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Cognitive Assessment and Task Management (CAT-M)

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14. ABSTRACT

Cognitive Assessment and Task Management (CAT-M) continued to focus on pushing the cutting edge of cognitive-based systems. The work conducted was a continuation of the Augmented Cognition Phase 4 program that has been successfully executed under the direction of the ONR. Initially, the Augmented Cognition program has focused on cognitive overload situations. Looking towards a complete solution for Augmented Cognition, another situation required the understanding of the concept of task under-load. Together, the measure of overload and under-load, allow us a complete measure of operator "vigilance." When fully recognized, optimal vigilance will minimizes the impact of under-loaded personnel while maximizing the task loading that personnel can successfully execute.

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1 BACKGROUND

Cognitive Assessment and Task Management (CAT-M) continued to focus on pushing the cutting edge of cognitive-based systems. The work conducted was a continuation of the Augmented Cognition Phase 4 program that has been successfully executed under the direction of ONR.

Initially, the Augmented Cognition program has focused on cognitive overload situations. Looking towards a complete solution for Augmented Cognition, another situation required the understanding of the concept of task underload. Together, the measure of overload and underload, allow us a complete measure of operator "vigilance." "Vigilance" is defined as a state of mind in which a person has their attention focused on a task at a level sufficient to perform that task or attentiveness to a primary task. When fully recognized, optimal vigilance will minimizes the impact of underloaded personnel while maximizing the task loading that personnel can successfully execute.

The CAT-M system, investigated under this project, focuses narrowly on the integration of technologies demonstrating and validating a system targeting the operators' state of cognitive underload and investigated mitigation strategies to minimize or eliminate the negative results of cognitive underload.

The program included system integration, testing, and demonstrations performed using the Mercedes-Benz G-Class that was built as a technology-demonstration platform during phases 3 and 4 of the Augmented Cognition project as well as Mercedes-Benz Actros trucks. An operational setting was used during these experiments that included USMC-relevant tasks. The experimentation was performed using civilian personnel who underwent familiarization training from Daimler AG personnel with respect to the vehicle and the advanced technology systems.

The focus of the research efforts in CAT-M was threefold:

- Implement algorithms for the detection of cognitive states of cognitive underload,
- Implement algorithms for the detection of driving contexts that may require system support for the driver who is detected to be in a state of cognitive underload,
- Implementation, testing and evaluation of the above approaches (a.) and (b.).

1.1 Technology Integration and Vehicle Adaptation (G-Wagon)

The current test vehicle (G-Wagon) was modified to fulfill the requirements of the new tasks and scenarios under investigation, i.e., convoy driving. The vehicle was provided by Mercedes-Benz for use during the program execution and will remain property of DaimlerChrysler AG. In addition to currently available systems, a high-resolution steering angle sensor was installed into the steering wheel. Technology was inserted to be tested with respect to its capability to maintain the drivers' condition at a safe level and activate the driver in periods of low vigilance and fatigue. Vehicle modifications were performed to insert the B-Alert EEG into the vehicle with respect to hardware as well as software integration.

1.2 USMC Task Analysis and Scenario Description

Literature and technical reports were reviewed to assess the state of the art of the efforts performed thus far in the research field under consideration. A vehicle operator's survey was used to analyze the causes and the consequences of fatigue induced accidents in a USMC-specific driving scenario, with specific emphasis on convoy driving.

A task analysis for crew members of an LAV (or future system such as a MEFFV) was performed to better understand the specific functions performed by all Marines as drivers. The goal of such a task analysis was to determine potential opportunities to, through the use of cognitive low-vigilance and/or fatigue detection, mitigate these states, in real-time, through activating the vehicle driver and thus improve mission related performance as well as driving safety.

1.3 Cognitive State Detection

Cognitive state was detected using neurophysiological (EEG and EKG) measures, as well as by analyzing the driver's interaction with the vehicle (steering wheel, acceleration, braking, etc.). Based on the neurophysiological ground truth it was investigated to what degree cognitive state detection can be realized solely based on vehicle data. Supervised and unsupervised machine-learning approaches were investigated. Cognitive state detection was used to quantify the condition maintenance and condition improving functionality of the proposed technical measures.

1.4 Data Analysis

Data analysis was performed on several levels, the goal being to provide qualitative and quantitative measures of effectiveness. In order to have a sound statistical basis, data from at least 20 subjects was recorded in all conditions. This provided a broad data basis to apply parametrical and non-parametrical statistics in order to obtain a sound scientific interpretation.

The EEG-based, as well as the vehicle data-based, cognitive state detection was analyzed with respect to time resolution, inter- and intra-subject reliability and robustness. In order to provide a measure for driving safety, an according measure was derived from vehicle data to obtain a quantification of effectiveness of the proposed measures.

1.5 Program Management

Program Management was executed on two fronts. The Program Manager (Daimler AG) was responsible for the execution of the contracts technical content including the performance of all subcontractors. The Program Administrator (Chrysler LLC) was responsible for day-to-day operations of all contractual issues, financial performance and reporting, and schedule and deliverable adherence. The task also included the travel required to ensure that the program was efficiently and effectively executed.

2 EXPERIMENTAL DESIGN AND TESTING #1

The objective of this experiment is to investigate to possibility of measuring and classifying modulations of low-engagement cognitive state during a convoy-type driving task. The experiment was performed using a Mercedes-Benz G-Wagon and two Mercedes-Benz Actros 1860 equipped with cognitive-state assessment devices.

Figure 1: Mercedes-Benz Actros (left and middle) and Mercedes-Benz G-Wagon (right).

2.1 Operational Environment

In collaboration with a transition partner, the United States Marine Corps (USMC), a job analysis was performed in order to design tasks with high domain validity while allowing sufficient experimental standardization. The tasks were constructed to resemble actual tasks of crew members in an LAV-25 armored personal carrier or the Marine Expeditionary Family of Fighting Vehicles (MEFFV) during convoy operations.

The main purpose of the experiment was to investigate the possibility of developing a system capable of detecting a driver's state of cognitive underload as a result of monotonous convoy operations.

2.1.1 Background Information

Maintaining the operator, i.e., driver, at an optimal state of performance regardless of the driver's cognitive state, represents the essence of AugCog; it is controlled by a system of hardware and software that uses physiological and behavioral data from the driving team. This physiological data, called "cognitive-state gauges," is obtained by the system through continuous EEG, EKG, and EOG monitoring. Behavioral data is acquired through sensors on the accelerator pedal, brake pedal, steering wheel, turn signal, etc. This combination of physiological and behavioral information is analyzed by classifiers (software algorithms). The output is then translated by the AugCog system to trigger measures to maintaining the driver at an optimal performance level.

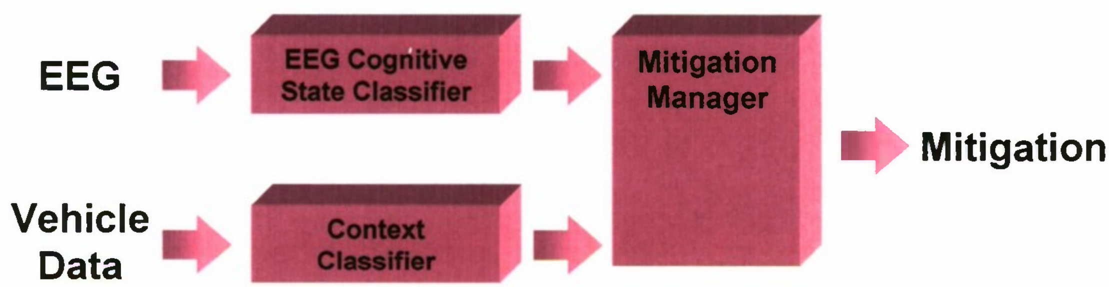

Figure 2: Conceptual depiction of automotive augmented cognition system.

2.2 General Preparation

2.2.1 Location

The experiment was conducted near Münsingen, Germany, on a decommissioned military training facility, formerly belonging to the German Federal Armed Forces (Figure 3). This location constitutes an undisturbed environment with controlled traffic conditions.

Figure 3: Map of the decommissioned military training facility at Münsingen, Germany, where the experiment will be conducted (approximately 50 miles southeast of Stuttgart, Germany).

2.2.2 Participants

In total, 60 drivers participated in the study, i.e., 3 drivers per day (1x G-Wagon, 2x Actros trucks) for 20 experiment days. Subjects were recruited from a database of subjects provided by the local company in Münsingen that now maintains the test facility (Experience Area Münsingen GmbH). The advantage of using subjects from the database is that the subjects were familiar with the Münsingen area, as well as the test track, which minimized familiarization effects. Once completed, the research physician evaluated the screening questionnaire and, if the requirements were met, then the candidate would be invited to participate in the study. As an incentive, participants were monetarily rewarded for taking part in the study, being paid EURO 200.00 for the completed study visit.

Inclusion Criteria

Subjects must have met all of the following inclusion criteria in order to be eligible for participation in the study.

- Valid driving license (all drivers)
- Valid truck driving license (truck drivers)
- G-Wagon driver: male or female, 20-30 years old

    - average of at least 20,000 km in the past 2 years (2005 and 2006) for the "experienced group"
    - average of maximum 5,000 km in the past 2 years (2005 and 2006) for the "inexperienced group"
- Truck driver: male or female, maximum 60 years old
    - average of at least 50,000 km in the past 2 years (2005 and 2006) OR more than 10 years job experience as truck driver for the "experienced group"
    - average of maximum 10,000 km in the past 2 years (2005 and 2006) for the "inexperienced group"
- Normal or corrected-to-normal vision and normal hearing
- Native speaker of German

Exclusion Criteria

Any of the following conditions excluded the subject from participating.

- Any health problem or medications that may have interfered with the subject's driving performance or physiological monitoring, as determined by the research physician (e.g., history of seizures, vertigo, heart disease or other cardiac irregularities, insulin-dependent diabetes, amputee, anti-depressants, etc.)
- Any medication or health condition which may have affected EEG, EKG, or EOG readings (e.g., pacemaker, ICD, neuro-stimulators, etc.)
- Pregnancy
- Any other condition that may have interfered with the subject's participation, as determined by the research physician

2.3 Experimental Testing

The sections below provide an overview of experimental test plans and details of the experimental tests.

2.3.1 Overall Procedure

The experiment began with a briefing that summarized the experiment and researchers answered questions or concerns raised by the participants. After all questions have been addressed, the subjects were asked to sign a consent-release form. The subjects' participation lasted one day. A number of different sessions within a single experiment were required for each day of the experiment. During these sessions, the subject underwent neurophysiological monitoring (EEG, EKG, and EOG).

This neurophysiological monitoring will comprised 28 EEG channels, according to the standard international 10-20-electrode placement system, 2 EOG channels, and 1 EKG channel. The research physician reviewed the baseline EKG and no abnormalities were noted.

In order to establish a baseline for each subject, a calibration test (Alertness and Memory Profiler (AMP) by Advanced Brain Monitoring, Inc., CA) was performed, during which time data were collected for approximately 20 minutes. The AMP consists of a neurocognitive battery of vigilance, attention, learning, and memory tests during which EEG data and behavioral data are recorded. The testing battery evaluates working and recognition memory using verbal and visuo-spatial tasks. The neuro-cognitive constructs evaluated by the AMP included sustained attention, processing speed, and verbal and visuo-spatial memory. AMP results were compared to Advanced Brain Monitoring's normative database.

Once a baseline has been established, participants were familiarized with both their assigned vehicle and their tasks. During the familiarization, EEG sensors remained in place to allow participants to become more comfortable with the sensor net. Participants then completed a whole course of the test track in a convoy-type configuration with the other two experiment vehicles. The intent was to provide an opportunity for participants to become sufficiently familiar with the vehicle and experimental test conditions in order to reduce the effects of learning on the experimental results. This phase of the study required approximately one hour.

During the next phase of the study, participants were asked to perform their assigned experimental tasks, described in the following sections, while EEG measures, psycho-physical data, and vehicle data were collected. During all driving, subjects were required to use seatbelts and obey all traffic rules.

2.3.2 Experimental Session

A single experiment trial consisted of three vehicles driving in a convoy formation at a speed of 40 (+/- 2) km/h while keeping a safe following distance between vehicles of 20 meters. The convoy drove the rounds six (6) times per experiment day, each circuit having a distance of about 37 km. After the first three rounds, the convoy stopped and took a one-hour break during which time the subjects were able to eat, drink, and relax. After the break, the convoy completed the remaining three (3) rounds.

Before, during (only driver of the G-Wagon) between and after each session, the subjects were asked to answer a set of questionnaires (Appendix 1 – 10) according to the following plan:

Before Session 1 (all):	Appendix #1, #2, #3, #4, #5, #6
During Session 1 (only G-Wagon):	Appendix #6, #9
After Session 1 (all, at the beginning of the break):	Appendix #6 (all)
Before Session 2 (all, at the end of the break):	Appendix #6 (all)
During Session 2 (only G-Wagon):	Appendix #6, #9
After Session 2 (all):	Appendix #6, #7, #8, #9

Tasks of the G-Wagon Driver

The role of the G-Wagon driver was to drive in the convoy in the rear-most position, being required to keep a safety distance of 20 meters to the truck driving in the middle position.

While driving, the G-Wagon driver heard a random sequence of high tones (1000 Hz, 20% probability, *deviant tone*) and low tones (500 Hz, 80% probability, *frequent tones*). The G-Wagon driver was asked to react as soon as possible to the high tones (*deviant tones*) by pressing a button affixed to the right hand thumb with the right hands middle finger. The tones were presented randomly with an inter-stimulus interval (ISI) varying randomly between four (4) and six (6) seconds (4.0s; 4.5s; 5.0s; 5.5; 6.0s). Reaction times and classification of all responses was logged to a file. It was ensured that the button could be easily pressed, no matter where the subject's hands were positioned on the steering wheel.

