, fatigue on the part of clinicians could be cited as a contributing factor (146).

Sleepiness related traffic accidents
In 2000, consensus statement concerning transport operation was issued by an international group of sleep researchers: “sleepiness is the largest identifiable and preventable cause of accidents in transport operations (between 15 and 20% of all accidents), surpassing that of alcohol or drug related incidents in all modes of transportation” (23). It seems obvious that sleepiness related accidents should be recognized as major traffic and work problem. However, it is not just a problem for professional drivers; it also applies to those driving to or from their work place, especially for risk groups as shift-workers, untreated sleep apnea syndrome, or young people (26).

The actual number of sleep related accidents is difficult to determine. The lack of reliable methods to identify a sleepiness related accident and separate it from other types of accidents often leads to an underestimation of sleepiness as an explanation of the accident and contributes to the fact that studies of official statistics are often lower than estimates based on research (18, 79, 147, 148). Studies of traffic accidents related to sleepy drivers reveal a broad variation of results. In a study from England, 16% of all vehicle accidents on major roads were found to be sleep related while 20% of the accidents on motorways were sleep related (149). Another report from England found that 9 – 10% of the accidents on all roads were sleep related, while 15% of the accidents on motorway were sleep related (149). An American report estimates that 17% of road accidents are sleep related (150). Another American study on two roads with heavy traffic found that 50% of fatal accidents were related to sleepiness (151). Another study involving heavy trucks estimates that 30% - 40% of the accidents were related to sleepiness (152). The Australian Road Safety Organisation (153) estimates that 25% - 35% of accidents are related to sleepiness. Lower estimates have also been reported. A Norwegian survey found that in general only 3.9% of the road accidents were related to sleepiness (154).

Even if it is a major risk to drive sleepy, not every sleepy driver ends up being involved in a road accident. It seems logical to reason that the prevalence of sleepy drivers on the road is higher than the prevalence of sleepiness related accident. In a Finnish questionnaire study, about 40% of the long-haul truck drivers reported problems staying alert on average every fifth drive and over 20% had dozed of more than once (31). Another survey reported that 31% of the drivers admitted having dozed off at least once while driving during the previous twelve months. In
a telephone survey in New York, it was found that about 55% of the drivers had been driving while sleepy and 23% had even fallen a sleep at the wheel (155). Dawn (156) reported that 29% of the driving population had nodded off at least once in the previous year while driving. Interviewing long distance truck drivers revealed that 25% had fallen asleep in the past year and about 47% had fallen asleep at the wheel in their trucks (157). In a recent study, 22% of the lorry drivers reported that they had fallen asleep while driving. Furthermore, 39% of the drivers had been involved in an accident and of these drivers 16% admitted that sleepiness could have been a contributing factor (158). From these results it could be concluded that sleepiness while driving is very common.

**Predictors of sleepiness related traffic accidents**

**Time of day as a predictor**
According to a study that investigated drivers involved in sleep related vehicle accidents, three peaks during the twenty-four hour day were identified when accidents most often occurred: 2 a.m., 6 a.m., and 4 p.m. (149) Another database study including 4333 sleep related crashes showed that midnight to 7 a.m. and the mid-afternoon (3.00 p.m.) were the most common periods for sleep related traffic accidents (159). Others have found similar results; an accident peak between midnight and 6:00 a.m. and another peak during the late afternoon (160). In an American report of crashes due to driving while sleepy, 60% of the accidents occurred between 11 p.m. and 7 a.m. (155). Sagberg (154) reported that 20% of the sleep related traffic accidents occurred during the night. A Swedish study of driving during the night showed an increase of the risk for accidents with up to six times, peaking around 4 a.m. compared to before noon (161). In a review of sleep related vehicle accidents, the authors concluded that when driving around 6 a.m., drivers were 20 times more likely to fall asleep at the wheel than around 10 a.m. When driving around 4 p.m., the risk was three times higher (147). In a recent summary by the NHTSA, it was stated that late night/early morning or mid-afternoon is a critical period for sleepiness related accidents (26). There seems to be strong evidence supporting a link between sleepiness related traffic accidents and time of day. The vulnerable hours from midnight to 7 a.m. and around 4 p.m. correspond very well to the circadian rhythm.

**Driving conditions as a predictor**
Monotonous driving for longer periods, work related driving, and driving on a motorway are more likely to result in falling asleep at the wheel (147). An American report found increased accidents rates on motorways and non built-up roads, 16 – 20%, compared to built-up roads, 5% (162). Roads in densely built-up areas are less prone to sleepiness related accidents due to the higher activity level, which can help the driver to stay alert (151).
The driver as a predictor
Three main risk groups of drivers have been identified: male drivers aged 16 - 29 years, shift workers, and people with sleep problems (26). Sleepiness is common among young male drivers when driving at night (24). A study found that about 50% of the drivers involved in sleep related accidents were dominated by males under 30 years (149). Similar results were obtained in an American who found that drivers aged 25 years or younger were involved in 55% of sleepiness related crashes (163). A Finnish study correlated with age and time of day. They reported that the accident peak between midnight and 6:00 a.m. involved young drivers (18 to 20 years old), while the second peak during the late afternoon involved drivers 56 years or older (160).

Characteristics of a sleepiness related traffic accident
A sleepiness related traffic accident is characterized by running off the road or a collision with another vehicle or object without signs of braking before the crash (149). The accidents tend to be more severe due to higher speed at impact and no avoidance actions taken before the collision. Risk of serious injury or death may be greater in sleep related accidents than in other types of accident (26, 149). The typical sleepiness related accident involves a single vehicle leaving the road, on a motorway in the early hours of the morning, or between 3:00 and 4:00 pm with no attempt to brake or swerve to avoid the accident, and the driver is alone (148).
MATERIAL AND METHODS

To study indicators of sleepiness, data collections were carried out in an experimental setting and in a field study. In the experimental setting (Study I – IV) during four different test occasions, objective and subjective methods were used to measure sleepiness under two different test conditions, rested and sleep deprived. In the field study, data regarding sleepiness among professional drivers was obtained by questionnaires. An overview of data collection, study designs, subjects, preparations, procedures, and methods are presented in Figure 4.

<table>
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<th>Preparation at the laboratory</th>
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<table>
<thead>
<tr>
<th>Study</th>
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<th>Method</th>
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<tr>
<td>V</td>
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<td>Questionnaire</td>
<td>Prior sleep habits, Driving conditions, Individual characteristics</td>
<td>120 fulfilled, 7 excluded</td>
<td>+ 34 fulfilled</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sendlist: 227 drivers</td>
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Figure 4. An overview of design, subjects, preparations, procedure, and methods to measure sleepiness and symptoms of sleepiness. Study I – IV above and Study V below. The grey area represents the course of events in the laboratory.

Study I- IV

Subjects
Ten students recruited from Umeå University participated in the study (five men and five women ranging from 21 to 32 years of age (mean = 26 years)). All subjects were health screened. They rated themselves as being normal good sleepers with normal sleep routines, and they considered themselves in good health. They exercised on a regular basis at least every week, did not use medication, and did not smoke. The subjects received both verbal and written information before participation in the study and they were assured of
confidentiality regarding their identity. Written consent of participation was collected. Subjects were reimbursed SEK 1500 (approximately USD 100) for their participation.

**Preparation and procedure**

**Preparations before arriving to the laboratory. Test conditions.**

The experiment for each subject consisted of four test occasions that varied in length and type of condition. Three test occasions were performed under a sleep-deprived condition – 60 minutes, 90 minutes, 120 minutes – and one test occasion was performed in a rested condition for 120 minutes. The order of the four test occasions was randomised for each participant, and they didn’t know the length of each test. In general the average duration between each test occasion was eight days, and the average duration between sleep deprived test occasions and a following rested test occasion was nine days.

In the three sleep-deprived test occasions, sleepiness was provoked by instructing the subjects to only sleep between 11 p.m. and 3 a.m. the night before the test. The subjects were permitted to sleep according to their normal pattern the day before a rested test occasion.

For the 24-hour period immediately proceeding each test occasion, the subjects were instructed to maintain normal levels of activity during the morning hours, not to smoke or consume alcohol, to avoid sunlight, and not to watch television the morning of a test.

Each test occasion was carried out between 8 a.m. and 1 p.m. with no opportunity for the participants to make up for their lack of sleep if sleep deprived.

