



# **Vehicle Driver Monitoring, VDM.**

*An Experimental framework for driver state measurements.*



Project within Strategic Vehicle Research and Innovation (FFI)

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### FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: [www.vinnova.se/ffi](http://www.vinnova.se/ffi)

## 1. Executive summary

To prevent road crashes it is important to understand driver related contributing factors, suggested to be the critical reason in 94% of crashes. Important factors often include alcohol, sleepiness, distraction or fatigue. The overall aim of the project Vehicle Driver Monitoring was to advance the understanding of two such factors; sleepiness and cognitive distraction. The project aimed to find methods to measure them and to study their effect on driver behaviour. An important research question was if physiological measures could be used as indicators. Other important research questions concerned effects of contextual, inter- and intra-individual factors and if it is possible to detect the states using machine learning methods.

The project was carried out from April 2013 to end of March 2017. The work involved two PhD students; one from academy and one from industry and also experienced researchers from Statens Väg- och TransportforskningsInstitut (VTI), Mälardalens Högskola (MDH) and Volvo Car Corporation (VCC). At the start a literature review was done to gather an updated view of the State of the art e.g. in the constructs of sleepiness and cognitive load, driver models, indicators including physiological measures and experiment designs. The data collection was done in several laboratory and driving simulator experiments. The sleepiness simulator experiment was unique in its design with participants repeating their drives on six occasions during both day and night. In addition, cognitive distraction experiments were designed to advance the understanding of effects of cognitive distraction. Substantial knowledge and novel insights were gained from the experiments. Examples of key results are:

- There seemed to be a relationship between lane departures and local sleep in brain regions associated with motor function.
- Self-reported sleepiness level and driver performance differed when the same experiment was repeated three times in identical settings.
- Darkness was found to be an additive factor in several sleepiness indicators but had no effect on the number of line crossings.
- Professional drivers reported lower levels of sleepiness, even though the more objective indicators indicated that they were actually sleepier than the non-professional drivers and had greater problems to stay in their lane.
- Support for the Cognitive Control Hypothesis was found in different traffic scenarios.
- The pupil diameter was found to be the physiological measure with the closest relationship to cognitive load.
- It was demonstrated that while several physiological measures correlated with the level of cognitive load, their similarities and differences at the same time reflected other driver state variations.
- Well established EEG frequency power measures only showed a difference between levels of cognitive load when the driving task was simple.

- A novel combined approach showed better result in mobile EEG artefact handling.
- Automatic sleepiness and cognitive load classifications were improved by the use of contextual and behavioural measures as compared to physiological measures only.

The results clearly demonstrate that context (individual related and environmental related) has a great impact on driver behaviours, measures and experiences. Further research is needed to increase the understanding of the contextual effects and to learn how they can be compensated for in order to reach an understanding good enough to identify promising countermeasures. Research should also continue to focus on how cognitive load and sleepiness affects traffic safety. For example, by continuing study effects of local sleep with high time resolution, to look at combinations of physiological signals like EEG and slow eye moment for example, and to explore the dynamic interplay between the driving task and the distraction task, especially in traffic situations where cognitive control is needed.

## 2. Background

Road traffic injuries are listed as one of the top ten major causes of mortality and morbidity worldwide. It is the goal of the Swedish government to reduce the number of people killed per year in road traffic crashes to less than 220 by the year of 2020. To prevent road crashes it is important to understand driver related contributing factors, which have been suggested to be the critical reason in 94% of crashes. Some commonly studied factors are, for example, alcohol, sleepiness, distraction, cognitive distraction and fatigue.

*In this project, the Vehicle Driver Monitoring project (VDM), we focused on two such factors, sleepiness and cognitive distraction.*

### Driver sleepiness

Driver sleepiness is a condition that cause severe injuries and fatalities, and it has been estimated that the proportion of accidents that are due to sleepiness is about 10 – 20%. In this project, we aim to learn more about some factors affecting sleepiness, especially how to exploit this new knowledge to design better methods to measure and predict sleepiness.