During the experiment, the G-Wagon driver received 4 phone calls during an entire experiment day. The vehicle was equipped with a hands-free cell phone that allowed the driver to respond to incoming phone calls without having to take his or her hands from the steering wheel. The driver was called by one of the study associate investigators. The driver was engaged into a conversation for duration of five (5) minutes. The conversation started with assessing the subjective sleepiness according to the scale in Appendix 6 and was followed by responding to a set of questions listed in Appendix 10.

Tasks of the Actros Truck Driver

The role of the two Actros truck drivers was to drive in the leading and middle position in the convoy. Two times, once during the first three rounds and once during last three rounds of an experiment day, the Actros truck drivers received information to switch positions, i.e., the driver of the middle truck had to overtake the leading truck. After this driving maneuver was complete, all vehicles in the convoy were required to reset their safety distance to twenty (20) meters. The information for this maneuver was presented on a computer screens mounted in the visual field of each Actros truck driver. At all times, the Actros trucker driver in the leading position was asked to drive at a speed of 40 km/h.

While driving, the Actros truck drivers also heard a random sequence of high tones (1000 Hz, 20% probability, *deviant tone*) and low tones (500 Hz, 80% probability, *frequent tones*). The Actros truck drivers were asked to react as soon as possible to the high tones (*deviant tones*) by pressing a button affixed to the right hand thumb with the right hands middle finger. The tones are presented randomly with an inter-stimulus interval (ISI) varying randomly between four (4) and six (6) seconds (4.0s; 4.5s; 5.0s; 5.5; 6.0s). Reaction times and classification of all responses is logged to a file. It was ensured that the button could be easily pressed, no matter where the subject's hands were positioned on the steering wheel.

In the morning session, truck #1 started first, in the afternoon session truck #2 started first. At the beginning of each experiment day, the truck drivers assigned randomly to each truck.

2.4 Results

2.4.1 Performance Data

In the study participated 21 G-Wagon drivers, and 42 Actros drivers (two per day). The experiment took place on 21 days, resulting in 5,000 km corresponding to 130 hours of G-Wagon driving and 10,000 km Actros driving corresponding to 230 hours respectively.

Eight data sets of the Actros truck drivers were corrupt and were excluded from further analysis, which resulted in 34 valid data sets (two female and 32 male truck drivers). The average age of the subjects was 41 years, with a minimum age of 20 years and a maximum age of 70 years.

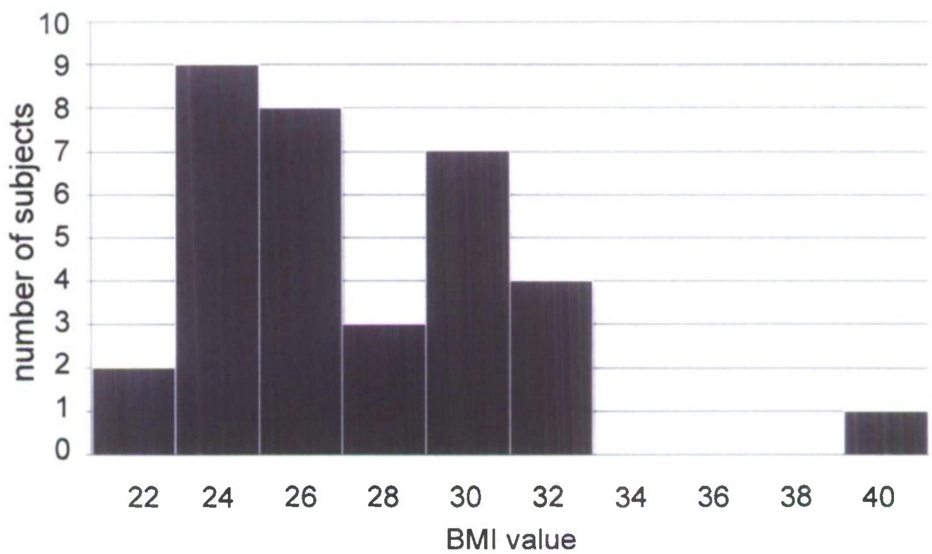

Figure 4: Histogram of BMI distribution of the 34 Actros truck drivers.

In order to assess the entry level of fatigue, we applied the Questionnaire from Appendix 1 which revealed results depicted in Figure 5.

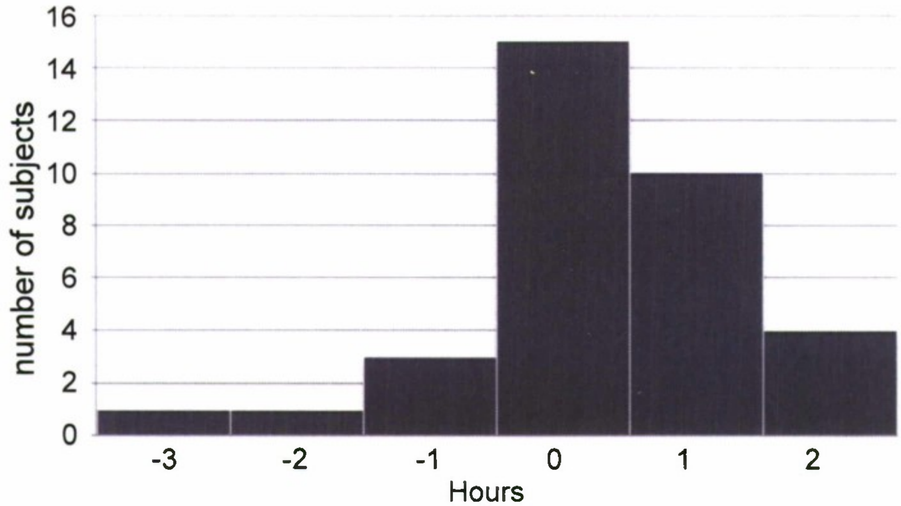

Figure 5: Difference between hours slept the night before the experiment and normal number of hours.

The morning results of the questionnaire in Appendix 2 showed a normal average value of 1.27 (min = 1, max = 4.2). However, the results after finishing the experiment showed an average value of 3.7 (min = 2, max = 5), indicating that the subjects were fatigued due to the experiment and time of day.

Appendix 5 was used to asses the truck drivers individual sleep propensity in order to distinguish between sleepiness induced by monotonous driving and subject's daytime sleepiness. Results show that 18 subjects were scored "0", 14 were scored "1", one subject was scored "2" and one subject was scored "3". The scores are: 0 = no chance of dozing, 1 = slight chance of dozing, 2 = moderate chance of dozing, and 3 = high chance of dozing.

In accordance with the results of the questionnaires, the data of all subjects were used for the analysis.

In order to assess the influence of the phone call on the G-Wagon drivers fatigue assessed by means of the driver's capability to react on the presented deviant stimuli, we calculated the mean reaction time of the 80% slowest reaction times within a time period of 20 minutes prior as well as after the phone call for the forenoon and for the afternoon session. The results depicted in Figure 6 show a significant effect between the forenoon and the afternoon session. The differences between the periods before and after the stimulus are statistically not significant.

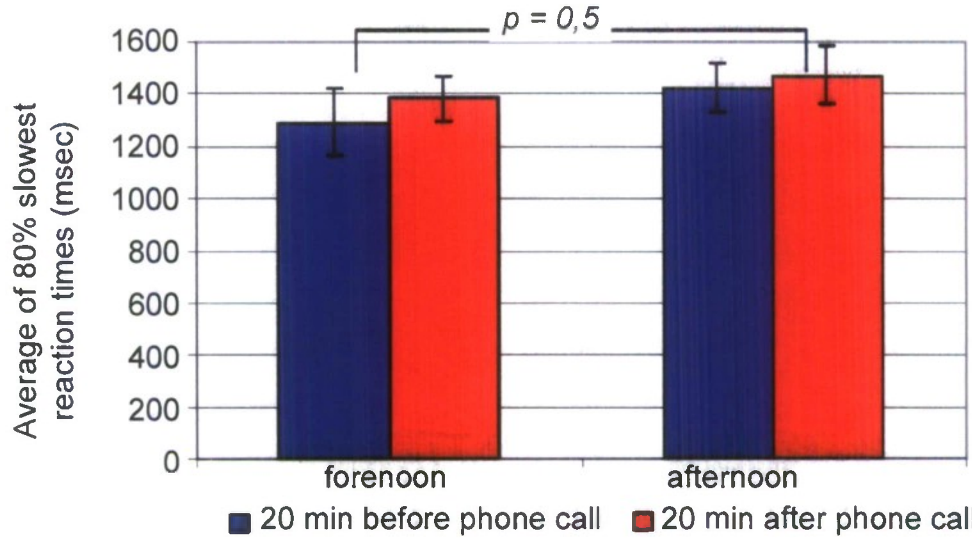

Figure 6: Average reaction time of the 80% slowest reactions of the G-Wagon driver for the 20 minutes intervals before and after the phone call for the forenoon and for the afternoon session.

The subjectively perceived fatigue level of the G-Wagon drivers was assesed using the questionnaire in **Fehler! Verweisquelle konnte nicht gefunden werden.**, the values are depicted in Figure 7.

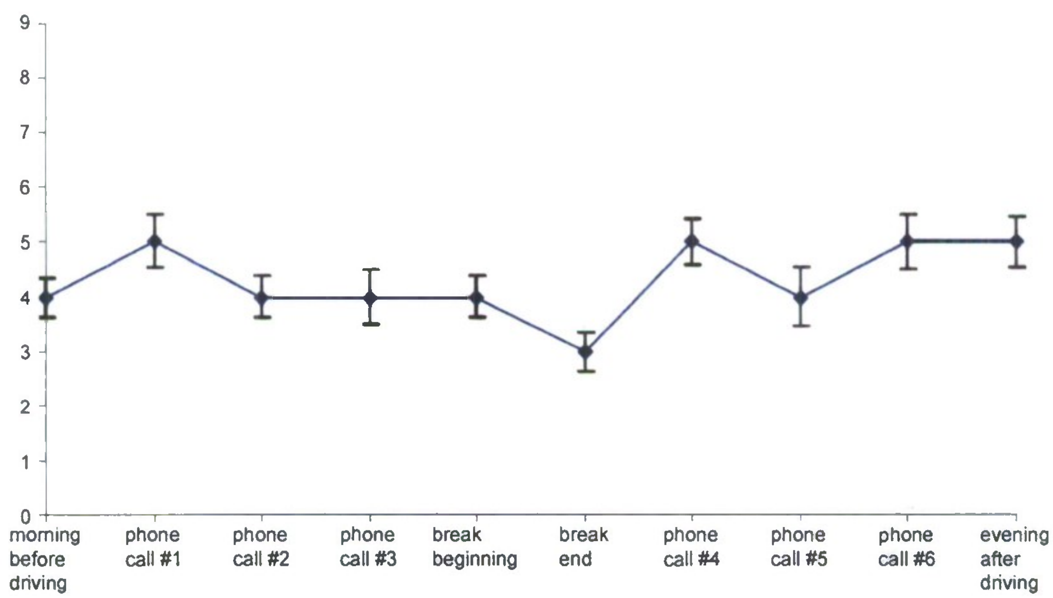

Figure 7: Average subjective fatigue values for G-Wgon driver. Values are according to the questionnaire in Fehler! Verweisquelle konnte nicht gefunden werden..

The mean reaction time of the truck drivers shows a significance between the forenoon and the afternoon sessions (p=.012(F=7.328); η^2=.220). There was no statistical difference between the drivers mean reaction times between the conditions leader and follower.

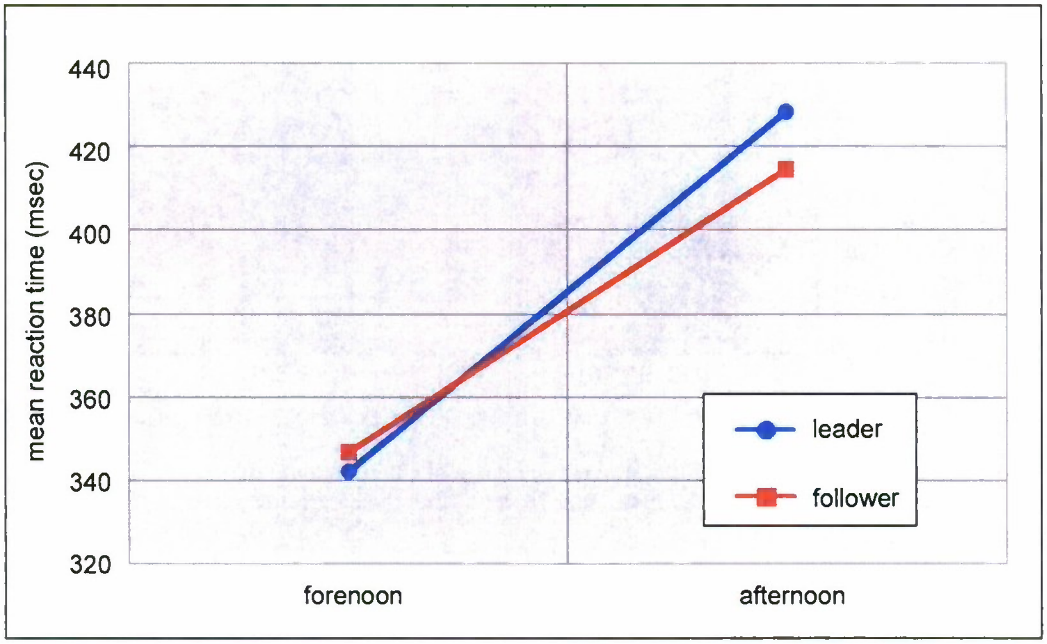

Figure 8: Mean reaction time of truck drivers in the conditions leader and follower for the forenoon and for the afternoon session.