**Preparations at laboratory before each test occasion**

Before each test occasion, the participants answered a questionnaire about how they had slept the previous night and on their sleep habits for the previous week. Hours of sleep the night before each test occasion was on average 3 hours and 52 minutes (s.d. 33 minutes) for sleep-deprived test conditions and 7 hours and 25 minutes (s.d. 52 minutes) for the rested test condition. No statistical significant differences were found in sleep hours before the sleep-deprived test occasion, but before the rested test occasion the subjects slept significantly longer.

After arrival at the laboratory and answering the questionnaire, the subject was instructed to sit in a driver’s chair. Next the participants were connected to the monitoring devices (EEG, EOG, ECG and Inclinometer; for details see specific device). This took about an hour. Each testing occasion began with a baseline registration of the subject’s EEG activity, heart rate, and head movements. These measurements were made twice – 5 minutes with closed eyes and 5 minutes with open eyes. Directly after this baseline registration, the test proceeded.
Test period, awake phase
During the test, the subject was instructed to sit down, to stay awake, to not lean their head on the chair or on their hands, to keep their eyes open, and to focus on a computer monitor in front of them. The computer screen showed a still picture of an empty road and the subject was instructed to press a button as fast as possible each time they saw a yellow dot blink on the screen. The performance test stopped after every 15 minutes and the subject restarted it after he/she had completed the ratings and the questionnaire (done in approximately one minute). The rating scales were placed on a table in front of the subject. The subjects rated their own level of sleepiness and filled in a questionnaire at the start (every fifteen minutes) and at the end of each session. Registration of EEG as well as ECG and head movement was continuous.

Test period, sleep phase
As soon as the test was finished, the subject was placed on a bed in a private, screened-off section of the sound proofed lab and allowed to sleep for 60 minutes. Lights were turned off. EEG and ECG monitoring continued during the sleep phase.

Objective methods to measure sleepiness
Electroencephalographic, EEG
EEG was used in Study I – IV. The recordings of two derivations of the EEG, O2 – P4 (occipital), and C4 – A1 (central) were done with silver electrodes, 10 mm in diameter, placed according to the 10-20 systems. The occipital ground electrode was positioned at Pz, so the distance to O2 and the P4 electrodes were identical. The central ground electrode was positioned at C2. Before attaching the electrodes, the hair was combed to reveal the measuring point. The skin was rubbed and cleaned using skin prepping gel and acetone. The silver electrodes were attached to the measuring points with adhesive tape in two layers. To facilitate transfer of the EEG signals, a conductive EEG paste was used between the skin and the electrodes. When all electrodes were in place and mounted, the subject put on a hairnet. The EEG signals were transmitted to a preamplifier, which was mounted as close to the electrodes as possible, and brain waves were amplified and calibrated against a 30 µV sine wave signal. EEG signal was sent to a computer for gathering, processing, and analyzing of the data.

The sampling rate of the EEG was 64 Hz with an established band-pass-filter (0.5 and 30 Hz).
Spectral analysis – Fast Fourier Transformation (FFT) – of the EEG was performed. After each analysis four-second epochs were examined visually throughout the whole registration. were deleted from the recording and further analysis was conducted. To avoid arousal effects on the EEG, the mean values of the alpha and theta power for each 15 minutes was calculated using an exclusion
The mean value was calculated by averaging over the obtained values for the previous and following 7.5 minutes minus the 90 seconds immediately before and after the 15-minute mark. Thus, the EEG data collected when the subjects were performing sleepiness ratings was excluded in the analyses. EEG mean during sleep values were calculated over every 5 minutes. Alpha (8 – 12 Hz) and theta (4 - 8 Hz) power density were analyzed to determine changes in sleepiness during the wake period, and delta (< 3 Hz) power density was analyzed to reflect deep sleep during the sleep phase.

**Heart rate and Heart rate variability, HR/HRV**

Three electrocardiography (ECG) electrodes were applied to the chest in order to obtain a single channel ECG. The ECG signals were transmitted to a preamplifier. The ECG signal was recorded on a tape recorder for further processing and analyzing. The sampling rate was 500 Hz. The recordings were manually inspected and corrected for R-wave detection errors. Interpolation was done to replace artefacts caused by signal saturation due to baseline wander or arrhythmic beats. The beat-to-beat heart rate (HR) was calculated and converted to a time series by cubic spline interpolation and re-sampling at 2.4 Hz. The mean HR was calculated and power spectrum analysis was assessed on detrended data from 5-minute segments using autoregressive (AR) modelling of order 30 (164). The detrending was accomplished using a digital filter with a cut-off frequency at approximately 0.02 Hz as described above (165). The total spectral power (PTOT), the power of the very low frequency region (VLF) (PVLF: 0.02-0.04 Hz), the power of the low frequency region (LF) (PLF: 0.04-0.15 Hz), and power of the high frequency region (HF) (PHF: 0.15-0.40 Hz) components were calculated. Spectral power was expressed in mHz2 to avoid negative values after log-transformation because of skewed distributions.

HRV mean values from the wake data collection are based on the 5 minutes immediately before and after each 15 minutes minus 90 seconds immediately before each 15th minute. During the sleep phase, HRV mean values were calculated every 5 minutes.

**Performance test**

A computer monitor (20”) was placed in front of the subject showing a static picture of an empty road in a rural landscape. A button was placed on a table easily reachable for the subject. The subject could choose if the button should be on her/his right or left side. The subject was instructed to hold her/his hand close to the button and to press the button as fast as possible each time a small yellow light flashed in the screen. The lights blinked randomly 13 times every 15 minutes in one of four locations on the monitor. The performance test stopped after each 15-minute interval, and the subjects restarted the test after completing the ratings. The number of responses and the average reaction times calculated for each 15-minute block were stored in the computer.
Head movements
Head movements were obtained by using an inclinometer, a triaxial accelerometer (ADXL05EM-3 by Analog Devices, Inc.) The forward-backward and left-right head movements were recorded. The inclinometer was attached to the subject’s forehead with double-sided adhesive tape under the same hairnet that was used for attaching the EEG electrodes. The head movements, sampling one angle every second, were recorded during the whole test. The data were stored on a DAT-tape (SONY DIGITAL PC204A) and further processed using a computer (PC, Brüel & Kjær LabShop version 6.0). The recorded angle for each second was subtracted from the previous second’s angle to calculate angular velocity in degrees. After processing the data from head movements, the data during the period when the subjects rated their sleepiness were excluded. Excluded data were from the first two minutes, the five minutes around every 15-minute interval, and the last three minutes of each test. This resulted in time blocks of 10 minutes with 601 values available for statistical analyses.

Electrooculography, EOG
The recordings of eye movements were done with silver electrodes, 10 mm in diameter, placed around the right eye. Before attaching the electrodes, the skin was rubbed and cleaned. The silver electrodes were attached to the measuring points with adhesive tape in two layers. To facilitate transfer of the signals, a conductive paste was used between the skin and the electrodes. The EOG signals were transmitted to a preamplifier. The EOG signals were stored on a PC and the blink rate was calculated manually by visual inspection of the recording. A strip of the 5 minutes pre-test recording with controlled blinking was used as a pattern to facilitate the calculation (unpublished data).

Subjective methods to measure sleepiness
Karolinska Sleepiness Scale and the Category-Ratio Scale, KSS/CR-10
The Karolinska Sleepiness Scale, KSS, and the Category-Ratio Scale, CR-10 (also referred as the Borg-scale) were used to measure subjective sleepiness. The former was used in Study I-IV, and the latter was used in all studies. The subjects received written information about both scales by mail before participating for the first time. Before or during the mounting of EEG, ECG, and the inclinometer, the scale instructions were reviewed and subjects were given an opportunity to ask questions about them. The KSS is a 9-point graded, bipolar category scale with the verbal anchors of “very alert” (value =1), “alert” (3), “neither alert nor sleepy” (5), “Sleepy – difficulty remaining awake” (7), “Extremely sleepy – fighting sleep” (9). The steps between verbal labels have scale values but not verbal expressions (Appendix A). KSS has been used extensively in research concerning measurement of subjective sleepiness and has also been validated (122, 123). The subjects were asked to rate their sleepiness using the verbal expression or number that best corresponded to their experienced sleepiness.
The CR-10 scale is constructed to combine category scaling and ratio scaling (131, 166). It consists of verbal expressions, category scaling, anchored to a number scale, and ratio scaling that grows approximately exponentially (Appendix B). The rating of 10 – “Extremely strong – Max P” (P=perception) is a main point and corresponds to the subject’s previously worst experience of the feeling in question. Although the highest numerical value is anchored with the verbal expression “extremely strong”, the maximum lies outside of the number range in order to allow the subject to rate without constraint at maximal levels. That is, if the perception of sleepiness is stronger than what the subject has ever experienced, he or she can rate 11 or 12 or even higher.