It is generally believed that it is easy to measure sleepiness but a solid physiological measure of sleepiness has yet to be found and the quantification of sleepiness remains a challenge. Commonly used physiological indicators of driver sleepiness include brain waves (electroencephalography - EEG), blink behaviour (via cameras or electrooculography - EOG), respiration and heart rate (electrocardiography - ECG). Sleep research is currently undergoing a paradigm shift. Historically, sleep was thought to be a passive state but later it was proven to be an active dynamic process. Sleep was also thought to be a global phenomenon, but it has now been found that local regions of the brain “fall asleep” at different times. This is referred to as local sleep. Unlike micro sleep, brief periods of local sleep occur when you are still entirely conscious and functioning. This may be the reason why sleepiness is so difficult to measure in active individuals –



the global EEG is seemingly typical of an awake state even though parts of the brain may be sleeping. If local sleep affects regions that are needed to carry out some task, performance on that task decline substantially.

*In VDM, we investigated if local sleep provides an explanation as to why some sleepy drivers are able to stay on the road whereas others are not. The hypothesis was that signs of local sleep can be found in motor related parts of the brain in the lane departure cases, but not in the corresponding matched baseline events.*

Both sleep and sleepiness are affected by a variety of internal and external factors.

*In VDM, we investigated the impact of two environmental factors – light condition (daylight versus darkness) and complexity of surrounding environment (rural versus suburban). The hypotheses were that darkness will make it harder to stay awake, and so will it be in a monotonous environment compared to a more stimulating environment.*

These two factors are believed to affect driver sleepiness, but there is very little research on the topic. For example, it is generally assumed that sleepiness and fatigue are countered by the alerting effect of a more stimulating or demanding environment such as in the city. However, there is very little research that actually support this claim. Light exposure in general is a well-known factor that increase the arousal level. Despite this knowledge, the confounding effect of light conditions is seldom considered in the driver sleepiness literature.

The negative impact of sleep loss on driving performance show large inter-individual differences, some individuals are affected more than others. It is generally believed that professional drivers can manage quite severe fatigue before routine driving performance is affected.

*In VDM, we investigated the impact of sleep deprivation on professional drivers compared to “normal” drivers. The hypothesis was that professional drivers are less susceptible to sleep loss.*

Although performance degradations from sleep loss varies between individuals, they have also been found to be stable within individuals. Despite this intra-individual robustness, there are many potentially confounding external factors that may cause a severe first-encounter effect.

*In VDM, each participant carried out the same experiment three times to investigate systematic differences between the repetitions. The hypothesis was that the participants are less susceptible to sleep loss in the first trial.*

Automatic sleepiness assessment based on machine learning is usually based on a multitude of physiological and behavioural signals. Despite proper employment of cross validation techniques, no attempt has provided robust solutions that function across different data sets and different individuals. Our previous attempts have shown equally promising results, but the developed models are always disappointing since they do not generalize to new data sets.

*In VDM, on top of the physiological information, we also incorporated features about the environment.*

## Cognitive distraction

Driver distraction (drivers allocating physical and mental resources to other tasks than the primary task of driving) is usually viewed as having a detrimental effect on traffic safety. However, while visual distraction (not looking at the road while driving) both intuitively and empirically has a clear coupling to increased crash and near crash risk, the effects of being cognitively distracted (being engaged in non-visual but working memory loading activities) are less clear, both intuition-wise and empirically.

The cognitive control hypothesis might help to understand the role of cognitive distraction in crash causation. The cognitive control hypothesis states that “cognitive load selectively impairs driving subtasks that rely on cognitive control but leaves automatic performance unaffected”. It thus implies that cognitive distraction will delay a driver response if that response relies on, or is facilitated by, cognitive control. It will however not have any effect on automatized responses.

*In VDM, we tested the cognitive control hypothesis by designing experimental driving scenarios where cognitive control can enhance driving performance, respectively where responses are automatically triggered.*

A key difficulty in research on cognitive distraction is that validated ways of measuring it during driving are lacking. The high face validity makes it attractive to measure cognitive distraction by studying brain activity using EEG. However, since brain activity is difficult to record in real driving as well as hard to interpret in general, other measures are also sought for. One relatively new option is tracking the pupil diameter of the driver with an eye tracker. The pupil diameter follows changes in ambient light, but also mental activity and emotions. Further, numerous studies, including driving studies, have found an increased heart rate (HR) during increased cognitive load. It could possibly be explained by the increased energy consumption in the brain. It is however not clear if cognitive load alone (i.e. without the stress or emotions that often comes with it) is enough to cause an increased HR in car drivers. Similar to HR, the electrodermal activity (or skin conductance, SC) and respiration rate typically increase during increased cognitive load, but, again, it is not clear if cognitive distraction alone is enough to induce those changes.