2.4.2 Behavioral-Data Classification

At the highest level, the purpose of the behavioral-data classification system is to detect the underload condition by transforming readily available vehicle data into an automated determination that the driver is exhibiting behavior associated with underload. That is, we constrained the behavioral-data classification system to sensors that are available on current-generation commercial vehicles, or next-generation military vehicles. The only use of nonstandard sensors, such as EEG, ECG, EOG, and cameras, is to validate the performance of the classifier's output using those sensors as "scaffolding" that will not be required in a deployed system.

A survey of recent literature indicates that drivers are overwhelmingly distracted while driving. In particular, the 2006 US Department of Transportation's 100-car Naturalistic Driving Study shows that 73% of the time "drivers are engaging in secondary tasks, driving while drowsy, or looking away from the forward roadway very frequently (Klauer p.22)." The implication is that drivers are typically in the "underload" condition and creating a software classifier that identifies this common behavior is not useful on its own. The software classifier should instead focus on the extremely small number of situations, and driver behavior, that are potentially dangerous. This system must have a low false (or "nuisance") alarm rate; otherwise such a system will not be accepted by drivers.

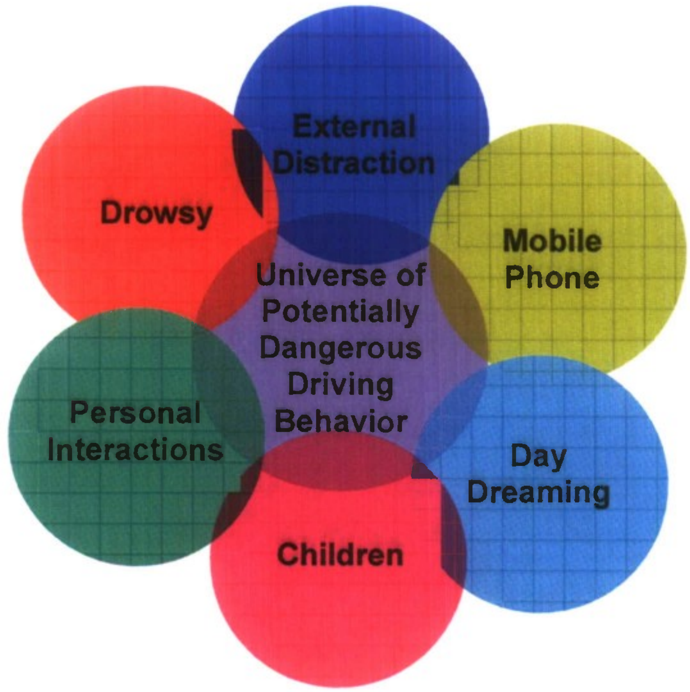

Figure 9: Notional Venn diagram about the intersection of Potentially Dangerous Driving Behavior with other behaviors common to drivers.

In other words, we are not necessarily looking for just underload conditions and associated behaviors, but behaviors that are potentially dangerous. This universe of potentially dangerous driving behavior certainly includes small portions of the associated behaviors, such as talking on a mobile phone or day dreaming. But, ultimately, it is identifying the small fraction of driving behavior that is potentially dangerous.

The same US Department of Transportation study also showed that "For drivers over the age of 18, having a passenger in the vehicle is associated with less likelihood of crash or near-crash involvement than if there was no passenger in the vehicle. A possible interpretation of this result is that the passenger is also scanning the environment and can warn a driver of an impending dangerous situation (Klauer p.34)." This study showed that having a passenger in the vehicle reduces the odds-ratio of having a crash by 50%. The goal of this research is not to automate driving, but to identify and mitigate potentially dangerous situations for the driver, similar to a "backseat driver," resulting in safer vehicles by improving the driver-vehicle interface without relying on exotic sensors.

2.4.3 Algorithmic Description of Behavior-Data Classifier

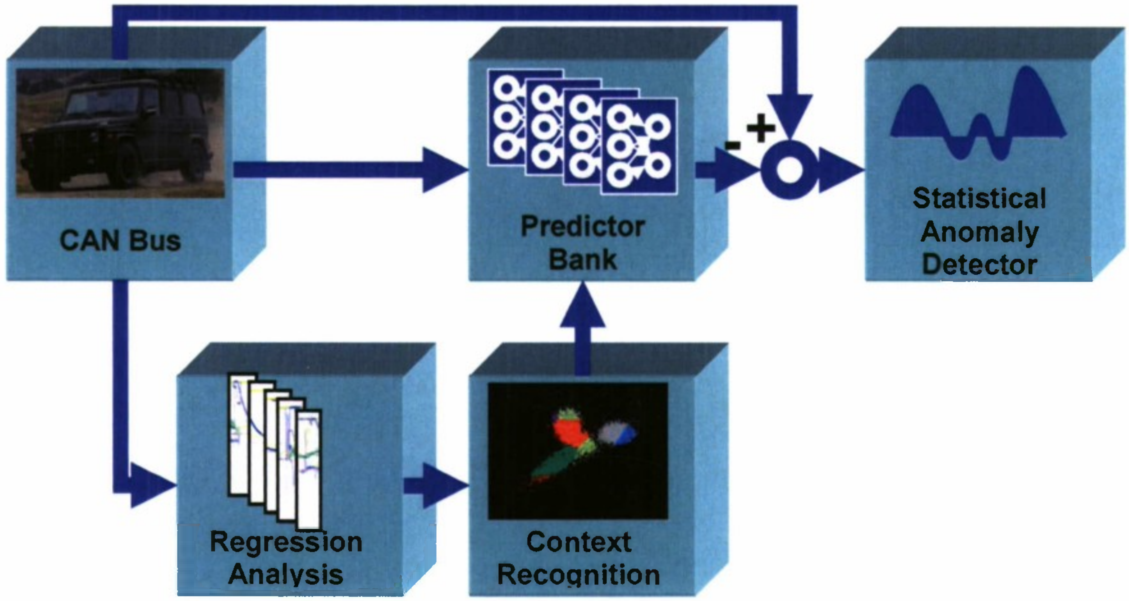

Figure 10. High-level diagram of the behavior-data classifier.

The high-level diagram of the behavior-data classifier is shown above. The system is based on the concept of learning patterns of "normal" driving behavior and then looking for divergences from that behavior. To do this, the system requires an expectation of what the driver will do in the near future (the context recognition and predictor bank), which is then compared with what the driver actually does.

The system begins by sampling sensor data from the CAN bus of the G-Wagon at 4Hz. The Disctronic system is a proprietary Daimler is a radar-based system that measures the distance to a moving object in a narrow, forward-looking field of view. After evaluating many candidate combinations of sensors as input to the system, we finally settled on the following sensors:

- Steering Wheel Angle
- Brake Pedal Force
- Accelerator Pedal Deflection
- Disctronic Acceleration Relative
- Disctronic Distance
- Disctronic Distance Relative
- Disctronic Impact Time (computed)
- Disctronic Speed Relative
- Electronic Stability Control Flag
- GPS Elevation

- Gear Number
- Lateral Acceleration (computed)
- Average Wheel Speed (computed)

We measure behavioral anomalies with respect to how a driver interacts with the vehicle. The primary controls that the driver uses in a vehicle are:

- Steering Wheel Angle
- Brake Pedal Force
- Accelerator Pedal Deflection

Note that we are using the controls as input to the prediction system. This means that we are, in effect, predicting how the driver will change the values of the controls in the near future.

The first step in the classifier is to take the inputs from the CAN bus and put them into a pre-defined time window, typically five seconds (20 samples at 4Hz) in width. We then fit a straight-line regression curve to each sensor, computing the slope (m) and offset (b) coefficients for the time window. The slope (coefficient "m") gives a notion about how the signal has changed in the time window, while the offset (coefficient "b") yields a sort of low-pass filtered value of the current value of the signal.

The next step in the classifier is that the slope-and-offset sensor values are fed into a context recognizer. The context recognizer is created by providing unlabeled driving data to a clustering algorithm that constructs multivariate Gaussian distributions for each cluster. The algorithm we use to construct these clusters is a variant of the well-known k-means algorithm that incorporates the removal of clusters that have insufficient evidence for their existence (i.e. the number of cluster members is significantly less than 1 / k). The result of passing the data through the context recognizer is the probability that the current situation belongs to each of the possible contexts.

These context probabilities are then used by a bank of prediction functions; one predictor for each context. The prediction functions are learned using supervised-learning techniques by mapping the inputs to the state of the primary control surfaces at some point in the future. The prediction functions are made unique to each context by weighting each example by the probability the example is from that context, which is provided by the context recognizer. At runtime, each of the predictors is evaluated and their contribution to the overall prediction for each control signal is weighted by the probability that the current situation belongs to the predictor's corresponding context. In Figure 7, we show that the system performs statistically significantly better using the context-based prediction mentioned above. At 1-second, the context-based system predicts 81% of driver variance; at 4-seconds, the context-based system predicts 48% of driver variance.

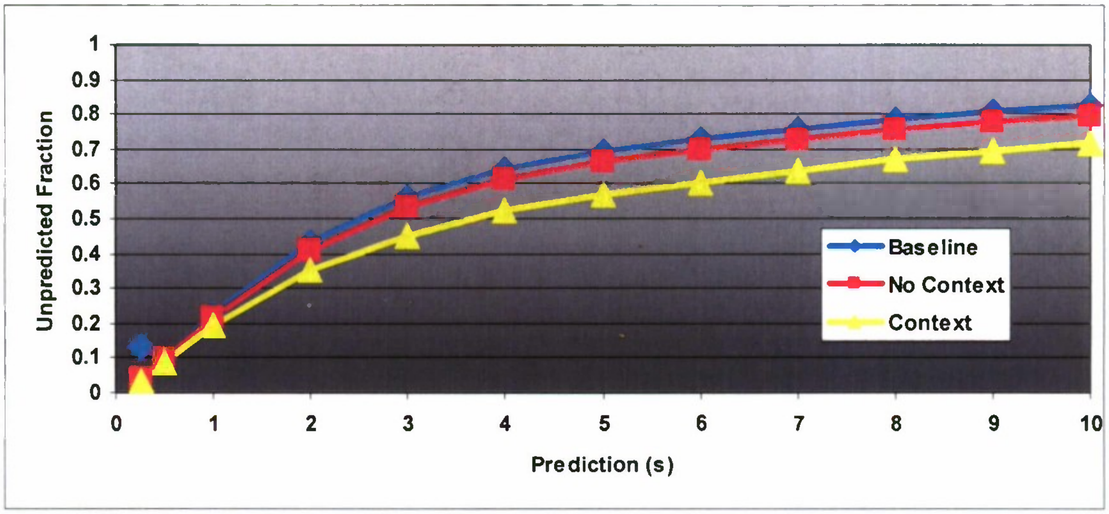

Figure 11. shows the improvement of using context-based predictions as a function of time into the future. The top-most line shows driver variance. The middle (magenta) line shows the ability to predict driver behavior without contexts. The lowest (yellow) shows the prediction ability using contexts.

Once this prediction for the state of the control surface is created, the prediction is compared to the actual control surface value in the future. In Figure 8, we show the accuracy of the prediction system for the Accelerator Pedal, Brake Pedal, and Steering Wheel Angle. At time >2.5 seconds, the Accelerator Pedal and Brake Pedal become statistically significantly easier to predict than Steering Wheel Angle.

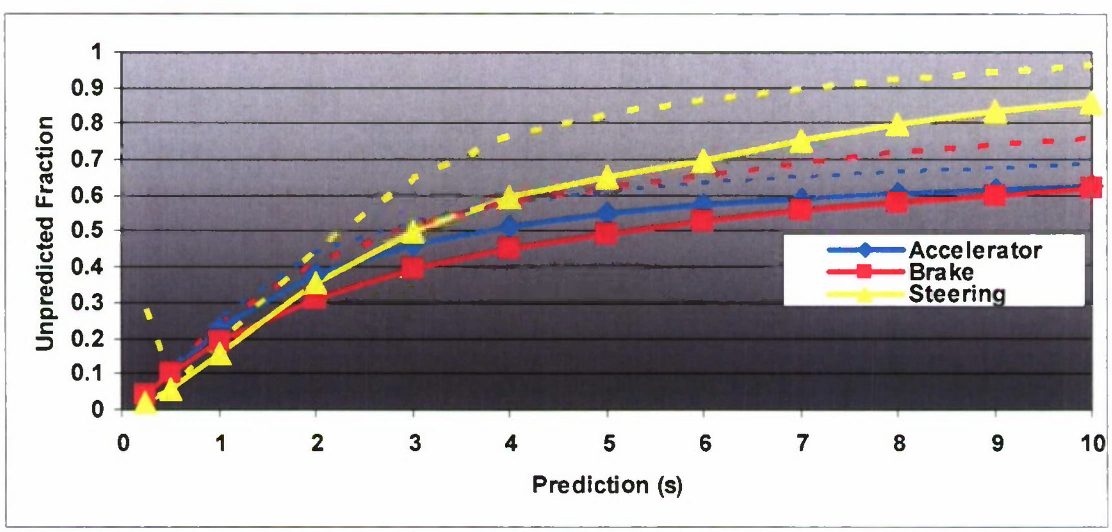

Figure 12. Prediction accuracy as a function of prediction time into the future. The dashed line represents the upper 95% confidence interval for predictions of that control sensor.

At each time step, typically at 4Hz, we compute a prediction for each of the Accelerator Pedal, Brake Pedal, and Steering Wheel Angle for a time into the future. We then compare the actual values that the user performed to the predicted signals and treat any difference as an error. This error is then fed into a statistical anomaly detector. The statistical anomaly detector is created by estimating the mean and full covariance matrix using a chi-square distribution with three degrees of freedom (representing the three control sensors). At runtime, the error is fed into the statistical anomaly detector and an anomaly threshold of 10^{-100} is used. Given this threshold, the system focuses on truly anomalous behavior; not just infrequent situations.