The subjects were instructed to use the scale by first finding the verbal expression that best matches their perception and then to use the number scale to make adjustments to that rating. The basic question to the subject was this: “How would you rate your perceived intensity of sleepiness; that is, how heavy and strenuous does the sleepiness feel to you”? In this study the CR-10 scale was also used to let subjects rate their eye tiredness (called CR-10 eye).

The subjects were encouraged to only attend to their subjective feelings and not to any physiological cues. They were also encouraged to be as honest as possible, not to overestimate or underestimate their subjective feelings of sleepiness.

Swedish versions of the both scales were used.

**Questionnaire of sleepiness related symptoms during the test period**

Immediately after rating the sleepiness and before restarting the performance test, the subjects were instructed to answer six multiple-choice questions to rate the experience of common sleepiness related symptoms. The question asked about the experience of irritation in the eyes, heavy eyelids, the ability to focus the eyes, double vision, if time went slowly, and episodes of being absent during the last 15 minutes. (Unpublished data)

**Laboratory setup**

The experiment was carried out in a soundproofed laboratory with a temperature of 20°C to 23°C and with subdued lighting of approximately 5 Lux. The driver’s chair in which subjects were sitting was similar than truck chairs and did not have a headrest. A table with the rating scales and the computer screen was placed in front of the subject (Figure 5). Behind the subject was a table with technical equipment for processing the signals. The EEG, EOG, and ECG signals were all connected to a preamplifier each. These preamplifiers decrease the impedance of the obtained signals and optimize the signals. The preamplifiers are connected to a case containing amplifiers and power supply. The signals from the inclinometer (the instrument that measured head movement) were connected to another case that acted as a power supply, amplifier, and isolator. The signals are gathered and led out of the laboratory to an advanced printer (Picker Schwarzer ED14). Signals from the inclinometer were led to a separate printer. The functions of this printer
are for isolation of signals (preventing dangerous voltages to jeopardize the subjects’ health), further amplify signals, and filter the signals (band pass filter). The outgoing signals from the printer go to both a tape recorder and through a second low pass filter and synchroniser to a computer. To imitate the environment of a driver's cab, a sound system was installed in the room to produce normal vehicle noise (approximately 60 dBA) next to the test subject. The sound system was placed approximately two metres behind the subject.

Figure 5. Part of the laboratory setting, illustrating the subject’s chair, table, computer monitor, and the part of the equipment used to secure and amplify signals.

Study V

Subjects
The subjects for this study were 154 professional drivers in active duty, 149 men and 5 women (average 44.5 years (S.D. 13.00) with 18.9 years (S.D. 12.9) of driving experience). The majority of the drivers were normally engaged in long distance driving (n=127) either driving a long distance truck (n=96) or long distance bus (n = 31).
Subjective health status was rated as good or very good by 121 drivers, good by 28, and fairly or poor by 5 drivers. Over half (n = 91) of the drivers were non-smokers/non-moist snuff users and 59 drivers were either smokers or used moist
snuff. The majority (n = 61) of the drivers never or rarely exercised and 55 drivers exercised once a week and 28 drivers exercised two of more times a week. Those who completed and returned the questionnaire were mailed a lottery ticket with a value of about 25 SEK.

Procedure
Using different registries and addresses for haulages and drivers in northern Sweden, a list of 227 truck and bus drivers was compiled. The questionnaire was coded so the authors could send a reminder to those who had not completed and returned the questionnaire within approximately two weeks. The first dispatch of the questionnaires was done in October 2004 and a reminder was sent in November 2004. The answers were entered into computer without identifying the respondents. Seven of the questionnaires were excluded because they were returned due to an unknown address. Of the remaining 220 questionnaires, 120 (54.5%) were returned after the first dispatch and 34 (15.5%) were returned after the reminder. The overall participation rate was 154 (70.0%).

Questionnaire
The questionnaire is based on the experiences from questionnaires used in previous field studies of professional drivers (89, 92, 167). The authors developed a questionnaire based on their previous studies on sleepiness (168, 169). The final seven pages was a self-completion questionnaire containing 28 questions with 84 items. The majority of the questions were multiple-choice questions with more than three alternatives. Two questions were open-ended. The questionnaire contained the following sections about individual and work characteristics: age, sex, year of driving experience, type of vehicle, type of driving (long distance, short distance, or mixed driving), driving time before rest, type of work shift, self-rated health, tobacco use, exercise habits, usual amount of sleep hours before driving, and sleep pattern/quality.

The questionnaire contained the following questions about sleepiness while driving: self-rated sleep quality before driving, experience of sleepiness – fighting sleepiness and head nodding while driving, experience of sleepiness that forces the driver to stop driving, and season and time of day when sleepiness is most pronounced. The CR-10 rating scale (166) was used and the drivers were asked to rate their sleepiness and when they had felt so sleepy that they needed to stop driving and take a nap.

The questionnaire contained the following questions about the symptoms of sleepiness while driving, when these symptoms occurred, and countermeasures taken by the driver. The following symptoms of sleepiness were listed: (1) yawning; (2) difficulties with keeping track of time; (3) difficulties with keeping
one thoughts together; (4) difficulties concentrating on the road; (5) eye tiredness; (6) feeling of heavy eyelids; (7) difficulties to sitting still; (8) difficulties keeping head upright; (9) feeling of sickness; (10) feeling of dizziness. Countermeasures in the list for stop driving were (a) take a “coffee” break and (b) take a nap/sleep. Countermeasures in the list for driving were (a) drink coffee, (b) using tobacco, (c) eat snacks, food, or something else, (d) turn up the volume of the stereo, (e) call and talk to someone, (f) lower the temperature in the cabin, (g) increase the temperature in the cabin, (h) open the side window, (i) increase the light in the cabin, (j) change driving speed, and (k) others (open-ended).

Questions about factors contributing to sleepiness while driving include the following: (1) not enough sleep; (2) poor sleep quality prior driving; (3) poor work schedules; (4) too long driving shift; (5) annoying sound in the cabin; (6) annoying sound from the road; (7) vibrations in the cabin; (8) too warm in the cabin; (9) poor light conditions; (10) poor eating habits; (11) too little exercise; (12) too much exercise, (13) monotonous driving; (14) other factors (open-ended).

Statistical methods

Study I-IV
The statistical analysis was made using SPSS software version 11.0 (SPSS, Chicago, IL) and conducted using ANOVA for repeated measurements with either one within factor (time) when analyzing each variable or with two within factors (time and condition) when analyzing differences between sleep-deprived and rested condition. For variables with statistically significant interaction between test condition and time, we analyzed changes over time in each test condition, i.e., time as the only within factor. Huynh-Felt adjustments were used since the sphericity assumption was presumably violated. To analyze correlations between variables, Pearson’s correlation coefficient was used. For statistical tests, an alpha level of 0.05 was used.

Study V
The statistical analysis was made using SPSS software version 11.0 (SPSS, Chicago, IL). Beside descriptive statistics, Fischer S exact test was used for R x C contingency tables (nominal and ordinal data). Independent t-test were used for the interval data: age, year of experience, and sleep hours. To compare scores between groups, Mann–Whitney test for 2 independent samples was used.
RESULTS

In Study I – IV, both objective and subjective indicators of sleepiness were investigated to study both the pattern and the relationship between the indicators. Study V deals with prevalence and predictor of sleepiness and sleepiness related factors. To facilitate the reading of this section, an overview is presented in Table 2.