*In VDM, we recorded a number of physiological signals and derived measures which (for different reasons) have shown to correlate with cognitive load. We studied the effects of cognitive distraction, as well as of habituation, driving duration and driving demand, and explored the different measures' potentials in assessing cognitive distraction. In addition, we used machine learning to automatically detect periods of cognitive distraction.*

Differences between individuals are large in most physiological measures. Factors such as age, gender, personality and fitness level all influence the physiological responses and have to be addressed.

*In VDM, we limited the individual variability through participant inclusion criteria. We also applied basic normalization and used a study design which enables within-subject analyses.*

Cognitive distraction is not a static state, there is a dynamic interaction between the driving task and any cognitively loading secondary task(s). How the driver prioritizes between the tasks, and how difficult they are perceived to be, will influence both task

performance and physiological responses (due to effects on e.g. stress level and cognitive activity). However, while numerous physiological studies exist on the effects of different levels of driving demand and of cognitive distraction, the interplay between the two over time has received limited attention.

*In VDM, we designed traffic scenarios, in which our participants have performed cognitively loading tasks, which consists of both simple driving periods and more demanding periods. This enabled us to study how changes in driving demands affect the physiological measures differently during different levels of cognitive distraction.*

### 3. Objective

The overall objective in the project was to advance the understanding of the driver states sleepiness and cognitive distraction. Based on the objective, six generally formulated research questions were formulated. One main research question and five sub research questions were formulated:

1. Can physiological measures, expert judgments and self ratings be used to measure different levels of mental load and sleepiness?

Sub research questions:

2. What is the relation between levels of mental load and/or sleepiness and levels of impaired driving performance?
3. Which factors explain the intra-individual differences as well as the inter-individual differences in the indicators of mental load and/or sleepiness?
4. Do contextual environment factors cause significant differences in indicators of mental load and/or sleepiness?
5. Is driver state affected by the measuring equipment?
6. Is it possible to devise an automatic system for online estimations and predictions of mental load and sleepiness levels?

During the project the research questions were refined based on the difference in advances within the research areas of sleepiness and cognitive distraction and the currently interesting issues within them. This led to different focus between sleepiness and cognitive distraction, which was reflected in the experiments, see section four.

An expected result described in the project application was the development of a driver state model based on the model from the VHM-project. However, since there were several models available for both sleepiness and cognitive load in the literature a somewhat different approach was taken. Instead of developing a new model, existing and established models were used as a starting point in order to design experiment and to test new hypotheses and advance knowledge. In addition, the use of established models also make the publications and presentations based on the experiments and results in the project more acceptable by the research community and increases the possibility to advance the research area.



Another expected main result was to develop an experimental platform including hardware and software tools for measuring and analysing data of human responses including physiological signals within the project. The experimental platform was defined in the project together with an in-house VCC project. The experimental platform, hardware and software, was developed jointly by several suppliers of measurement equipment and is commercially available.

One VCC industrial PhD student was planned in the project, and is scheduled to be finished 2020. The PhD student will use the knowledge and data acquired during the VDM project and continue the work of measuring and understanding cognitive distraction. After the start of the project a second PhD student from MDH was added, this work will be finalized during the beginning of 2018. The MDH PhD student works in the area of diagnosis and prediction of sleepiness and cognitive load using machine-learning algorithms.

## 4. Project realization

The project was initially planned from April 2013 to March 2016 but was extended to March 2017. The work was done by researchers from the Swedish National Road and Transport Research Institute (VTI), Mälardalen University (MDH) and Volvo Car Corporation (VCC). Two PhD students, one industrial and one academic were attached to the project.

During the whole project, the management team had bi-weekly meetings to discuss technical and administrative issues. The project team, whole or in part, met on a need-to-meet-basis to discuss technical details about e.g. measures and results during the project.

The project was realized based on the project member's experience and knowledge from previous work and research projects in the area of driver monitoring, sleepiness and cognitive distraction. An initial State of the Art literature review (SoA) was performed in order to gather the latest advances. The SoA comprised e.g. the constructs of sleepiness and cognitive load, driver models, indicators including physiological measures and experiment designs. The SoA was documented in an internal project report.