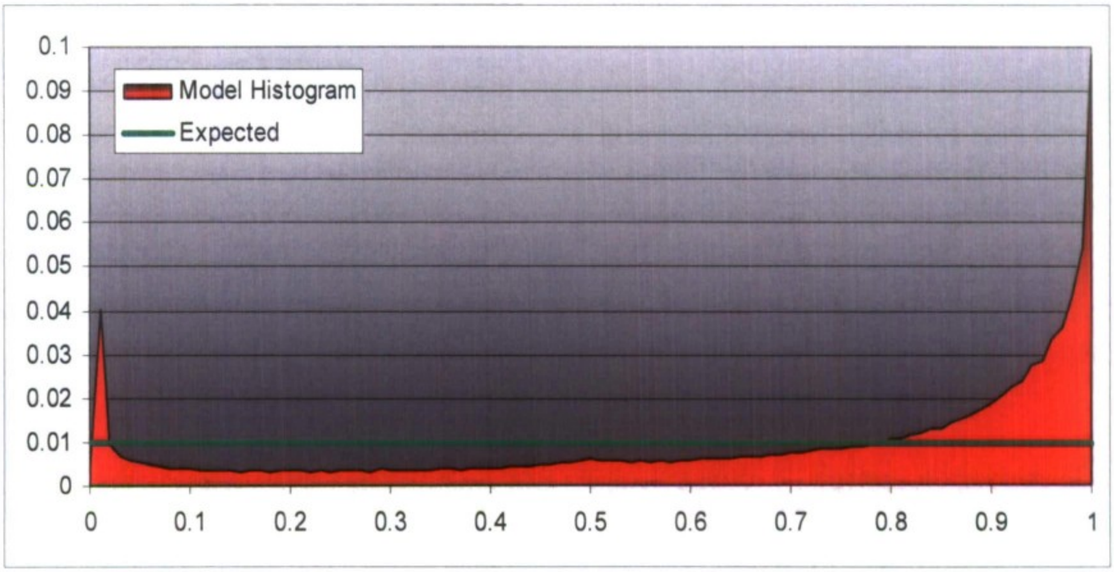

Figure 13. Distribution of the prediction errors for the test conditions. If the theoretical assumptions of Gaussian iid errors were correct, then the distribution should follow a flat line, marked by the "Expected" gree line. The actual distribution of error probabilities is shown with the red histogram. A Kolmogorov-Smirnov test indicates that these probability distributions are almost certainly different.

From the experimental data, we accumulate the prediction probabilities as a histogram. If the theoretical model were correct, then this histogram would be flat. The distribution of estimated prediction probabilities in Figure 9 shows that the model's histogram has very heavy tails. That is, there are far too many "perfect" or "almost perfect" predictions of the driver's behavior (40% of predictions have a probability >0.9). Furthermore, there are too many extremely unlikely predictions (4.5% of predictions have a probability <0.01). A Kolmogorov-Smirnov (K-S) test between the theoretical distribution and the empirical distribution indicates that the distributions are almost certainly different. This implies that the theoretical model does not reflect the empirical data. As the famous statistician George Box once said, "All models are wrong, but some are useful." And just because the theoretical distribution appears to be wrong, it still remains to be seen if it can be useful in identifying anomalous behaviors and, ultimately, potentially dangerous driver behavior.

2.4.4 Behavior-Data Classifier Results

To evaluate the performance of the classifier, we split the data into training and testing sets, built the classifier using the training set, and then applied it to the testing set. The training set consisted of 11.5 hours (165 812 samples) of data collected from four G-Wagon subjects, split randomly between morning and after sessions (VM04, NM05, VM06, NM09). The test set consists of 93.6 hours (1 347 921 samples) of data from 17 subjects (33 sessions). In total, we identified 318 anomalies with the highest likelihood. However, we quickly discovered that three of the subjects (all young males) deliberately disregarded the experimental protocol and "fooled around." (This involved drag racing, getting quite close to the lead vehicle, two-foot driving, etc.) These three subjects generated 204 anomalies between them, about 64% of all anomalies observed. With those three subjects excluded, the remaining 14 subjects generated 114 anomalies in 76.6 hours (1 102 795 samples) of driving data, or one anomaly every 40.3 minutes. We then took each of the anomalies that the classifier identified and had a human manually assess whether or not it was truly an anomaly. A sequence of anomalies with less than 10 seconds between occurrences was considered to be a single anomaly. This method allowed us to identify how many true positives and false positives the system was producing, but does not allow us to gather statistics about the rates of true negatives or false negatives. That is, it does not identify anomalies that the system may have missed. We took this approach to the analysis because of the large amount of very monotonous data. The human assessor was provided with a video feed of the subject plus the raw sensor values from the vehicle to use in order to make the assessments. When we quantified these anomalies, we judged that 49 were definitely due to anomalous driver behavior; 12 were probably due to deliberate driver behavior and not potentially dangerous; and 53 were unclear as to why the driver behaved so anomalously. Examples of anomalous behavior include falling asleep at the wheel, last-minute braking due to an on-road obstacle, etc. Examples of explicitly safe anomalous behavior are carefully avoiding an on-road obstacle or braking for a herd of sheep, etc. Examples of unexplained behavior are sudden braking when the driver is not visibly sleeping, making an emergency stop for no obvious reason, etc.

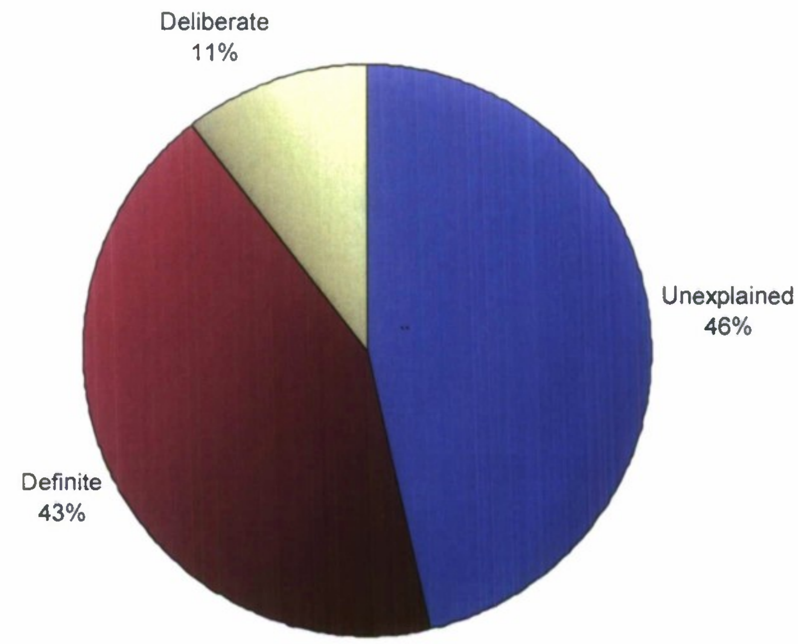

Figure 14. Of the anomalies from the "valid" subjects, 43% were definitely due to potentially dangerous behavior, 11% were due to deliberate driver behavior that was explicitly not dangerous, and 46% were unclear as to why the driver behaved so anomalously.

2.4.5 Behavior-Data Classifier Conclusions

The results of the behavior-data classifier indicate that the classifier is able to pick up on certain types of anomalous behavior in the experiment, but it also has room for several potential improvements. One such potential improvement would be to incorporate some sort of asymmetric error measure. For example, in the current classifier an error where the system expected the driver to apply 1000 Nm of force to the brake pedal and applied none would have the same amount of error as if the system expected the driver to apply 1000 Nm of force and applied 2000 Nm; both have a difference between actual and expected values of 1000 Nm of force. Qualitatively there is a difference between not pressing the brakes and pressing them too hard, but this type of information is currently not available to the system.

The current classifier also has the limitation that it only considers a fixed time window of the previous 5 seconds in order to detect anomalous behavior. While this is fine for finding large differences between expected and actual behavior, it is unable to detect the accumulation of a lot of small discrepancies that, which may be more indicative of drowsy driving behavior. Subjectively from looking at the data, it seems that subjects with many or repeated anomalies should probably not continue driving.

We plan to include these improvements in future versions of the classifiers.

2.4.6 Neurophysiology Data

Results from ABM Analysis

For the Daimler EEG files provided from 2007, a total of 48 subjects had baselines and driving sessions that ABM was able to convert and analyze. Of these 48 subjects, 13 had higher than expected probabilities of distraction across the entire testing period. Two subjects had data that was predominantly classified as Sleep Onset, and one subject had excessively high probability of High Engagement, suggesting that the b-alert model did not fit to the subject correctly likely due to sleep deprivation. For the 2007 data there is no corresponding AMP performance data that would have allowed for a comprehensive analysis that could have determined the cause for the poor model fit.

The EEG configuration used to collect the Daimler data resulted in a PO recording that was amplified 2-4 times greater than all other EEG inputs requiring a hand adjustment for the calculations and a slightly higher contribution of PO site to the definition model. The amplitude of PO likely accounts for the 13 subjects whose alpha/distraction classifications were slightly higher than expected.

G-Wagon Driver (Results from Daimler AG analysis)

17 out of the 20 data sets were used for the analysis. Data sets had to be excluded form analysis since they were not complete (experiment had to be interrupted due to sever weather conditions).

Using an alpha-spindle detector, a fatigue index was calculated for all subjects and all rounds. In order to assess the impact of the communication task, i.e. of the phone conversation on the driver's fatigue level, the average fatigue level was calculated for 5 minute intervals before and after each phone call. The results for all participants are depicted in Figure 15. In order to aggregate all results, we calculated the changes of the average fatigue level with 5-minute periods as % change relative to the respective subject's average fatigue level over the entire period of the experiment. The results show that the phone call has a significant activating impact. The effect lasts for about 15 minutes after which the fatigue level before the phone conversation is reached.

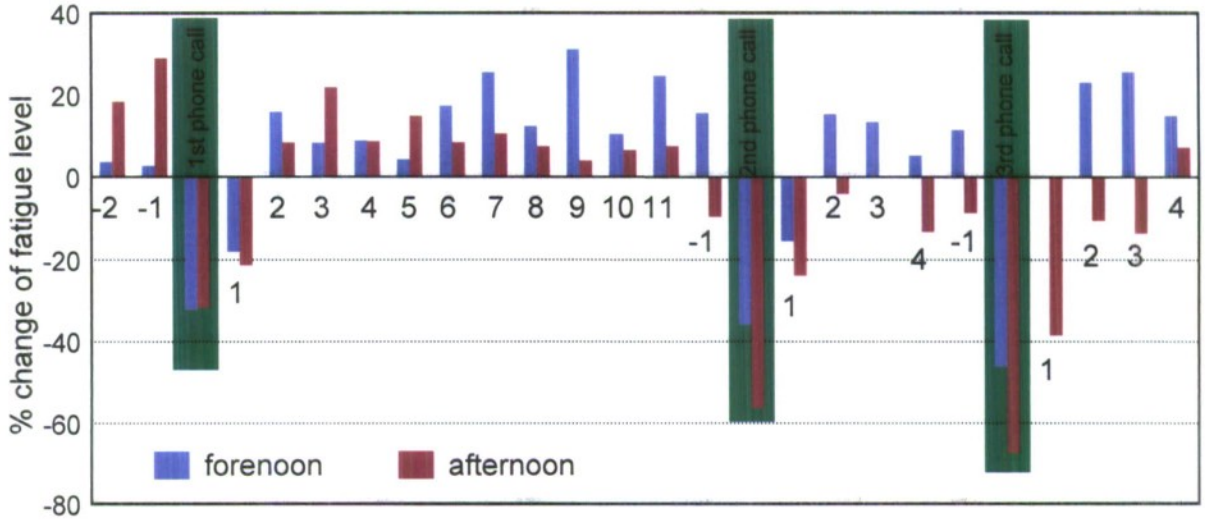

Figure 15: Average changes of fatigue levels in 5 minute intervals before and after each phone call, calculated as % changes relative to the driver's individual average fatigue level during the entire period of the experiment.

Actros Driver (Results from Daimler AG analysis)

Using an alpha-spindle detector, a fatigue index was calculated for all subjects, all rounds and for all experimental conditions. In order to investigate the effect which the overtaking maneuver as well as the effect which the position in the convoy (leader or follower) has on the driver's fatigue level, we calculated the average fatigue level for these conditions as well as during the overtaking maneuver. The results for all participants are depicted in Figure 15. In order to aggregate all results, we calculated the changes of the average fatigue level with 5-minute periods as % change relative to the respective subject's average fatigue level over the entire period of the experiment. The results show that the phone call has a significant activating impact. The effect lasts for about 15 minutes after which the fatigue level before the phone conversation is reached.