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<td></td>
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<td>Performance</td>
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<td>Subjective indicators</td>
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<tr>
<td>The relationship between indicators</td>
<td>Between objective indicators</td>
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<td>Performance - EEG / HR / HRV</td>
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<td>Head movements - EEG / HR / HRV</td>
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<td>Between objective and subjective indicators</td>
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<td>Contributing factors to sleepiness</td>
<td>V</td>
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</tbody>
</table>

The pattern of objective indicators of sleepiness

**EEG, alpha and theta power density**

The changes of alpha power density over time during sleep deprived and rested conditions are described in Figure 6. A significant increase of alpha power density (p < .05) is seen in the 60-minute test condition. For theta power density, a significant increase when sleep deprived could be found for the 60- and 90-minute test condition and during the first 60 minutes in the 90-minute test condition (p < .05 and p < .05 respectively). When the subjects were rested, both alpha and theta power density increased significantly over the 120-minute period. When comparing the 120-minute sleep deprived condition with 120-minute rested condition, no significant interaction could be found in the alpha and theta activity, and no difference was noted in the level of the alpha or theta power density.
Heart rate and heart rate variability
The average HR was higher when the subjects were rested compared to when sleep deprived. However, during the 120-minute test periods, the average HR decreased to approximately 63 beats per minute in both test conditions. For this period, a significant interaction for the factors time and conditions were found (p < .05), indicating that HR when being sleep deprived had different patterns over time and at different levels compared to when rested.

Changes of the average total heart rate variability, P_{TOT}, during awake and sleep for both the 120-minute test conditions are presented graphically in Figure 7. All HRV components increased significantly over time during the 120 minutes (p –value ranging from <.001 to <.01). However, no significant interactions effect (time x condition) could be found for any of the components.
Figure 7. Mean $P_{\text{TOT}}$ averaged over individuals during both sleep deprived and rested conditions for the wake phase followed by the sleep phase. Standard deviations for $P_{\text{TOT}}$ in sleep-deprived condition ranged from 0.2 – 0.3 in awake phase and from 0.4 – 0.8 in the sleep phase. In the rested condition, the corresponding ranges were 0.2 – 0.3 and 0.4 – 0.5.

During sleep, HR remained constant in both test conditions. However, during the sleep phase, all average HRV components values dropped more over time when the subjects had been sleep deprived compared to when being rested (for $P_{\text{TOT}}$ see Figure 7). Interaction effects between time and condition were found for $P_{\text{TOT}}$, $P_{\text{VLF}}$, and $P_{\text{LF}}$ ($p < .01$, $p < .05$, $p < .05$ respectively), which became significant after about 40 – 45 minutes (simple contrasts post-hoc test).

**Performance**

The reaction time over time increased for both test conditions. Analysis found no significant interaction effect (Condition x Time); however, when the subjects were sleep deprived, they had a significantly longer reactions time compared to when rested ($p < .05$). Thus regardless of test condition subjects reaction times slowed over the test period; however, when sleep deprived, the reaction times were slower compared to when rested.

When rested, subjects on average missed approximately one response per block (Mean = 0.8, SD = 0.4). When sleep deprived, the average missed response rate was 3.4 per block (S.D = 0.5) (Figure 8). ANOVA for repeated measures confirmed that when the subjects were sleep deprived, they had significantly more misses than when rested ($p < .05$). No significant result for time was found; that is, it could not be shown that the subjects had more misses in the end of test compared to the start.
Head movements

The velocity of the head movements in the forward – backward direction in the three sleep deprived test condition ranged from −118 to 118 degrees. For the corresponding left – right direction, it ranged from - 147 to 134 degrees (S.D ranged from 5.6 to 6.3). When rested, the velocity in the forward – backward and left – right direction ranged from −103.9 to 77.8 degrees and −88.5 to 95.3 degrees respectively. A vector velocity was calculated (Pythagorean theorem) from each of the forward – backward and corresponding left – right velocity.

Analyses of the distance of head movements over time found no significant interaction between condition and time. However, significant main effects for time (p values ranging from p <.001 to p < .05) could be found for both the sleep deprived condition and the rested condition, suggesting that the distance of head movements increased equally over time for both conditions. When comparing sleep deprived or part of sleep deprived conditions with the rested 120-minute test or part of the rested condition, significant main effects for conditions were found, suggesting that the sleep-deprived subjects moved their head more than when they were rested (p values ranging from p < .001 to p < .05).

Analyses of extreme head movements found similar results as the analyses of distance of head movements. Number of extreme velocities of head movement increases equally in both test conditions. However, when sleep deprived, the
number of extreme velocities of head movement are on average significant at a higher level than when rested (Figure 9).

![Figure 9. The average number of extreme vector velocities. Velocity is over the time blocks for each test condition. The filled markers are test condition when the subjects are sleep deprived.](image)

No statistical differences could be found when comparing head movements in the forward – backwards direction and the left – right direction.

**The pattern of subjective indicators of sleepiness**

**KSS and CR-10**

The subjective ratings increased during roughly the first hour; thereafter the ratings levelled off. The average sleepiness ratings on the KSS scale, when sleep deprived, started at around 6, “Neither alert nor sleepy” to “Sleepy – but no difficulty remaining awake”. The ratings increased significantly during the first hour to an average of approximately 8, corresponding to a verbal expression between “sleepy – but no difficulty remaining awake” and “Extremely sleepy – fighting sleep”. After the first hour, the ratings remained relatively flat throughout the test period.
Perceived sleepiness using the CR-10 scale (Figure 10) started on average at about 3, corresponding to a verbal expression of "Moderate" intensity of sleepiness and increased significantly to approximately 7 ("Very strong" intensity of sleepiness). After 60 minutes, the rating levels off and increased slightly during the remaining period.

The increase in sleepiness over time using both KSS and CR-10 was significant in all the sleep-deprived conditions (p < .001). In the majority of the post-hoc analyses of CR-10 a linear function best described the pattern of increasing sleepiness.

No significant interaction effects were found between condition and time for either ratings of sleepiness. However, the levels of sleepiness ratings were significantly lower in the 120-minute rested test condition compared to the sleep deprived condition (p < .001).
The relationship between indicators of sleepiness

**Between objective indicators**

When the subjects were sleep deprived, the correlation between the indicators was low and insignificant except for the correlation between reaction time and heart rate (Table 3). Similar results were found when comparing alpha, theta, and head movements for other test conditions than the two 120-minute test conditions. However, when the subjects were rested, significant correlations were found (Table 2). Graphically these correlations appeared to be linear.

<table>
<thead>
<tr>
<th>Test condition/indicator</th>
<th>Theta</th>
<th>HR</th>
<th>HRV, Ptot</th>
<th>Reaction time</th>
<th>Head movement, extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SLEEP DEPRIVED.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alpha</td>
<td>0.587</td>
<td>0.040</td>
<td>0.224</td>
<td>0.321</td>
<td>-0.438</td>
</tr>
<tr>
<td>Theta</td>
<td>-</td>
<td>-0.219</td>
<td>0.086</td>
<td>0.691</td>
<td>0.228</td>
</tr>
<tr>
<td>HR</td>
<td></td>
<td>n.m</td>
<td>-0.866**</td>
<td>-0.480</td>
<td></td>
</tr>
<tr>
<td>HRV, Ptot</td>
<td></td>
<td></td>
<td></td>
<td>0.709</td>
<td>0.143</td>
</tr>
<tr>
<td>Reaction time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head movement, extreme</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RESTED</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alpha</td>
<td>0.945***</td>
<td>-0.701*</td>
<td>0.846***</td>
<td>0.341</td>
<td>0.885**</td>
</tr>
<tr>
<td>Theta</td>
<td>-</td>
<td>-0.785**</td>
<td>0.888***</td>
<td>0.545</td>
<td>0.946**</td>
</tr>
<tr>
<td>HR</td>
<td></td>
<td>n.m</td>
<td>-0.811*</td>
<td>-0.966**</td>
<td></td>
</tr>
<tr>
<td>HRV, Ptot</td>
<td></td>
<td></td>
<td></td>
<td>0.659</td>
<td>-0.810*</td>
</tr>
<tr>
<td>Reaction time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head movement, extreme</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* = p < .05; ** = p < .01; *** p <0.001; n.m = not measured

During the sleep phase (Study II), high and significant negative correlations were found between delta power activity and all the HRV components (r = -0.880 to -0.839; all p < .001) when the subjects had been sleep deprived. For rest, no correlations were found.