In order to investigate the research questions much effort was put to design the experiments. With a starting point in the SoA and the differences in advances within the research areas of sleepiness and cognitive distraction and the six general research questions, main focus for sleepiness and cognitive distraction was defined. For sleepiness the main focus was:

- Inter individual differences, professional drivers vs. "normal" drivers
- Intra individual differences, repeated visits with the same settings and preparations (3 days/3 nights).
- The relationship between task related fatigue and sleepiness.
- The confounding of light and darkness during day and night.



For cognitive load the main focus was:

- Effect of cognitive load on driving performance in non-critical and critical scenarios
- Physiological indicators of levels of cognitive load

Physiological signals were measured for brain activity (EEG), eye activity (EOG), heart activity (ECG), breathing (RSP), sweating (GSR) and muscle activity (EMG). In the cognitive load experiments also gaze behaviour was measured using eye trackers.

Before executing the main simulator experiments for sleepiness and cognitive load several smaller experiments were performed to look at specific issues.

These comprised several tests to evaluate different cognitively loading tasks, to study the effect of having the equipment (e.g. the EEG cap) mounted for longer periods combined with some basic tests, e.g. light in the eyes. Another important experiment was designed to generate controlled artefacts in EEG-data for design of an automatic artefact removal algorithm. Removal of artefacts from the EEG-signal is an important step before the variable calculation is possible.

The main simulator experiment for sleepiness was performed with 26 male participants who visited VTI on six occasions, three during daytime and three during night-time. On each visit they drove three scenarios, a rural drive in daylight, the same rural drive but at night (=dark) and an urban environment in daylight. The experiment was performed in a moving base simulator, SIMIII, at VTI in Linköping.

There were two main simulator experiments for cognitive load with a total of 72 planned male participants. They drove the simulator at one occasion on a rural road in daylight, passing several non-critical scenarios and one critical lead vehicle brake scenario in the end of the drive. In the first experiment the participants performed an easy cognitively loading task (1-back) during the drive and in experiment two both 1-back and a more demanding task (2-back). The experiments were performed in the same moving base simulator, SIMIII, at VTI in Linköping.

The data, including all physiological data, simulator data and video from the experiments was pre-processed (e.g. artefact removed from the EEG-signal) and stored in a database.

The results of the analyses were published in peer reviewed journal papers, conference papers, at symposiums and summarized in the peer reviewed VTI-report Vehicle Driver Monitoring – Sleepiness and Cognitive load (Nilsson et al., 2017).

One of the PhD students has written a licentiate thesis (Barua, 2015).

## 5. Results and deliverables

### **Main results for sleepiness:**

- Results from the sleepiness experiments showed a relationship between lane departures and local sleep in brain structures that are currently needed for driving. This is a novel exploratory analysis that prompts for further validation.
- Brain connectivity analyses of multi-channel EEG data indicate that some connections between brain regions could be important for sleepiness level classification. But when trying to distinguish three levels of self-rated sleepiness (alert, somewhat sleepy, sleepy) classification results was poor. Even though the accuracy was low the methodology should be investigated further using a different time scale.
- In the experiments, professional drivers reported significantly lower sleepiness levels in KSS, while indicators of sleepiness indicated higher degree of sleepiness and more involuntary line crossings. The reason for the discrepancy between the two groups of drivers might be due to more experience of sleepiness while driving among the professional drivers.
- The repeated sleepiness experiments showed that drivers performed differently comparing the same setting but at different visits. This is important to consider to understand the validity of the results only using one visit for alert and one for sleepiness.
- Driver sleepiness has been suggested to be countered by the alerting effect of a more stimulating and demanding environment. Here the results indicate that also road geometry can be an alerting factor, at least as much as a stimulating environment. However, further investigations are needed in order to know if this is also the case in real road driving.
- In the present study subjective, behavioural and physiological indicators of sleepiness increase with reduced light in the driving scenario. However, effects of driving at night are stronger. Light and time of day did not interact, indicating that light conditions has an additive effect on sleepiness level. Thus, light is an important factor to consider in driver sleepiness discussions.

### **Main results for cognitive distraction:**

- Decreased brain responses to visual intake (called eye fixation related potentials) has been suggested to reflect decreased visual attention. In the present experiments no effect of the cognitive distraction was found but an increase in a more visually demanding driving environment was found.
- Results indicate that EEG theta power can distinguish between driving with and without cognitive distraction during simpler driving but not during more demanding driving. When driving without cognitive distraction there was a difference in theta

power between a resting period and the simpler driving on one hand, and the more visually demanding scenarios on the other hand.