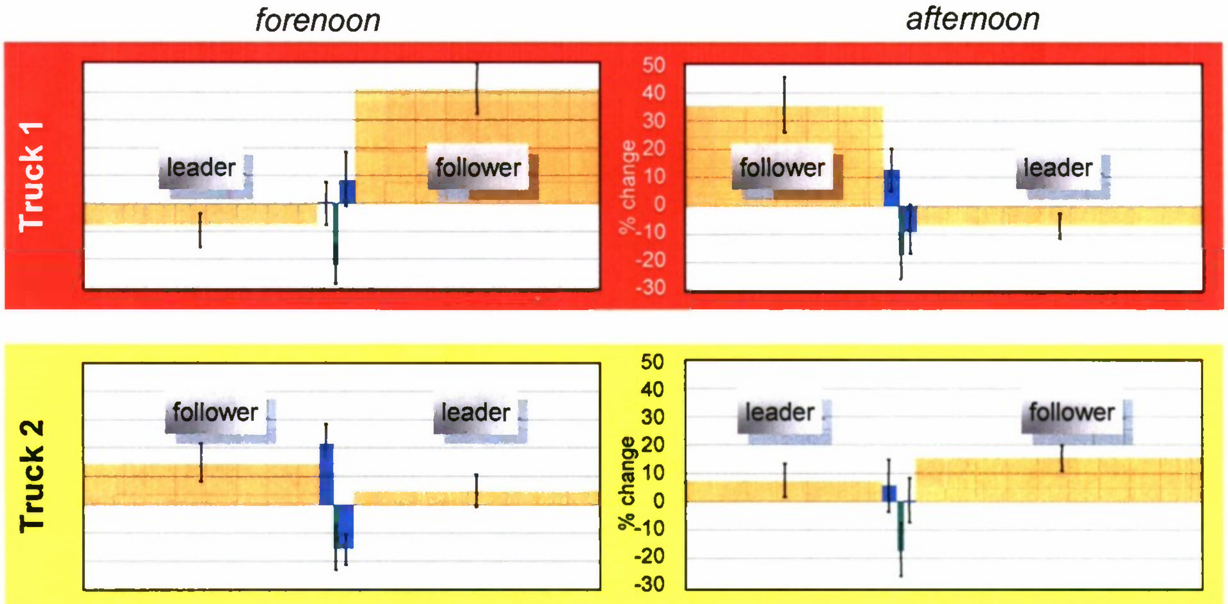

Figure 16: Average changes of fatigue levels during all experimental conditions, calculated as % changes relative to the each driver's individual average fatigue level during the entire period of the experiment.

The main purpose of this experiment was to investigate the influence of (a) the position within a convoy, (b) an over passing maneuver and (c) a communication task on the driver's fatigue level.

With regard to the driver's position within a convoy, i.e. leader or follower, the results show that in the leader position, the driver's overall fatigue level is lower than in the follower position. There is also an order effect, i.e. it seems to make difference if the driver starts as a follower in the morning or in the afternoon.

The over passing maneuver has a very small direct influence on the driver's fatigue.

The results suggest that engaging the driver into a communication task alerts the driver, lowering his level of fatigue. The phone calls we used during the experiment had an average duration of about 5 minutes. All physiological measures assessed indicated that the activating effect of the phone conversation in these monotonous conditions lasted for about 15 minutes.

3 EXPERIMENTAL DESIGN AND TESTING #2

The sections below provide an overview of experimental test plans and details of the second experimental tests.

3.1 Objectives

In collaboration with a transition partner, the United States Marine Corps (USMC), a job analysis was performed in order to design tasks with high domain validity while allowing sufficient experimental standardization. The tasks were constructed to resemble actual tasks of crew members in an LAV-25 armored personal carrier or the Marine Expeditionary Family of Fighting Vehicles (MEFFV) during convoy operations.

The main purpose of the experiment was to investigate the possibility of developing a system capable of detecting a driver's state of cognitive underload as a result of monotonous convoy operations. Based upon the system's detection capabilities, driver support systems will be developed.

3.1.1 Background Information

See 2.1.1.

3.2 General Preparation

3.2.1 Location

The experiment was conducted near Münsingen, Germany, on a decommissioned military training facility, formerly belonging to the German Federal Armed Forces (Figure 3). This location constitutes an undisturbed environment with controlled traffic conditions.

3.2.2 Participants

In total, 24 drivers participated in the study, i.e., 2 drivers per day (2x Actros trucks) for 12 experiment days. Subjects were recruited from a database of subjects provided by the local company in Münsingen that now maintains the test facility (Experience Area Münsingen GmbH). The advantage of using subjects from the database was that the subjects were familiar with the Münsingen area, as well as the test track, which minimized familiarization effects. Subjects from the database responding to the announcements were selected based on the below listed inclusion and exclusion criteria. As an incentive, participants were monetarily rewarded for taking part in the study, being paid EURO 200.00 for the completed study visit.

Inclusion Criteria

Subjects must have met all of the below inclusion criteria in order to be eligible for participation in the study.

- Valid truck driving license
- Male or female, maximum 60 years old
    - average of at least 50,000 km in the past 2 years (2005 and 2006) OR more than 10 years job experience as truck driver for the "experienced group";
    - average of maximum 10,000 km in the past 2 years (2005 and 2006) for the "inexperienced group".

- Normal or corrected-to-normal vision and normal hearing
- Native speaker of German

Exclusion Criteria

Any of the following conditions excluded the subject from participating.

- Any health problem or medications that may interfere with the subject's driving performance or physiological monitoring, as determined by the research physician (e.g., history of seizures, vertigo, heart disease or other cardiac irregularities, insulin-dependent diabetes, amputee, anti-depressants, etc.)
- Any medication or health condition which may affect EEG, EKG, or EOG readings (e.g., pacemaker, ICD, neurostimulators, etc.)
- Pregnancy
- Any other condition that may interfere with the subject's participation, as determined by the research physician

3.3 Experimental Testing

The following subsections describe in detail the experimental test protocol.

3.3.1 Overall Procedure

The experiment started with a briefing that summarized the experiment and researchers answerer questions or concerns raised by the participants. After all questions were addressed, the subjects were asked to sign a consent-release form. The subjects' participation lasted one day. A number of different sessions within a single experiment were required for each day of the experiment. During these sessions, the subject underwent neurophysiological monitoring (EEG and EOG).

This neurophysiological monitoring comprised 28 EEG channels, according to the standard international 10-20-electrode placement system and 2 EOG channels. No abnormalities were noted.

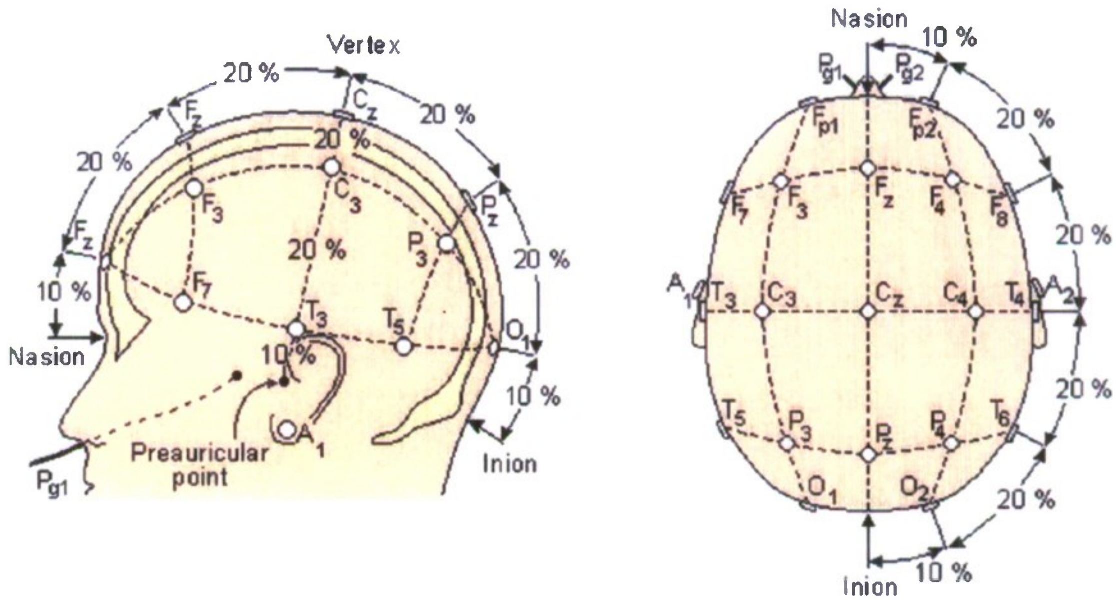

Figure 17: Electrodes alignment in the international 10/20 system after Jasper (1985).

In order to establish a baseline for each subject, a calibration test (Alertness and Memory Profiler (AMP) by Advanced Brain Monitoring, Inc., CA) was performed, during which time data were collected for approximately 20 minutes. The AMP consisted of a neurocognitive battery of vigilance, attention, learning, and memory tests during which EEG data and behavioral data are recorded. The testing battery evaluates working and recognition memory using verbal and visuo-spatial tasks. The neurocognitive constructs evaluated by the AMP include sustained attention, processing speed, and verbal and visuo-spatial memory. AMP results are compared to Advanced Brain Monitoring's normative database.

Once a baseline was established, participants were familiarized with both their assigned vehicle and their tasks. During the familiarization, EEG sensors remained in place to allow participants to become more comfortable with the sensor net. Participants then completed a whole course of the test track in a convoy-type configuration, following the leading truck. The intent was to provide an opportunity for participants to become sufficiently familiar with the vehicle and experimental test conditions in order to reduce the effects of learning on the experimental results. This phase of the study required approximately one hour.

During the next phase of the study, participants were asked to perform their assigned experimental tasks, described in the following sections, while EEG measures, psycho-physical data, and vehicle were collected. During all driving, subjects were required to use seatbelts and obey all traffic rules.

3.3.2 Experimental Session

A single experiment trial consisted of two vehicles driving in a convoy formation at a speed of 45 (+/- 5) km/h while keeping a safe following distance between vehicles of 25 meters. The convoy drove the rounds six (6) times per experiment day, each circuit having a distance of about 37 km. After the first three rounds, the convoy stopped and took a one-hour break during which time the subjects were able to eat, drink, and relax. After the break, the convoy completed the remaining three (3) rounds.

Before, between and after each session, the subjects were asked to answer a set of questionnaires (Appendix 1 – 10) according to the following plan:

Before Session 1:	Appendix #1, #2, #3, #4, #5, #6
After Session 1 (at the beginning of the break):	Appendix #6
Before Session 2 (at the end of the break):	Appendix #6
After Session 2:	Appendix #6, #7, #8, #9

Tasks

The role of the Actros truck drivers was to drive in the follower position in the convoy. The drivers drove one session with adaptive cruise control on and the other session without the system turned on. Adaptive cruise control, known as ACC, is a commercial off-the-shelf radar-based system that attempts to keep the desired speed and, in the case of a slower vehicle in front of the driver's vehicle, adjusts the speed of the driver's vehicle to maintain a safe following distance. There were two pairs of Actros trucks on the road at the same time, which allowed recording two subjects per day. The two convoys will be 15 minutes apart from each other to avoid interference. The leading trucks (first truck in both convoys) were driven by professional truck drivers that remained the same during the entire experiment. During the course of each round one to three signs were presented on the side of the road (see Figure 18). As soon as the drivers recognized these signs, they pressed a button, acknowledging their recognition. By recording the GPS position of each sign and the position of the vehicle at the moment of the button press, it was possible to calculate the distance between both points, which was used as a psychophysical measure of performance.

Figure 18: ***Sample target as it will be placed alongside the course.***

3.4 Results

3.4.1 Performance data

Post processing of the data revealed that 24 out of 28 data sets were suited for further analysis. The data sets were generated by 24 male drivers. The average age was 42.0 years (20 – 68 years). Three of the participants were familiar with the Adaptive Cruise Control System (ACC). The distribution of their yearly driving performance is summarized in Figure 19 (left), the categories describing the type of driving is described in Figure 19 (right).

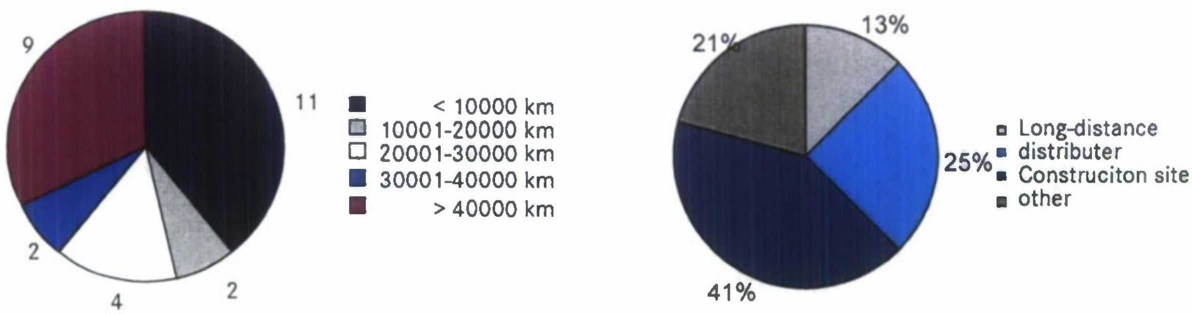

Figure 19: Description of riving performance and of type of driving of the study participants.

One of the main questions of the experiment was, whether due to an active ACC system that automates the longitudinal control of the vehicle, the driver has more attention resources that enable him to better detect targets at the side of the road.

The analysis of the target detection task revealed that when driving with ACC turned on, the drivers detected the targets 630 ms on average faster than when driving without active systems. Taking into consideration the driving speed of the truck, the benefit translates into a distance of 7 meters on average. In total, there were 423 valid events in which the drivers should have detected targets (24 (drivers) x 18 (targets/day) – 9 non-valid events). Nine events had to be excluded from the analysis due to CAN-bus errors (5x) and misplaced targets (4x). With ACC system turned on, the drivers missed 44 targets, whereas without the support of the ACC system, the drivers missed 60 targets (36% more failures).