**Between objective and subjective indicators**

The theta power density was the EEG variable that correlated to subjective sleepiness ratings when the subjects had been sleep deprived, while alpha power density correlated significantly only to the sleepiness ratings when the subjects were rested (Table 4). Significant correlations were also found between theta power density and sleepiness ratings by both KSS and CR10 during the first 60 minutes in two of the three sleep-deprived test conditions. Correlations between reaction time and sleepiness ratings were higher when sleep deprived than when rested (Table 4). When the subjects were rested, high and significant correlations
could be found between subjective ratings of head movements; however, when sleep deprived, correlations in general were low and insignificant with the exception of the correlation between KSS and extreme head movements.

Table 4 Correlations between objective and subjective indicators in the two test conditions that lasted 120 minutes.

<table>
<thead>
<tr>
<th>TEST CONDITION</th>
<th>Alpha</th>
<th>Theta</th>
<th>Reaction time</th>
<th>Head movement, extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 min sleep deprived</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KSS</td>
<td>0.530</td>
<td>0.763*</td>
<td>0.950***</td>
<td>0.806*</td>
</tr>
<tr>
<td>CR-10</td>
<td>0.351</td>
<td>0.725*</td>
<td>0.920***</td>
<td>0.861</td>
</tr>
<tr>
<td>120 min rested</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KSS</td>
<td>0.833**</td>
<td>0.917*</td>
<td>0.763*</td>
<td>0.933**</td>
</tr>
<tr>
<td>CR-10</td>
<td>0.805**</td>
<td>0.915*</td>
<td>0.764*</td>
<td>0.892**</td>
</tr>
</tbody>
</table>

Between subjective indicators
Subjective sleepiness ratings made by KSS and CR-10 were found to correlate significantly with each other both in rested and in sleep-deprived conditions, including the partial time periods (r = 0.943 to 0.988; p < 0.05 to p < .001).

The prevalence of sleepiness

Drivers’ characteristics
The majority of the drivers (84%) were normally engaged in long distance driving and most of the drivers (66%) transported mixed cargo, including timber and ore. The majority of the drivers (75%) had either a shift-driving schedule including both daytime driving (06.00 - 18.00) and night time driving (18.00 - 06.00) or solely night time driving and more than half of the drivers (57%) usually drove for 2 to 4 hours without a break.

Sleepiness and among the drivers while driving
Sleepiness while driving was reported by 14% of the drivers to occur often or more than often and 30% of the drivers occasionally had to fight sleepiness while driving. The majority of the drivers (77 %) reported that they, at least once, needed to stop their driving due to sleepiness. Furthermore, 23% of the drivers occasionally or more frequently experienced such intense sleepiness that they were forced to stop driving. The corresponding rating of the sleepiness that forced them to stop driving at that time was on average 5.0 (S.D 2.4) on the CR-10 scale, which
corresponds to an intensity of sleepiness of “strong, heavy and difficult”. The most frequent symptoms of sleepiness while driving reported by the drivers that occurred during their driving were yawning (94%), eye tiredness (83%), and heavy eyelids (75%). Occasional head nodding/drop offs while driving was reported by 8% (n = 12) of the drivers.

Most frequent factors contributing to sleepiness while driving reported by the drivers were not getting enough sleep, poor sleep quality prior to driving, and poor work schedules. When asked which single factor contributed most to sleepiness while driving, 30% of the drivers reported not getting enough sleep, and 20% of the drivers reported poor sleep quality before driving, and 20.5% (n = 31) of the drivers reported poor work schedules.

Sleepiness and time
The majority of the drivers (66%) reported autumn to be the time of year that they considered sleepiness to be most troublesome, and 21% of the drivers reported winter as the most troublesome period of the year. Almost half the drivers (46%) reported that sleepiness was most severe between 3 a.m. and 6 a.m., and 14% reported that sleepiness was most severe between 12 p.m. to 3 a.m.

Countermeasures
Frequently used countermeasures to sleepiness reported by the drivers were to eat snacks or food, stop for a break, and turn up the volume on the stereo. Other countermeasures were drinking coffee while driving or using tobacco.

Predictors of sleepiness

General comparisons
Three areas of predictors of sleepiness while driving were created; sleep habits before driving, work conditions, and individual characteristics. In each area, the drivers were divided differently into two groups, and comparisons were made using dependent variables in four main themes: general aspects of sleepiness, specific sleepiness symptoms, countermeasures, and contributing factors. For the before sleep habits, 37% of the all the comparisons were found significant at level of p < .05 or higher. For work conditions and individual characteristics, 15% and 13% respectively of all comparisons were significant (Figure 11).
Prior sleep habits

The predictors in the area of prior sleep habits are prior sleep time before a driving shift, general feeling of sleep quality, prior sleep quality to a shift, and rated sleep problems. Drivers with short sleep (< 7 h), poor sleep quality both in general and prior a driving shift and with a higher degree of sleep problems experienced significantly more sleepiness while driving, fought more often against sleepiness than those with long sleep, good sleep quality, and a low degree of sleepiness problem (Table 5).

Sleepiness symptoms include eye tiredness, feeling of heavy eyelids, difficulties sitting still, keeping one’s thoughts together, and keeping the head upright. These were significantly more common for drivers who reported short sleep, poor sleep quality, or a higher frequency of sleepiness problem.

Countermeasures significantly more often used by drivers with poor sleep habits were turning up the volume of the radio, lowering the temperature in the cabin, or changing the driving speed.

Drivers with short sleep, poor general sleep quality, poor sleep prior to driving, or high frequency of sleep problems more often reported poor work schedule as contributing factor to sleepiness. Poor sleep prior driving was also reported more often as a contributing factor to sleepiness while driving by drivers with poor sleep quality.
Work conditions
The predictors in the area of work conditions were driving time, type of driving, and work shift. Long distance drivers reported to experience sleepiness more often, in general more often use countermeasures, and reported more contributing factors to sleepiness than drivers who drove in densely populated areas. Night shift drivers reported in general symptoms of sleepiness to occur more often than day shift drivers. Driving time, when divided into more or less two hours of driving time without taking a break, could not be found as a predictor of sleepiness.

Individual characteristics
The predictors in the area of individual characteristics were age, driving experience, exercise habits, tobacco use, and self reported health. The majority of the comparisons were insignificant and no clear picture was evident. However, young or less experienced drivers significantly rated the level of sleepiness on the CR-10 scale that forced them to stop driving higher than older or more experienced drivers. Younger drivers more often used countermeasures such as coffee, tobacco, food/snacks, or turning up the radio volume than older drivers. Drivers who reported good health in general had fewer sleepiness symptoms and used countermeasures to sleepiness less often.
Table 5. Analyses of prior sleep aspects interference with sleepiness and sleepiness related variables. The drivers were grouped in four different ways (first row) and analyzed against sleepiness/sleepiness related variables (first column). Frequency distributions of the first four variables are shown and the significant level of Fischer’s Exact test are below each distribution. For the five lower variables, mean ranks and the significant level of the Mann-Whitney U test are shown.