- Many physiological measures (e.g. heart rate, pupil diameter, skin conductance) showed significant effects of cognitive task execution. The measure that best related to the levels of cognitive load was pupil diameter. Other factors also influenced the measures and the effect of cognitive load, including driving demand, time on driving task and task repetitions. Analysing how the different measures were affected by the different factors gave a better understanding of the driver state as a whole.
- In line with the cognitive control hypothesis, the present study did not find any effect of cognitive load on brake response time in a lead vehicle braking scenario. The scenario was completely unexpected and the brake response was assumed to be automatically initiated by the looming cues which appeared as soon as the lead vehicle started to brake.
- When being cognitively distracted drivers glanced at safety relevant but non-salient visual cues in the traffic environment (an approaching car in an intersection and a hidden exit) fewer times, as well as later, as compared to when not distracted. The results supports the cognitive control hypothesis that predicts that drivers under cognitive load makes less use of cognitive cues in the driving environment.
- A strong and unpredictable side wind did not have any influence on how cognitive load affected physiological as well as performance measures, indicating that the drivers' were unaffected by the wind. This is inconsistent with an earlier study and could possibly be due to that the previous study used a fixed base simulator while this study used a moving base simulator with motion cues.
- In the experiments the participants generally rated the equipment to have low effect on them. Even though some had higher ratings, e.g. the eye-tracking glasses, the participant's state did not seem to be affected. Even though, improvements should be done.

#### **Main results for automatic detection:**

- An automated algorithm (ARTE) was developed for handling artefacts in EEG data. The algorithm significantly reduces the number of artefacts in the recorded EEG signals, and is comparable with existing algorithms. An advantage with ARTE is that it is entirely data driven and does not need reference signals or manually defined thresholds, making it well suited for use in mobile settings.
- Classification of KSS sleepiness levels was made using different machine learning methods, using features based on EEG and EOG. Classification accuracy reached approximately 80% when including three levels of sleepiness and 90% when including only two levels. Accuracy in sleepiness classification was generally improved with contextual information.
- Classification of cognitive distraction (two cases: distraction and no distraction) with case based reasoning (machine learning) using features based on EEG reached an overall accuracy of approximately 75%.

**Measuring equipment:**

- An internal VCC project and the VDM project jointly defined specifications for a module-based measurement platform, both hardware and software. The platform made it possible to connect and record synchronized signals from different types of sensors, e.g. physiological amplifier for EEG, eye-trackers, signals from simulators or vehicles. The platform was realized by several measuring equipment suppliers in cooperation and is commercially available. It was used in the simulator experiments in VDM.

**5.1 Delivery to FFI-goals**

The project has advanced the understanding of two factors related to human errors and vehicle crashes. Increased knowledge on driver states is important to prevent road crashes. In addition, this is an area of importance for future work on different levels of automated driving and the interaction between the driver and the vehicle.

The project has widened and increased the competence for all the involved members in the area of understanding, measuring and analyzing physiological signals related to sleepiness and cognitive load. Especially the members' knowledge of measuring, pre-processing and analyzing EEG has increased. The increased competence comprises several researchers and especially two active PhD students, one academic and one industrial, within the project research areas. Thanks to the project there is also a deeper understanding of the complexity of the human drivers and the influence on cognition and sleepiness. We also learned the importance to consider that we are influenced by several factors while driving: environment, light etc. and that even though we are put into same context and situation there are still inter individual differences that needs to be considered.

The project created a network between the members from the three partners with knowledge that both overlap and complement each other in the area of driver states, measuring and analysis. During the project, contacts with other partners outside the project have been taken for specific issues, e.g. Karolinska Institutet, Linköpings University and Japan National Institute of Advanced Industrial Science and Technology (AIST). The PhD students are supervised both by project members and individuals outside the project with knowledge in the research areas.

## 6. Dissemination and publications

### 6.1 Knowledge and results dissemination

The project knowledge, data and results have been used for a licentiate thesis for the MDH academic PhD student. This work will continue and he will defend his thesis in the beginning of 2018. For the VCC industrial PhD student, the knowledge, data and results from the project will be used for both the licentiate and the doctoral theses with the aim to be ready during 2020.

All partners have initiated several master thesis projects on issues based on the VDM research questions, using the data from the experiments. Some of these projects are on-going and some are ended, see the publication list for ended projects.