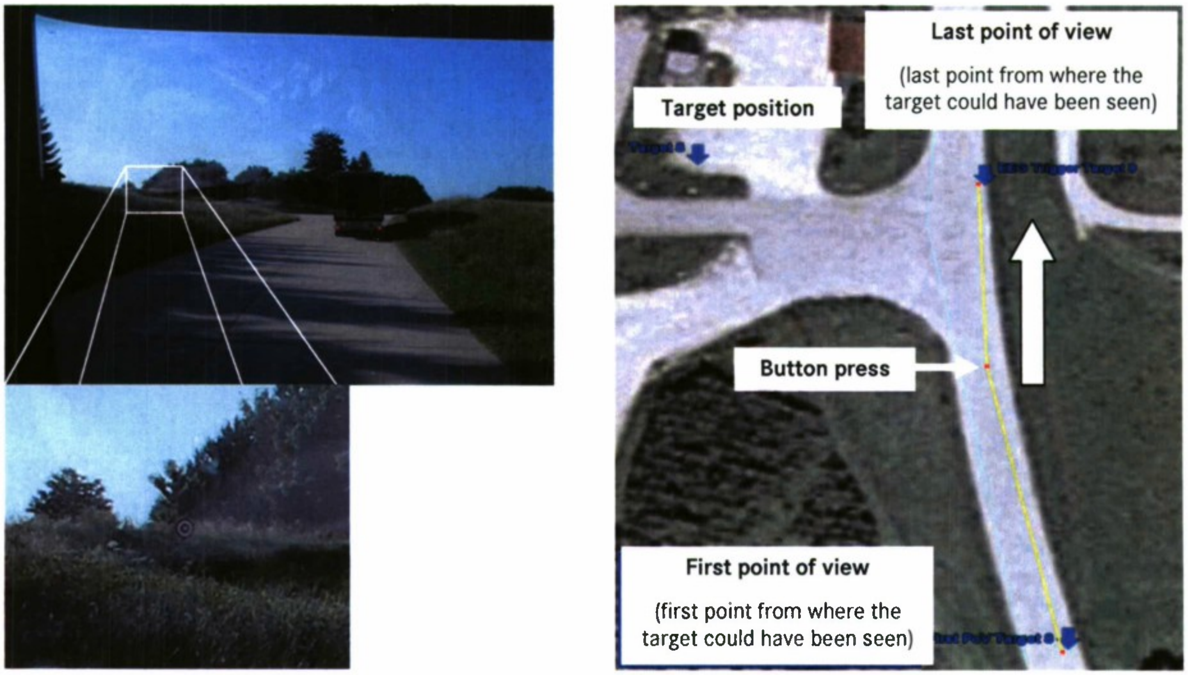

Figure 20: Example of a target (left). Relevant points to calculate driver's response.

3.4.2 Summary statistics derived from the B-Alert EEG analyses

Sensors were located at Fz, Cz, and PO, according to the International 10-20 system for EEG settings. Quantification of the EEG, referred to as the B-Alert™ system, was achieved using signal analysis techniques to identify and decontaminate fast and slow eye blinks, and identify and reject data points contaminated with EMG, amplifier saturation, lost data packets (from RF transmission), and/or excursions due to movement artifacts. The probabilities of each of four states of alertness ("High Engagement", "Low Engagement", "Distraction", and "Sleep Onset") were calculated for each one-second epoch of data. Classifications were obtained using a discriminant function analysis derived from a large normative database and fitted to each individual's unique EEG patterns with data acquired from three baseline tasks.

Each subject completed three Alertness and Memory Profiler (AMP) sessions consisting of (1) 3-Choice Vigilance Test (3-CVT, 20 minutes in duration during morning session; 5 minutes during afternoon and evening sessions), (2) Eyes-Open paced button press (5 minutes), and (3) Eyes-Closed paced button press (5 minutes). The data from the morning AMP test were used to create a personalized "definition" file for each participant that allows for real-time classification of participants' brain states. Performance (reaction time and % correct) was used to identify outliers or subjects who may have been sleep deprived. Each subject completed an AMP session at three time points: before morning drive, after morning drive, and after afternoon drive.

This analysis presents an overview of the EEG alertness classifications while driving, as well as trends in alertness and performance during the AMP sessions. The protocol was as follows:

- Morning baseline AMP session with 20 min. 3C-VT, 5 min. Eyes Open, 5 min. Eyes Closed

- Practice lap with technician in vehicle
- 3 laps- Truck 1 ACC OFF; Truck 2 ACC ON ("AUTO pilot" mode)
- Afternoon AMP session with 5 min. 3C-VT, 5 min. Eyes Open, 5 min. Eyes Closed
- Lunch
- 3 laps- Truck 1 ACC ON; Truck 2- ACC OFF
- Evening AMP session with 5 min. 3C-VT, 5 min. Eyes Open, 5 min. Eyes Closed

Lap by Lap analysis

EEG High Engagement levels decreased over the first three laps, reset to initial levels following the lunch break and then decreased over the final three laps. Repeated measures ANOVA showed a main effect of LAP, $F(5,115) = 3.24$ $p=.027$. Significant pair-wise comparisons are highlighted by the brackets in the above graph above.

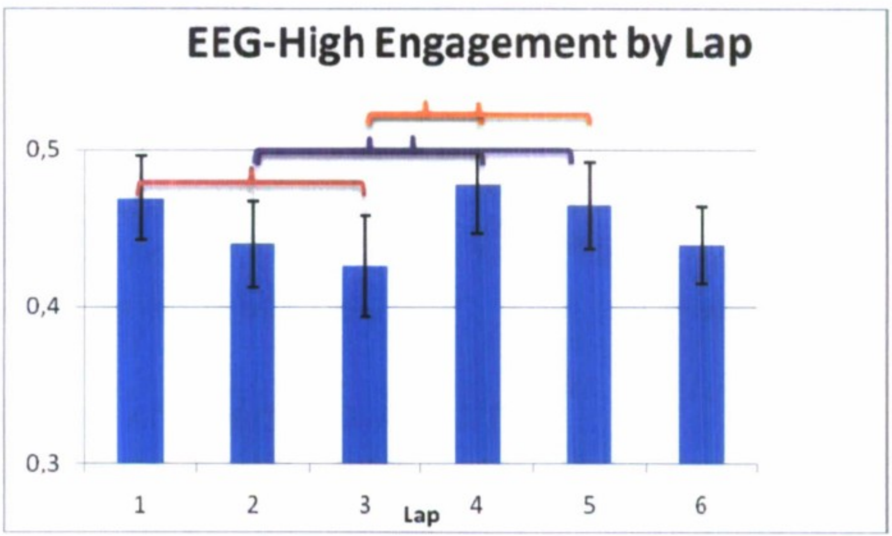

Figure 21: EEG high engagement analysis by lap.

Analysis of Lap by ACC ON/OFF for EEG High Engagement showed a trend towards lower EEG High Engagement levels when the automation (ACC) was ON (laps 1-3 for red group, laps 4-6 for blue group in above graph). The difference in Engagement between groups is particularly seen during laps 1-3 (P value for Lap 2 is .065, and Lap 3 is .086). High Engagement throughout the day was lower for the group with ACC ON in the morning.

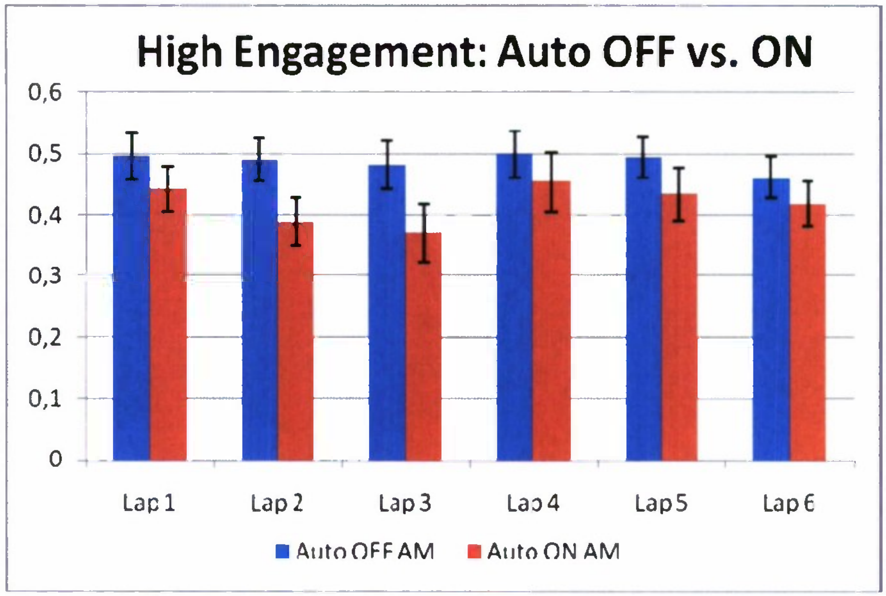

Figure 22: EEG high engagement results for adaptive cruise control (ACC = Auto) ON vs. OFF by lap.

EEG DISTRACTION did not show significant changes by lap. There was a suggestion in the data that EEG Distraction increased by lap, although nothing significant findings were observed (no main or interaction effects). This is likely due to the high between-subject variability and may suggest significant individual differences in the drivers' distraction levels over time.

Perhaps the most interesting trend is the difference between the group with ACC OFF vs. ON in the morning. The high degree of variance prevents this form being significant (p=.5). These are CHANGE FROM BASELINE (meaning LAP 1 in the morning for all groups) scores.

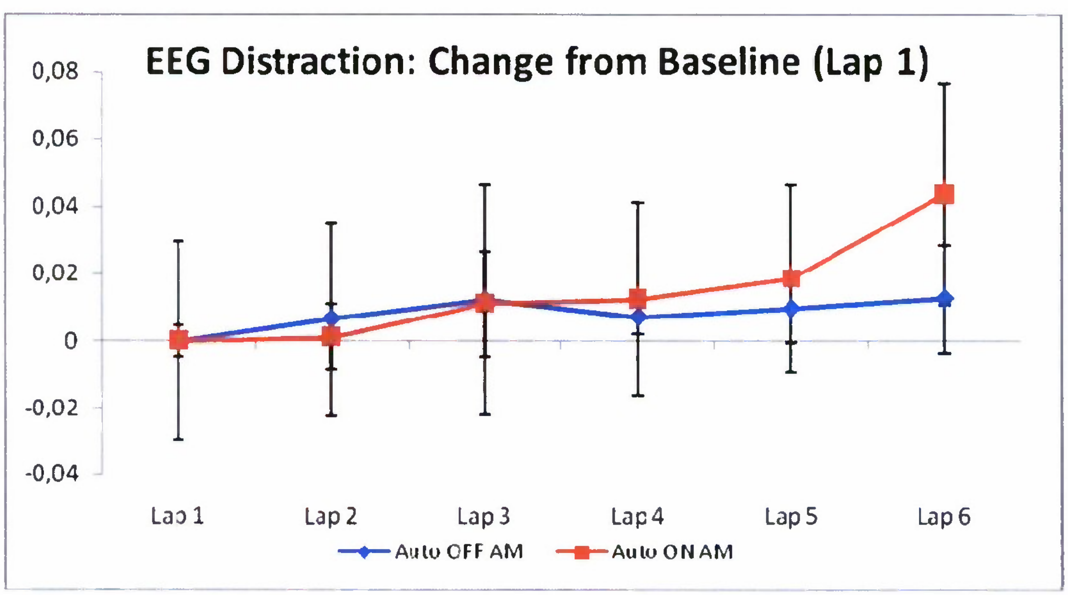

Figure 23: EEG results for changes from baseline (lap 1) by lap.

Preliminary analysis of the group demographics revealed some intriguing relationships.

Correlations with Age and BMI

Correlations	Age
All Subjects	
CHBL_HE2	-.506(*)
CHBL_HE3	-.518(**)
CHBL_DS6	.607(**)
DS_6	.454(*)
ACC ON in a.m.	
DS_3	.594(*)
CHBL_DS3	.705(*)
CHBL_HE5	-.612(*)
SlopeHE 4-6	-.643(*)
AUTO OFF in a.m.	
SO_autoON	.708(*)
SO_6	.776(**)

Table 1: Correlations between age and EEG results.

AGE Summary (Table 1): Age is negatively correlated with High Engagement (HE) levels during laps 2 and 3, and older drivers have less HE as laps 2 and 3 progress. Older drivers also have higher distraction levels during lap 6. The majority of these effects seem to be due to the AUTO ON in AM group. For this group age is positively correlated with distraction levels during lap 3 (last lap with auto on) and negatively correlated with the slope of HE levels during laps 4-6. Furthermore, high engagement decreases more quickly during laps 4-6 (while auto is off) for older drivers in this group. There are few correlations with Age for the Auto OFF in AM group (regardless of time of day of laps). For this group age is positively correlated with sleep onset during the 3 AUTO ON laps (which for this group were laps 4-6) and lap 6 in particular.

Correlations	BMI
All Subjects	
SO_1	.641(**)
SO_2	.747(**)
SO_3	.719(**)
AUTO ON in a.m.	
SO_3	.603(*)
SO_4	.833(**)
SO_5	.907(**)
SO_6	.902(**)
DS_4	.614(*)
HE_5	-.611(*)
LE_6	-.843(**)

LE_autoON	-.796(**)
SO_autoON	.903(**)
CHBL_DS5	-.618(*)
CHBL_DS6	-.707(*)

Table 2: Correlations between BMI and EEG results.

BMI Summary (Table 2): Sleep Onset for the first three laps is positively correlated with BMI: higher BMI means higher levels of Sleep Onset. The majority of these effects seem to be due to the AUTO ON in AM group. Sleep onset is positively correlated with BMI for laps 3-6, as well as various other measures- these do NOT link with the overall correlations, these are independent for the most part.

Analysis of Alertness and Memory Profile (AMP) Reports

Analysis of performance (% correct and RT) during baseline/vigilance tests shows that Subjects 204, 713, 1122, 1224, and 1428 performed outside the norms on all 3 baseline/vigilance sessions. In addition, Subject 1224's EEG was not accurately fit to the B-Alert Classification model during baseline, most likely because they were sleep deprived. As a result, the classifications for Subject 1224 during driving may not be valid. We would conclude that Subjects 204, 713, 1122, 1224 and 1428 were most likely sleep deprived, and should *not* be counted as 'Normal, Healthy' subjects.