<table>
<thead>
<tr>
<th>General variables of sleepiness, countermeasures and contributing factors to sleepiness</th>
<th>Short-sleep (%)</th>
<th>Long-sleep (%)</th>
<th>Good-sleep (%)</th>
<th>Poor-sleep (%)</th>
<th>Fischer’s Exact test</th>
<th>Mann-Whitney U test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Experience of feeling sleepy while driving</strong></td>
<td>Always/almost always</td>
<td>2.3</td>
<td>0.0</td>
<td>1.1</td>
<td>1.7</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Occasionally</td>
<td>58.1</td>
<td>35.8</td>
<td>48.4</td>
<td>49.2</td>
<td>43.2</td>
</tr>
<tr>
<td></td>
<td>Rarely</td>
<td>22.1</td>
<td>49.3</td>
<td>42.1</td>
<td>20.3</td>
<td>44.2</td>
</tr>
<tr>
<td></td>
<td>Never</td>
<td>1.2</td>
<td>7.5</td>
<td>3.2</td>
<td>5.1</td>
<td>5.3</td>
</tr>
<tr>
<td><strong>Experience of fighting sleepiness while driving</strong></td>
<td>Always/almost always</td>
<td>1.2</td>
<td>0.0</td>
<td>1.1</td>
<td>0.0</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Occasionally</td>
<td>9.3</td>
<td>3.0</td>
<td>2.1</td>
<td>13.6</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>Rarely</td>
<td>43.0</td>
<td>50.7</td>
<td>52.6</td>
<td>37.3</td>
<td>52.6</td>
</tr>
<tr>
<td></td>
<td>Never</td>
<td>8.1</td>
<td>26.9</td>
<td>20.0</td>
<td>11.2</td>
<td>23.2</td>
</tr>
<tr>
<td><strong>Experience of head nodding/drop off while driving</strong></td>
<td>Always/almost always</td>
<td>1.2</td>
<td>0.0</td>
<td>1.1</td>
<td>0.0</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Occasionally</td>
<td>11.6</td>
<td>3.0</td>
<td>4.2</td>
<td>13.6</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>Rarely</td>
<td>48.8</td>
<td>44.8</td>
<td>47.4</td>
<td>40.7</td>
<td>43.2</td>
</tr>
<tr>
<td></td>
<td>Never</td>
<td>38.4</td>
<td>52.2</td>
<td>47.4</td>
<td>40.7</td>
<td>51.6</td>
</tr>
<tr>
<td><strong>Experience of feeling so sleepy while driving that stop driving was necessitated</strong></td>
<td>Always/almost always</td>
<td>1.2</td>
<td>1.5</td>
<td>1.1</td>
<td>1.7</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>Occasionally</td>
<td>3.5</td>
<td>0.0</td>
<td>0.0</td>
<td>5.1</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Rarely</td>
<td>60.5</td>
<td>49.3</td>
<td>55.8</td>
<td>35.9</td>
<td>55.8</td>
</tr>
<tr>
<td></td>
<td>Never</td>
<td>10.5</td>
<td>35.8</td>
<td>24.2</td>
<td>16.9</td>
<td>27.4</td>
</tr>
</tbody>
</table>

| General occurrence of sleepiness symptoms | Mean ranks | 83.5 | 65.3 | 66.0 | 87.2 | 66.8 | 89.6 | 63.1 | 88.7 | p < .01 | p < .01 |
| | (n) | 84 | 66 | 93 | 58 | 93 | 57 | 75 | 76 |
| General appearance of sleepiness symptoms | Mean ranks | 75.9 | 71.6 | 73.4 | 76.2 | 72.3 | 76.9 | 73.9 | 75.1 | n.s | n.s |
| | (n) | 82 | 65 | 91 | 57 | 92 | 55 | 75 | 73 |
| General use of countermeasures | Mean ranks | 84.6 | 64.2 | 72.5 | 81.8 | 70.2 | 84.1 | 69.1 | 83.0 | n.s | n.s |
| | (n) | 83 | 67 | 94 | 57 | 93 | 57 | 76 | 75 |
| General opinion of contributing factors to sleepiness | Mean ranks | 82.5 | 68.9 | 76.8 | 78.9 | 72.7 | 62.7 | 74.6 | 79.4 | p < .01 | p < .001 |
| | (n) | 86 | 67 | 94 | 59 | 94 | 58 | 87 | 77 |
| **CR-10 rating scale** | Mean ranks | 57.7 | 61.6 | 55.9 | 64.7 | 55.2 | 64.0 | 54.0 | 64.0 | n.s | n.s |
| | (n) | 77 | 40 | 70 | 48 | 66 | 51 | 53 | 65 | n.s | n.s |
DISCUSSION

The figure presented in the introduction, can be used as a basis for this discussion. The five studies deal with different parts of sleepiness as illustrated in Figure 12. Studies I – IV deal mainly with indicators while Study V deals with prevalence, driving aspects, and predictors of sleepiness. That is, factors that affect the weight of either the left or right bowl and thereby the balance of the scale which in turn leads the indicator to gauge at another level of sleepiness. Study V also deals with factors related to the circadian rhythm and these factors determine the direction of “circadian rhythm–weight” which in turn also affect the level of sleepiness. The discussion will begin with the indicators followed by the factors affecting the right bowl – sleep debt, factors affecting the left bowl – countermeasures including internal/external stimulation, and factors related to the circadian rhythm.

Figure 12. Schematic illustration of the level sleepiness (arc) in a context of sleepiness indicator (arrow), sleep debt (right bowl), countermeasures (left bowl), circadian rhythm (the weight under the scale of balance) and risk of an accident (wedge). The way in which the five studies in this thesis deal with aspects of sleepiness are pointed out in the illustration.

Indicators – The gauge

When comparing results from the sleep-deprived condition and the rested condition it was found that absolute differences were most readily observable in the performance task, subjective ratings, and head movements and to a lesser degree HR. Subjects performed worse in the attention task, rated themselves more sleepy
and moved their head more frequently when they were sleep deprived compared to when they had rested. Absolute differences in EEG and HRV between the two conditions were not found. In fact, HRV does not seem to be an indicator of sleepiness in any respect while the subject is awake.

One reoccurring theme appeared in the analyses of the different indicators of sleepiness. In the sleep-deprived state values tended to change rapidly during roughly the first 60 min before levelling off and staying relatively constant until the end of the 2 hour test period. This was most evident with the subjective ratings, HR, and head movements, as well as occurring to a lesser degree in EEG. When rested, however, most variables tended to change only slightly and most often linearly during the test period.

One explanation to the EEG findings when the subjects were sleep deprived could be that their sleepiness, measured by alpha activity, was close to the border of falling a sleep already from the beginning of the tests and that this is reflected by a relatively constant alpha power density. Similar reasoning could be applied to theta activity, meaning that since the subject forced him/herself to stay awake, further increase in theta activity, as an EEG sign of sleep stage I, is not possible. In this study, beta activity, which represents active wakefulness, was not investigated, however if done it might have shed some light of the subjects’ prior level of wakefulness.

It can be difficult to find significant changes of alpha and theta activity due to sleepiness. In a study by Kecklund and Akerstedt (96), sleepiness among evening and night truck drivers when performing a 12-13 hour shift that included a 500 km drive, was investigated. Analysis revealed no significant changes between evening and night drivers, mean alpha, or mean theta over time and no differences were found during the first 2-3 hours. However, when analyzing the number of burst activities above a certain level, the night drivers had an increased alpha and theta burst activity during the last three hours of the drive.

Akerstedt and Gillberg (122) have pointed out a relation between subjects’ alpha and theta levels. They reasoned that when subjects become very sleepy and there eyes remain open, the activity in the alpha band is decreased with a corresponding increase in the theta band. They suggest an individual calibration, which was done in Study I, and another subdivision of the traditional alpha and theta band, which was not done in Study I. Inclusion in the analysis of beta activity, which represents active wakefulness, and delta activity, which has been found to increase with sleepiness (170), even if it traditionally has been seen to represent deep sleep, might have shed some light of the subjects’ prior level of wakefulness and pattern of sleepiness.
Horne and Reyner (33, 83) have stated that the sum of alpha and theta power density is a more accurate measure of sleepiness than either alone. Using sleep-deprived subjects, they found a significant increase of the sum of the alpha and theta power density over time with a levelling off after approximately 40 to 60 minutes. They also found a difference in the level of this sum between those who were sleep deprived compared to those who had a normal night sleep. Even if this approach was not the case in Study I, the pattern in the Horne and Reyner (33, 83) study is similar to the pattern of the alpha activity in Study I.

When subjects were sleepy from the beginning, EEG reflects sleepiness without distinguishing levels of sleepiness and one might suspect that this is the maximum or close to the maximum level of alpha and theta power density. However, motivated sleepy subjects put a lot of effort into staying awake and keeping their eyes open even if alpha/theta activity indicates high levels of sleepiness. Thus, motivation can be seen as a countermeasure/stimulation, the left bowl in Figure 12, which counterbalances the sleep debt. This phenomenon may be similar to the effect experienced by many runners who hit the “wall” of exhaustion that normally would have made them stop but find some motivation that can keep them running.

Heart rate did change significantly and differentially over time when comparing the sleep deprived and the rested test condition. When the subjects were sleepy they had a significantly lower HR after 45 minutes compared to when rested, where a lowering of the HR was first seen after 75 minutes. Investigation of HR in sleepiness trials in a laboratory environment has previously shown that HR decreases over time (171, 172), but in both of these studies no comparison was made between sleep-deprived or rested subjects.