The results from the project has been summarized in a report published as an easy to find peer reviewed VTI publication (Nilsson et al., 2017). It is a summary of the analyses and publications from the project with references to the papers it is based on. The results have also, up to now, been published or is planned to be published in total 26 publications (licentiate thesis, journal papers, conference papers and master theses) excluding the VTI publication.

MDH also work in a KKS project named SafeDriver initiated after the start of the VDM project. Besides VTI and VCC, Prevas AB, HÖK instrument AB, Anpassarna Gunnérius AB and Karolinska Institutet are members in the project. SafeDriver aim at measuring driver state using cameras and vehicle signals and data generated in the VDM project is used in the SafeDriver project.

### 6.2 Publications

#### Licentiate theses:

Barua S.: Intelligent Driver Mental State Monitoring System Using Physiological Sensor Signals. Licentiate, Mälardalen University, Västerås, ISSN 1651-9256 ; 217, 2015

#### Master theses

Danielsson, S. Investigation of feature selection optimization for EEG signal analysis for monitoring a driver. 2015. Student paper. Mälardalens högskola.

Jansson S: EEG local sleep analysis and its relation to driver sleepiness and road departure accidents. LiTH-IMT/BIT30-A-EX--16/539--SE, 2016.

Rivera, M. Monitoring of Micro-sleep and Sleepiness for the Drivers Using EEG Signal. 2013. Student paper. Mälardalens högskola.

Steen J: EEG signal processing for brain connectivity analysis to detect driver sleepiness. LiTH-IMT/MI30-A-EX-16/538-SE, 2016.

**Peer reviewed publications:**

- Ahlstrom C, Anund A, Fors C, Åkerstedt T: Driver sleepiness on suburban versus rural roads – a simulator study. 2017. Submitted for journal publication.
- Ahlstrom C, Anund A, Fors C, Åkerstedt T: The effect of daylight versus darkness on driver sleepiness. 2017. Submitted for journal publication.
- Ahlstrom C, Jansson S, Anund A: Local changes in the wake EEG precedes lane departures. 2017. Submitted for journal publication.
- Anund A, Ahlstrom C, Fors C, Åkerstedt T: Are professional drivers less sleepy than non-professional drivers? 2017. Submitted to Scandinavian Journal of Work, Environment and Health.
- Barua S., Ahmed M.U., Ahlström C., and Begum S.: Drivers' sleepiness classification using physiological signals. 2017. Plan to submit to a journal.
- Barua S., Ahmed M.U., Ahlström C., Begum S., and Funk P: Automated EEG artifact handling in mobile environments – with application in vehicle driver monitoring. 2016. Submitted to a journal.
- Barua S., Begum S.: A Review on Machine Learning Algorithms in Handling EEG Artifacts. 2014. 28th annual workshop of the Swedish AI Society (SAIS), Stockholm, Sweden.
- Barua S., Ahmed M.U., Begum S.: Classifying drivers' cognitive load using EEG signals. 2017. 14th International Conference on Wearable, micro & Nano Technologies, Eindhoven, The Netherlands.
- Barua, S., Begum, S., Ahmed, M.U., Funk, P.: Classification of Ocular Artifacts in EEG Signals Using Hierarchical Clustering and Case-based Reasoning. 2014. Workshop on Synergies between CBR and Data Mining at 22nd International Conference on Case-Based Reasoning, Cork, Ireland.
- Barua, S., Begum, S., Ahmed, M.U.: Clustering Based Approach for Automated EEG Artifacts Handling. 2015. 13th Scandinavian Conference on Artificial Intelligence, Halmstad, Sweden.
- Barua, S., Begum, S., Ahmed, M.U.: Intelligent Automated EEG Artifacts Handling Using Wavelet Transform, Independent Component Analysis and Hierarchical clustering. 2015. Workshop on Embedded Sensor Systems for Health through Internet of Things (ESS-H IoT) at 2nd EAI International Conference on IoT Technologies for HealthCare. Rome, Italy.
- Barua S., Begum S., Ahmed M.U.: Driver's State Monitoring: A Case Study on Big Data Analytics. 2016. The 3rd EAI International Conference on IoT Technologies for HealthCare, Västerås, Sweden.
- Ljung Aust et al. 2017. Lane keeping under cognitive load: hierarchical Control and Driving revisited. In preparation.
- Nilsson, E., Ahlstrom C., Barua, S., Fors, C., Lindén, P., Svanberg, B., Begum, S., Ahmed, M. U. & Anund, A. Vehicle Driver Monitoring – Sleepiness and Cognitive Load. 2017. VTI publication 937A.