AMP repeated measures testing did not reveal significant changes over time for the performance metrics. There were, however, several interesting trends for the AMP EEG.

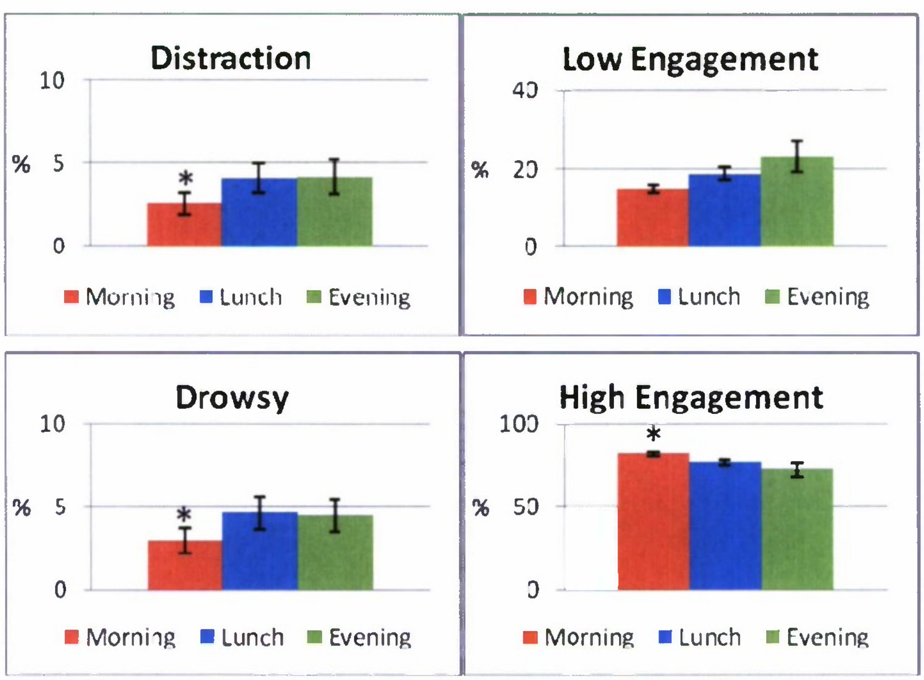

Figure 24: Results of the Alertness and Memory Profile (AMP) Reports.

The above graphs display the % of epochs during each 3C-VT session that were classified in each B-Alert category. Only the first 5 minutes of the morning baseline 3C-VT were used, as the Lunch and Evening 3C-VT's were only 5 minutes. Distraction and Low Engagement increased over the three sessions. High Engagement decreased proportionately. Drowsiness increased from morning to lunch 3C-VT's, and remained at about the same level during the evening session. There was a main effect for Distraction over time: $F(2,17)=4.018$, $p < .05$. There is no interaction with auto on/off. Low Engagement was marginal $F(2,17)=2.864$, $p = .085$. (Drowsiness: $F(2,17)=3.847$, $p < .05$; High Eng: $F(2,17)=5.038$, $p < .05$)

There was also an interesting (non-significant) effect observed in the Distraction levels of the Auto ON vs. OFF conditions.

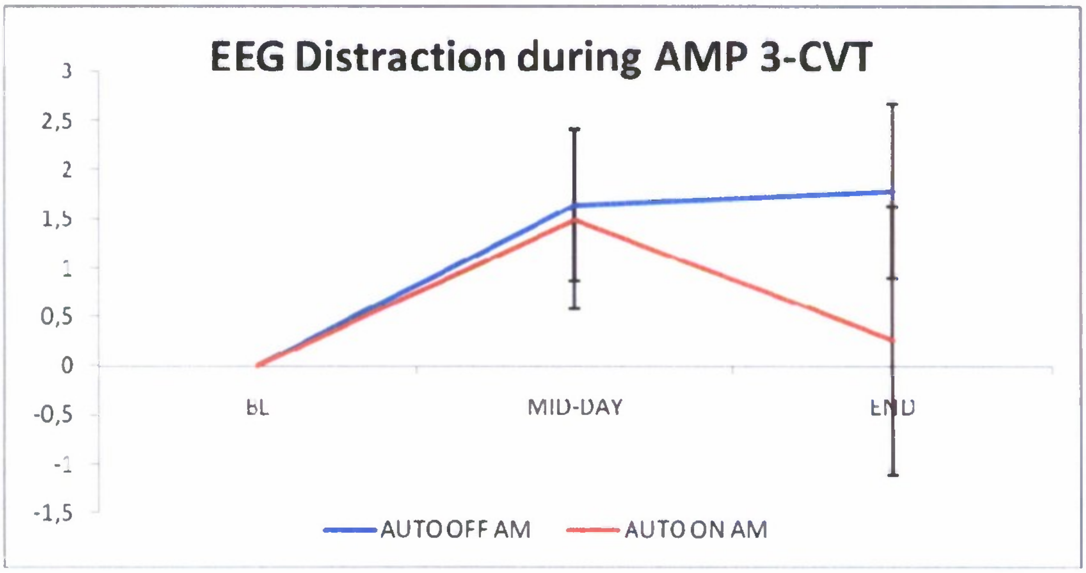

Figure 25: Results for the change from baseline score of distraction at each 3-Choice Vigilance Test (3-CVT) with respect to drivers with ACC ON or OFF.

Above is the CHANGE FROM BASELINE score of DISTRACTION at each 3CVT with respect to drivers with automation on or off. Drivers with automation OFF in the morning trended towards higher levels of EEG distraction during 3C-VT than drivers with automation ON in the morning. Between-subject variability precluded statistical significance and suggests individual differences in drivers' levels of fatigue and interaction of fatigue with the effects of automation.

Performance analysis during the 3C-VT sessions show that performance generally improved throughout the day (higher % correct, lower % incorrect/missed, and faster reaction time), although there were no statistically significant findings.

An interesting effect is observed when the subjects are divided according to how well they performed in target recognition while driving. Participants responded to on average about 14 of the 18 total targets, with a standard deviation of about 2. Subjects were therefore placed into one of three performance groups: (1) Good Performers- responded to at least 16 targets, (2) Medium

Performers- responded to 13-15 targets, and (3) Poor Performers- responded to less than 13 targets. According to this subdivision, there were 8 Good Performers, 15 Medium Performers, and 5 Poor Performers.

When performance during the 3C-VT task is evaluated using this grouping, Good Performers are shown to exhibit faster reaction times and lower % missed (unanswered) than other participants during the morning 3C-VT, before any driving. The distinction in reaction time and % missed is also seen during the afternoon and evening 3C-VT sessions, and is accompanied by higher % correct and lower % incorrect. Only the first 5 minutes of the morning 3C-VT were used, as the Afternoon and Evening 3C-VT's were only 5 minutes. Variability between subjects precludes statistical significance, although it is notable that variability for Good Performers is smaller than that of the other groups in most cases.

This finding suggests that 3C-VT performance may provide a predictor of driving performance. Individuals with slow reaction time or high % missed on the 3C-VT may benefit from interventions such as napping before they begin driving.

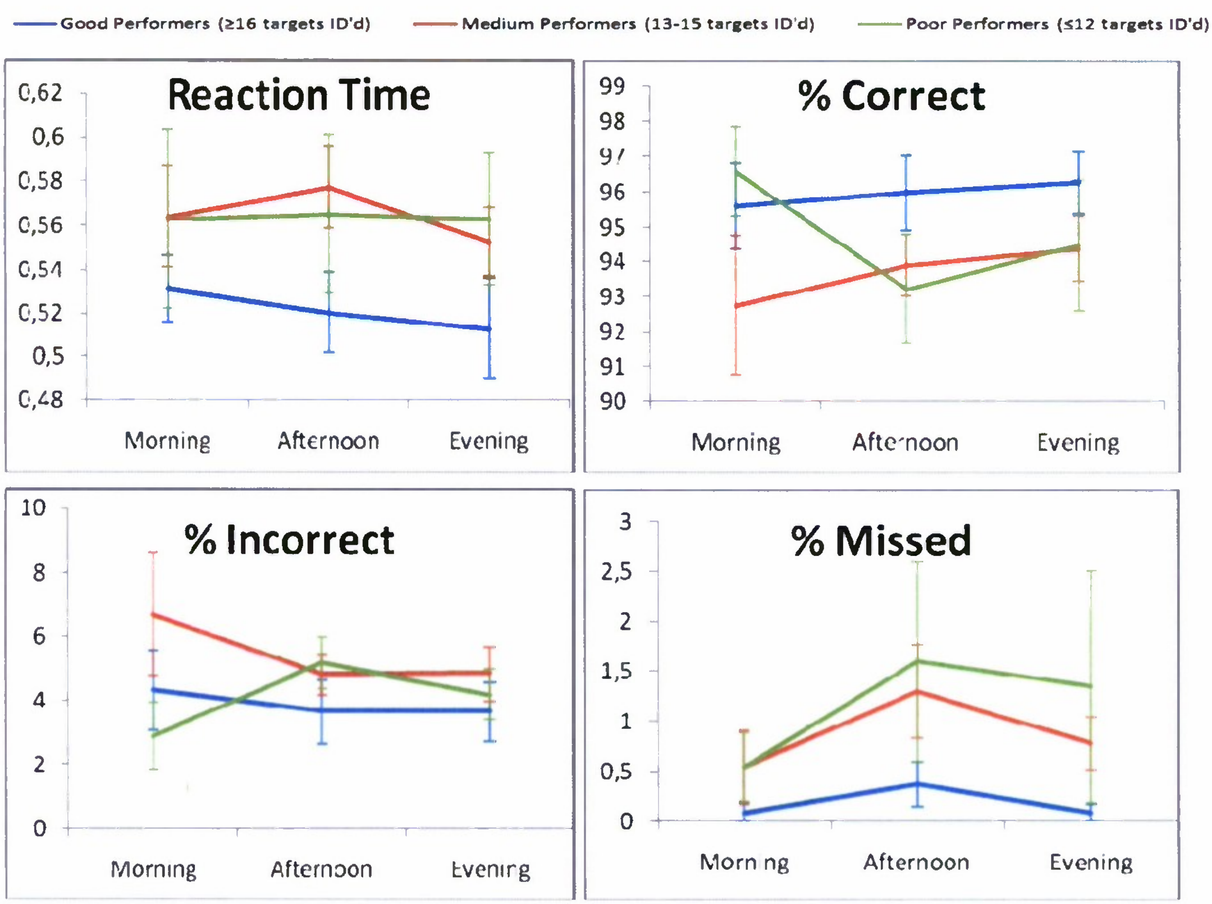

Figure 26: Performance during 3-PVT of drivers grouped after how well the performed during driving.

Separating drivers according to this grouping also reveals distinctions in the levels of EEG Low and High Engagement while driving. Good Performers tend to exhibit overall low levels of Low

Engagement and high levels of High Engagement. Poor Performers tend to exhibit high levels of Low Engagement and relatively low levels of High Engagement.

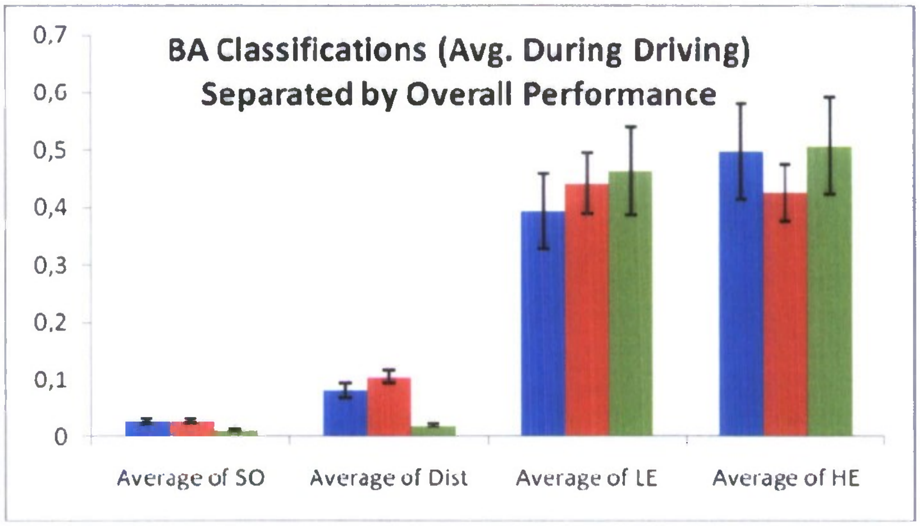

Figure 27: Cognitive state classification averages during driving separated by overall performance.

1-Minute Engagement Averages

We are providing graphs of the 1-minute averages of the B-Alert classifications (Sleep Onset, Distraction, Low Engagement, and High Engagement) for each subject separated by lap.

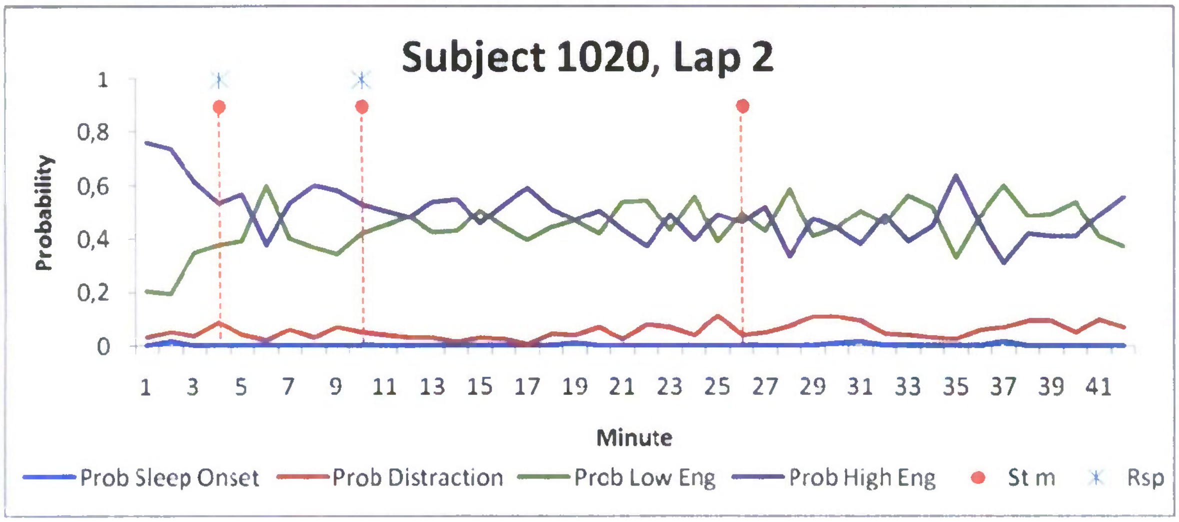

Figure 28: Results of cognitive state classification for subject 1020 during lap#2.