Decreased HR is usually associated with an increase of HRV. In a study by Riemersma (173), subjects performing a monotonous driving task showed a decrease in HR and an increase in HRV. It was concluded that these results more reflected an adaptation to decreased stress and habituation to sensory stimulation rather than to fatigue. This is also a plausible explanation for the HRV and HR results reported here.

HRV does not provide clear information about the development of sleepiness that could make it a relevant indicator of sleepiness. However, the strong relationship seen in Study II between HRV and delta power during sleep opens the possibility of using HRV as a sleep stage indicator.

The performance on a simple reaction time task during a two hour test was found to be both significantly slower, roughly about 20%, and poorer, about three times more misses, when the subjects were sleep deprived compared to when being rested. Gillberg and Åkerstedt (112) reported decreased performance from the start
of a single monotonous task with subjects sleep deprived due to a single night of lost sleep. When the subjects were sleep deprived they had a harder time detecting the signal and reacted slower when the signal was detected, reaction times when sleep deprived in the first 15 minute block appeared to be on par with reaction times when rested. The subjects may have initially been more alert due to the pre-test preparations, which is in contrast to Gillberg and Åkerstedt (112) where subjects may have been habituated to the testing situation.

The correlations between subjective ratings of sleepiness and reaction time were extremely high. This has also been observed in other studies with sleep deprivation (123, 174). There was also a significant correlation between theta activity and reaction time while misses only significantly correlated to some of the other variables and then only in the rested condition. The correlation seen in these data tends to support the claim made by Gillberg and Åkerstedt (112) that sleep loss may affect performance in terms of attention capability differentially than in terms of psychomotor response.

The increase of the velocities and number of extreme movements was evident from the beginning of the experiments. Most of the increase of the head movements when the subjects were sleep deprived appeared to occur during the first hour and then level off for the rest of test. An increase of head movements while driving in non-sleep-deprived subjects has been shown by Popiel, Simon, and Loslever (116). This increase in head movement appeared clearly after 150 km of 300 km of simulated monotonous driving. However, the results in Study IV suggest that head movement increased significantly during the first hour, independent of whether the subjects were sleep deprived or not. Thus, head movements may reflect an early phase of increased sleepiness and furthermore suggest that head movements are a time sensitive indicator of sleepiness.

The differences between head movements when subjects were sleep deprived and when they were rested supports the idea of a relationship between head movement and sleepiness. Even if statistical analysis did not show a clear picture of an interaction, the results indicate that head movements when sleep deprived not only have a different development over time but also is greater magnitude. Besides, the results show that a sleepy person changes head position more than an alert person. Behavioural activities due to symptoms of sleepiness (such as yawning or nodding) or countermeasures to sleepiness (changing head position, stretching, and so on) cause head movements. This has shown to increase over time under simulated monotonous driving conditions. Due to reduced muscle tone while sleepy, a person has a less stable head position and might increase head movements (175).

Subjective sleepiness ratings made by KSS and CR-10 show a similar pattern, and from Figure 10 in the result section, this appears to be a ceiling effect. This ceiling effect has also been shown by others (33), and given that the EEG measures do not
distinctly change during the entire period when sleep deprived, it might be more proper to view this levelling off as the ratings of perceived sleepiness catching up to the physiological measures. In contrast, others have suggested that changes in the EEG do not become manifest until the subjective sleepiness ratings are considerable, i.e. “sleepy” to “very sleepy” (122), suggesting that the EEG variables catch up to the sleepiness ratings. Furthermore, the same authors state that one should not expect a relationship between alpha/theta activity and sleepiness ratings if the subjects are not sleepy. The results in Study I indicate otherwise, i.e. the best correlations between EEG and subjective sleepiness rating were found when the subjects were rested.

As described previously, the KSS is a bipolar scale numbered from 1 to 9. The available number for the subjects to rate sleepiness is therefore limited to 6 to 9, i.e. four whole number steps. This was also shown in Study I. When the subjects were sleep deprived, they started their sleepiness ratings on the KSS on average around 6, which corresponds to the verbal expression: “Some sign of sleepiness” (33). As mentioned, the sleepiness ratings did level off after approximately one hour at a level around 8. Thus, a ceiling effect to be present in the KSS results was not so surprising. The CR-10 scale, a unipolar scale, ranges from 0 to theoretically infinity. This allows subjects to be more precise in their ratings of sleepiness. This was also reflected in the results of the CR-10 ratings that ranged from 3 to slightly more than 7. However, a levelling off was also seen for the CR-10 at the same time as KSS ratings and agreed with the steady state results seen in the physiological measurements. An indication in the present data of a ceiling effect with KSS ratings was when significant differences over time could be adequately described by both a linear and quadratic relationship while for the CR-10 scale it could only be significantly described by a linear relationship during approximately the first 90 minutes.

Thus, CR-10 has been shown to at least measure ratings of sleepiness as effectively as the established and validated KSS rating scale (122, 123). The CR-10 scale is a general scale for measuring perceived intensity and has been shown to work well with a wide range of perceptual experiences (166). To the author’s knowledge this might be one of the first times CR-10 has been used in measuring the perceived intensity of sleepiness. An advantage of using one scale to measure the intensity of several different symptoms or perceptions can be found for both the person administering the scale and the person rating. That is, only one general methodology has to be learned by both parties, saving time and resources.
The ceiling effect of the indicators of sleepiness

Except for the HR and the HRV components, EEG activity, reactions time, head movements and sleepiness rating showed a similar pattern. That is, when the subjects were sleep deprived, there was a marked increase during approximately the first hour before level off for the rest of the test period when rested there was a linear increase over the whole test period.

The studies carried out describe a ceiling effect among the above indicators. That is, when the subjects become increasingly sleepy, the measured values increased to a certain maximal level and thereafter remained relatively constant throughout the test period.

The most prominent ceiling effect was seen for the subjective ratings on the KSS as well as to CR-10 sleepiness ratings. The ceiling of subjective ratings can be interpreted as the subject not being able to rate their sleepiness higher without falling asleep because they are already struggling hard to stay awake. If the subjects should fall asleep, naturally no further sleepiness ratings would be obtained. Head movement, both velocity and numbers of extreme head movements also leveled off after approximately one hour when the subject struggled to stay awake. In a study by Wright and McGown (115), which measured head movements among pilots, head movement was present during work, but as expected when the pilots fell asleep, no head movements were shown. Thus, if this ceiling effect represents a maximum level of unconscious head movements, the next thing that happens when the subject falls asleep should be a decrease of head movement, probably drop to near zero. The same reasoning could be applied on alpha and theta activity. As long as the subject remains awake, some alpha and theta activity is present. When falling asleep, the power in this band will decrease while it will
increase in the delta band. Reaction time increased during the first hour after which it leveled off in the same pattern as noted in the above sleepiness indicators. Even in this case, if the subject falls asleep, naturally no the reaction time will be measured.

Thus, the common pattern for subjective sleepiness rating, head movements, reaction time, and EEG variables seems to be an increase of the measured values to a certain “maximum” level within the first hour when sleepy. This also indicates that all of these can measure sleepiness. A drawback of this leveling off, however, is that it makes these measurements rather blunt in a sense. All of these measurements with values at the or close to the “maximum” can be interpreted as indicating a high level of sleepiness and a potential risk of falling asleep. Even so, the subjects managed to stay awake for up to an additional hour.

Sleep debt – The right bowl

Drivers reporting poor sleep quality prior to driving, poor sleep quality in general, high frequency of sleep problems, and/or short sleep prior to driving were more likely to have the experience of fighting sleepiness while driving, having more sleepiness symptoms while driving in general, and to experience sleepiness while driving compared to drivers that reported long sleep, low frequency of sleep problems, and/or good sleep quality both in general and prior to driving.

Sleep prior to work is the most prominent factor that influences the waking state of a driver (26, 125). The lack of sleep is significantly linked to a reduction of sleep quality and a well-grounded opinion would be that observed driver sleepiness is a combined effect of both reduced sleep hours and sleep quality.

Thus, short sleep, poor sleep quality both in general and prior driving, and a higher frequency of sleep problems can independently or together contribute to a sleep debt. In Figure 12, this is seen as increased weight in the right bowl and thereby an increased level of sleepiness.