- Nilsson, E., Ljung Aust, M., Engström, J., Svanberg, B. and Lindén, P. Effects of Cognitive Load on Response Time in an Unexpected Lead Vehicle Braking Scenario and the Detection Response Task (DRT). 2017. Submitted for journal publication.
- Nilsson, E., Ljung Aust, M., Svanberg, B. and Lindén, P. Effect of cognitive load on driver behaviour in intersection and hidden exit scenarios. In preparation.
- Nilsson, E., Ljung Aust, M., Svanberg, B. and Lindén, P. Physiological responses to cognitive load during simulated driving. In preparation.

**Non-peer reviewed publications:**

- Ahlstrom C, Anund A, Fors C: The impact of external factors on driver sleepiness. 2016. International Symposium on Somnolence and Safety, Brussels, Belgium.
- Ahlstrom C, Jansson S, Anund A: EEG analysis of local sleep and its relation to lane departures. 2017. 10th International Conference on Managing Fatigue, San Diego, USA.
- Anund A, Ahlstrom, C, and Fors, C: Sleepiness and the effect on driving – Professional drivers vs. not professional driver. 2017. Accepted for presentation at the Tenth International Conference on Managing Fatigue, San Diego March 2017.
- Barua S., Begum S., Ahmed M.U., Ahlström C: Automated EEG Artifacts Handling for Driver Sleepiness Monitoring. 2016. 2nd International Symposium on Somnolence, Vigilance, and Safety.

## 7. Conclusions and future research

The project has advanced the state-of-art knowledge of sleepiness and cognitive distraction. It has widened and increased the competence for the partners in the area of understanding, measuring and analyzing physiological signals. The project has created a network between the members from the three partners with knowledge that both overlap and complement each other regarding mainly the driver states, measuring and analysis.

New knowledge and novel insights was gained in the VDM project. The key conclusion is that context is crucial and has a great impact on both driver behaviours, measures and experiences. It can hence not be disregarded in neither design, nor interpretation, of studies on driver states. This was evident in all results, also for automatic classification of driver states.

Support was found for the newly formulated Cognitive Control Hypothesis in several traffic scenarios. It was also found that several contextual factors had effects on driver sleepiness and cognitive load. The results emphasize the necessity to take the driving task and overall context into account when discussing effects of cognitive distraction or sleepiness, and to be cautious when generalizing results from one context to another.



For physiological measures, significant effects of cognitive load as well as of sleepiness was found in several physiological measures. However, the results also clearly showed how the different measures responded to other factors as well, e.g. task repetition. A better understanding of driver states can be found taking advantage of the different measures' similarities and differences.

For sleepiness, local sleep was studied and a relation between local sleep in motor cortex and lane departures was found. For cognitive load, more traditional EEG measures supported by highly controlled lab experiments were used but they seemed to be unsuitable in the more complex car driving setting. The results indicated that it had to do with the cognitive demand from the driving task, and the fact that cognitive distraction is not a static state. Taking advantage of the high time resolution of EEG other less established EEG measures might be more suitable to measure cognitive load.

In VDM, case based reasoning was focused when developing automatic classifications of driver states, producing results for sleepiness similar to other commonly used methods, e.g. support vector machines and k-nearest neighbor classifiers. The automated algorithm developed in the project for handling artifacts in EEG data produce results comparable with existing algorithms but has the advantage of being completely data driven making it well suited for mobile settings.

Implications for future studies: The large contextual impact emphasize the need to validate the findings from controlled experiments in naturalistic settings where the confounding variables cannot be controlled to the same extent and it becomes difficult to link cause and effect. To deal with this, research for increased understanding of the contextual effects and how they can be compensated for is needed. Further, increased knowledge is needed regarding how cognitive load and sleepiness affects traffic safety, e.g. by continued research on effects of local sleep and the interaction between the driving task and the distraction, especially in traffic situations where cognitive control is needed, but also when it comes to the interaction between sleepiness and cognitive distraction. Machine learning methods can be used to train automatic driver state classifiers based on large amounts of data with multiple concurrent driver states to be able to simultaneously classify several states and also combinations of states.

## 8. Participating parties and contact person



Volvo Car Corporation



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