Countermeasures and degree of stimulation – The left bowl

The basic assumption is that the use of countermeasures and a high degree of stimulations are intended to balance the level of sleepiness created by a sleep debt. These assumptions agree with Dement’s opinion (2) that the greater your sleep debt, the more stimulation that is needed to keep you awake. In general countermeasures were used more by drivers who had reported short sleep or a high frequency of sleep problem, i.e. drivers that probably might have had a sleep debt.
Sleepiness, long distance driving, and monotonous driving are usually associated (147) and long distance drivers in Study V reported sleepiness while driving more often than those who drove in densely build-up areas. They also reported using more countermeasures. No significant differences could be found between dayshift drivers and nightshift drivers concerning the experience of sleepiness while driving. Nightshift drivers, however, reported using more countermeasures than dayshift drivers, and they reported more symptoms of sleepiness than dayshift drivers, which could indicate a higher degree of sleepiness.

Drivers identified two of countermeasures to counteract sleepiness as most important: sleep before work and better working hours. This supports the statement that prior sleep time before work is an important, if not the most important, step to preventing sleepiness while driving. During work, naps with or without additional caffeine, are believed to be the best countermeasures to elevate sleepiness (26, 83), caffeine increasing the weight in the left bowl and naps decreasing the weight in the right bowl. However, stopping and take a nap as a countermeasure used by drivers was not an obvious countermeasure in Study V. Since the drivers also had complained about working hours, one might speculate that drivers do not have enough time to stop and take a nap/break during work hours. Exceeding the number of hours allowed for driving is a well-known phenomenon (31, 176).

Using countermeasures for sleepiness can be seen as a way of counteracting the sleep debt, putting more weight in the left bowl (Figure 12) and there by decreasing the level of sleepiness.

The circadian rhythm – The weight

Sleepiness was reported by 46% of drivers to be most troublesome between 3 a.m. and 6 a.m. This corresponds to one of the two peaks in normal circadian rhythm (61). Similar findings have been reported by others (31, 156). This supports the idea in Figure 12 that the scale shifts to the right during nighttime, increasing the level of sleepiness. However, the circadian rhythm also has a peak in the afternoon. But even if sleepiness reported by drives in Study V was more common between 3 p.m. and 6 p.m. compared to both the preceding and the subsequent three-hour period, this peak (12% of drivers) was clearly smaller than the peak between 3 a.m. and 6 a.m. Hakkanen and Summala (31), on the other hand, found that 32% of short haul drivers felt sleepy between 3 p.m. and 6 p.m. This might suggest an additional text line “forenoon – afternoon” is needed under Weight in Figure 12.

Even if autumn is considered by drivers to be the time of year when sleepiness is most troublesome, this issue and its relation to a biological rhythm is probably both more complex and beyond the scope of this thesis. However, when considering the
drivers’ opinion that poor work schedules contributes to sleepiness while driving, perhaps work schedules in general should be improved and adjusted/individualized depending on the time of day and year. Simply put, less driving during the early morning hours and during autumn would be advisable.

**Risk of an accident – The wedge**

In Study III, reaction time and misses were found to be longer and more common, respectively, for sleep-deprived subjects. Even if laboratory settings differ from real life, one can speculate the consequences of an increased reaction time of 20%. The stopping distance for a fully loaded truck moving at 70 km/h on dry asphalt is approximately 70 m, if the reaction time of the driver is 1 sec. With a 20% increase in the reaction time, the stopping distance is 4 m longer, approximately the length of a car (calculations made according to ECE regalement 13, 1999). However, one characteristic of sleepiness-related traffic accidents is absence of brake marks, suggesting a lack of any warning signal (26).
General conclusions

- HRV cannot be seen as a relevant indicator of sleepiness.
- Alpha and theta activity are indicators of sleepiness. However, the complexity of alpha and theta power density analysis, conflicting opinions in how to interpret alpha and theta activity, and the equipment surrounding EEG recording make EEG today impractical for routine use in, e.g., professional driving.
- Rating scales can be applied to indicate sleepiness. Since CR-10 is a unipolar scale with a high degree of resolution over the entire level of sleepiness, it has an advantage over bipolar scales. Subjective sleepiness rating scales are more practical to use in daily life.
- CR-10 is validated against the well-recognized KSS scale.
- Head movements are an indicator of sleepiness. The presence of relatively moderate movements even at early stages of sleepiness and a time history of its development supports this. The technical equipment to measure head movements in Study IV was small, light and not experienced as cumbersome. Future devices could probably be even smaller and lighter and built into a cap with wireless transfer of signals.
- Prior sleep habits, sleep time, and sleep quality are the strongest predictors of having or not having problems with sleepiness while driving.
- Performance can be used as an indicator of sleepiness and performance can be affected even with a modest degree of sleep deprivation.

Specific reflections and limitations

The results of the study should be considered in the perspective of the limited number of subjects included. Retrospectively, an alternative approach with 20 subjects participating two times, one time for a 120-minute sleep-deprived state and one time for a 120-minute rested state, might have been a more proper design. The sample size can thus be viewed as a limitation. However, the procedure is time consuming and the discomfort experienced by participants is high, which results in the sample size being as small as possible. Small sample sizes in studies of sleepiness are not uncommon (88, 122, 177).

Actigraphy to control the activity of the subjects prior to the experiment could also be used. For example, if the subjects went to bed when they were supposed to stay awake in the sleep deprived state, this would have been seen on the actigraphy. However, at the time of the study this equipment was not available. This reflection leads to the question of if the provoked sleep deprivation was enough. If it had been difficult to be sure if the subjects actually got up at 3 a.m., one could have increased the demand from 5 hours lack of sleep to letting the subjects stay awake
for an entire night. There was no indication that the subjects were dishonest, which leads to a conclusion that even small sleep debts quickly reveal effects.

Strong individual differences exist when measuring EEG. However, Akerstedt and Gillberg’s (122) suggestion of another subdivision of the traditional alpha and theta band might also have given a better picture of the EEG profiles. Delta activity is generally associated with deep sleep and not with sleepiness; nevertheless, delta activity has been shown to be present when sleepy (170). Including delta power density and even beta power density might give a better perspective of the changes of the EEG pattern over time.

Driving simulations are an issue that can also be discussed as a limitation. Failure to simulate actual driving conditions can be a threat to the validity, which suggests that laboratory studies should be followed by field studies under realistic conditions. The results might also be discussed in light of the Hawthorne effect. The Hawthorne effect refers to improvements of results mainly because the participants are aware of extra attention being paid to them. In the laboratory setting the subjects knew that they were being observed and that might have encouraged them to stay awake. The results might have been different if they, for instance, drove alone in the middle of the night without being observed.

In Study V, questions to the drivers about their sleep habits were of a more general nature. Another approach could have been to investigate sleep and sleepiness during a specific day and/or under specific driving conditions. For instance, the driver could have been asked to repeatedly and with suitable time intervals rate their sleepiness during a driving shift. Rating of sleepiness based on memory recollection in general probably resulted in underestimations.

**Future considerations**

Not only is it an unpleasant experience to fight sleepiness without being able to go to sleep, it is also strongly correlated to an increased risk of an accident with negative impact on the economy and, more importantly, injuries and loss of human lives. Sleepiness in life, including working life, is common and with the 24/7 society, sleepiness might become even a larger problem. Sleepiness and its related aspects are clearly a multidisciplinary field of research involving business, public interests and governmental responsibilities. During the last three to four decades there has been considerable research, but sleepiness while driving and in other in professions is still common and no change seems imminent. Thus, an attempt to solve or at least diminish its effects will require significant efforts. Society has a great need of a better understanding of sleepiness and especially its causes, predictors, and indicators. The implementation of current knowledge of predictors
and indicators is still remarkable low. Better focus should be given to making practical use of current knowledge. One important step of action would be to create a multidisciplinary network which would include researchers from different fields dealing with different aspects of sleepiness/sleep, as well as other specialist and key persons, e.g. representatives from labor unions, government, health care, educational institutions, technicians, engineers, and economists.
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APPENDIX A. Karolinska Sleepiness Scale

SÖMNSKALA A

1  mycket pigg

2

3  pigg

4

5  varken pigg eller sömnig

6

7  sömnig, (men ej ansträngande att vara vaken)

8

9  mycket sömning, kämpar mot sömnen
### APPENDIX B. Borg scale, CR-10 scale

**SÖMNSKALA B**

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<tr>
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- Absolut maximun
STUDY IV