Markers (red, dashed lines) are inserted in the graphs in the minute in which they passed a target. A blue asterisk was placed above the targets that had a related response. A target without a blue asterisk indicates that there was NO related response to that target.

Most subjects were predominantly High Engagement, Low Engagement, or a combination of both throughout the driving sessions. Most subjects had very low levels of Sleep Onset or Distraction.

An interesting trend is observed for one participant, Subject 1428. This subject demonstrates what appears to be a classic nicotine withdrawal pattern.

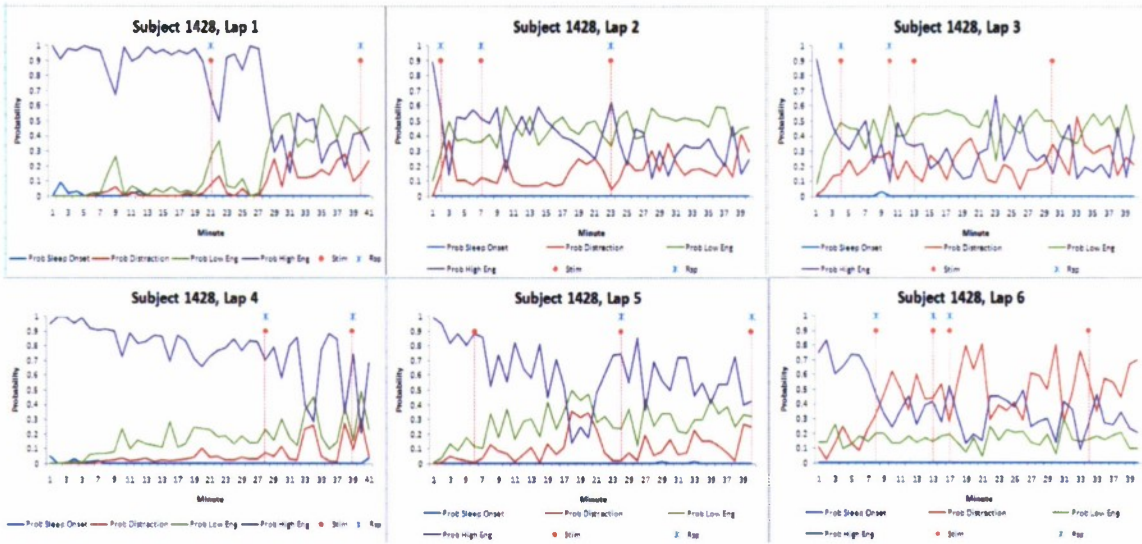

Figure 29: Results of cognitive state classification for subject 1020 for all six laps.

High Engagement is high at the beginning of both the morning (laps 1-3) and afternoon (laps 4-6) driving sessions. This presumably reflects heightened arousal caused by nicotine. This state of high engagement lasts approximately 20-30 minutes, then high engagement decreases and distraction increases. Distraction levels increase throughout the remainder of each driving session, particularly the afternoon session.

This pattern is interesting in that it provides what looks like a classic example of the effect of smoking and nicotine withdrawal on engagement and distraction levels while driving. It would be interesting to examine the relationship between smoking habits, EEG patterns, and driving performance for this set of participants.

Of the 56 total driving sessions (2 per 28 subjects), 7 sessions were problematic in some aspect. Three sessions suggest that the subject either moved the EEG cap or moved excessively such that the EEG signal was compromised (subjects 204 am, 611 pm, 1224 am). One session was deleted or overwritten most likely due to technician error (816 am). One session did not contain the necessary GPS markers in the EEG file (305 am). Two sessions were compromised due to ABM battery interface issues (305 pm, 306 am).

Neurophysiology Data (Analysis Daimler AG)

Using an alpha-spindle detector (7-13 Hz) the average fatigue level of each subject was calculated for each experimental condition (ACC on, ACC off). The results normalized for all subjects (z-score corrected) are depicted in Figure 30 and in Figure 31.

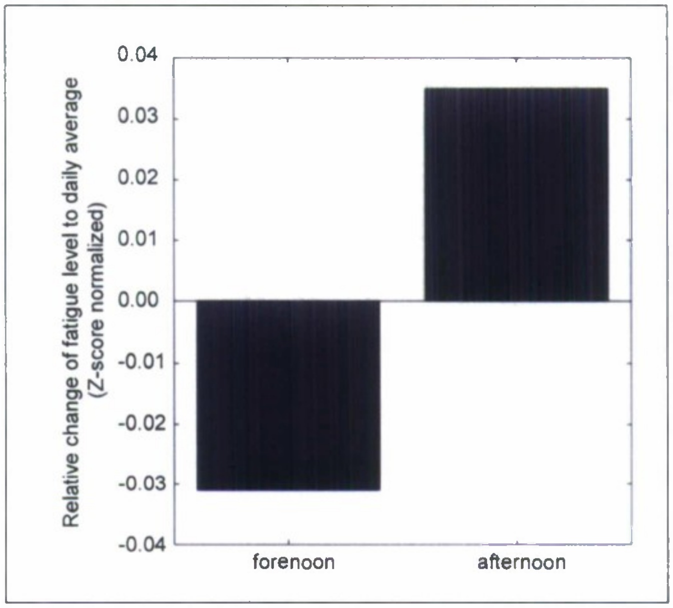

Figure 30: Average fatigue level for all subjects as z-score normalized values for the experimental conditions „forenoon" and "afternoon".

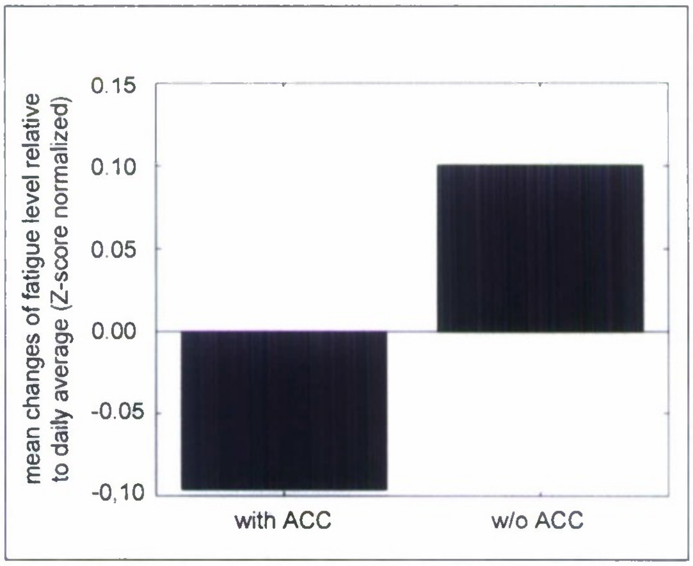

Figure 31: Average fatigue level for all subjects as z-score normalized values for the experimental conditions „with ACC" and "without ACC".

The analysis shows that the ACC supports the driver in that it lowers the driver's fatigue level. These findings are supported by the results form the analysis of the behavioural performance (higher hit rate with than without ACC). The circadian effect, i.e. higher fatigue level during the afternoon session that during the forenoon session is smaller than the activating effect of the ACC system.

The main purpose of this experiment was to investigate the influence of an adaptive cruise control system on the driver's visual detection capacity for targets placed on the side of the road as well the influence on the driver's fatigue level. The results show that on average the ACC has a positive impact on the driver's capacity for visual target detection. Despite the subjectively perceived increases monotony due to the ACC system, the behavioral as well as the physiological results show a benefit due to the support of the ACC.

APPENDIX 1

Intake Questionnaire

Purpose:

In this experiment we examine the driver's cognitive state and its changes over time which is hypothesized to be induced by long, monotonous driving. However, the subject's cognitive state might also be influenced by certain exceptional physical and/or psychical events occurred within 48 hours prior to the experiment as well as by intake of medication, alcohol and sleep duration within 48 hours prior to the experiment. This questionnaire assesses these factors, thus allowing taking into account their influence.

When did you wake up this morning? ____

How many hours did you sleep last night? ____________________________________

How many hours do you normally sleep per night?______________________________

What did you do after waking up? ____

How much mental effort did you expend during the last 2 hours?

0 none at all
1 almost none
2 little
3 moderate
4 a lot
5 almost maximum
6 maximum

How much physical effort did you expend during the last 2 hours?

0 none at all
1 almost none
2 little
3 moderate
4 a lot
5 almost maximum
6 maximum

How well did you sleep last night?

0 miserably
1 very badly
2 badly
3 OK
4 well
5 very well
6 excellently

How well rested do you feel from your sleep last night?

0 not at all
1 very slightly
2 slightly
3 a little
4 fairly
5 strongly
6 very strongly

When did you last drink caffeinated soda, coffee, green or black tea? _______________

How many cups or glasses? _______________

When did you drink alcohol the last time? _______________

How many drinks? _______________

How many hours ago did you last eat? _______________

What did you eat and how much? _______________

Did you work hard in the last 48 hours? □ Yes □ No

Did you take any medication or drugs in the last 48 hours? □ Yes □ No

If yes, what kind of medication or drugs and how much? _______________

Did you omit any medication in the last 48 hours that you normally take? □ Yes □ No

If yes, what medication do you normally take and how much?

____

Have you been experiencing any unusual physical or psychological symptoms?

□ Yes □ No

If yes, what kind of symptoms? ____

Did anything unusual happen to you in the last 48 hours? ☐ Yes ☐ No

If yes, what happened to you?

APPENDIX 2

Sleep Quality Questionnaire

Purpose:

Sleep quality is an important control variable for the assessment of driver cognitive state.

Reference:

Görtelmeyer R (1985): On the Development of a Standardized Sleep Inventory for the Assessment of Sleep. In Kubicki S and Herrmann MW (eds.): Methods of Sleep Research, Gustav Fischer 1985, 93-8.

Instruction:

Please make sure that you fill in this questionnaire after you woke up in the morning!

When did you go to bed last night? (example: 10: 25 p.m.) ______________________________

How much time did you need to fall asleep last night?

- Less than 5 minutes
- to 10 minutes
- 10 to 20 minutes
- 20 to 30 minutes
- 30 minutes to 1 hour
- more than 1 hour

If you could not fall asleep easily last night, why do you think that you could not?

You can select more than one answer:

- Personal/ job related problems
- Noise inside or outside the room
- Thinking about the problems of the day
- Unusual sleeping ambience
- Other ____

When you are dozing off do you often see clear images? Did you see such images last night?

- No
- Not sure
- Yes

Did you feel a convulsion of your muscles of your arms or legs when dozing off last night?

- No
- A little
- Strong

Did you feel pain in your heart or pain in your left arm?

- No
- Not sure
- Yes

How many times did you wake up last night?

- Not once
- Once
- Twice
- Three times
- More than three times

If you woke up during last night, why do you think you woke up? You can select more than one answer:

- Personal/ job related problems
- Noise inside or outside the room
- Needed the bathroom
- I dreamed
- Other____

If you woke up during last night, how much time did you spend awake?

- time: ______________________ minutes
- time: ______________________ minutes
- time: ______________________ minutes
- time: ______________________ minutes

Do you remember dreaming last night?

- No
- Yes, but I can´t remember what the dream was about
- Yes, I can remember what I dreamed

If you can remember what you dreamed, what kind of feelings did you have during the dream?

- Agreeable feelings
- Neutral feelings
- Disagreeable feelings

Did you sweat last night?

- No
- A little
- A lot

At what time did you wake up this morning?

____

Were you woken up by the radio or alarm clock or by yourself?

- Woke up by myself
- When I was woken up, I was half asleep
- When I was woken up, I was sleeping deeply

Did you have headache this morning?

- No
- A little one

- A strong one

Did you drink alcohol after your dinner last night?

- No
- Yes, during the evening
- Yes, directly before going to bed

Did you take any sleeping pills?

- No
- Yes

What kind of sleeping pill?

____

Was the last day stressful?

- Not stressful
- A little stressful
- Very stressful

APPENDIX 3

Personal questions and vehicle details

Purpose:

The independent variables assessed in this questionnaire are important in order to calculate any dependency of the assessed sleepiness on these factors. If existent, the according independent variables will have to be taken into consideration in any system for objective sleepiness detection.

Instruction:

Dear participant, thank you for supporting our study. In this questionnaire please answer some personal questions.

1. Family status single ❑$_1$ married ❑$_4$
Living in partnership ❑$_2$ divorced/widowed ❑$_3$

2. How many persons are living in your household? ....

3. How many of them are fewer than 18? ....

4. I am working in
long-distance traffic ❑$_1$ splitter traffic ❑$_2$ construction site traffic ❑$_3$

5. How long are your typical driving tours? (From home back to home)? ..... day(s)

6. How many hours are you working in average per day? .... Hours per day

7. How many hours you are driving in average per day? .... Hours per day

8. How many times are you driving at night (between10p.m. and 6a.m.)?
never ❑$_1$ some times ❑$_2$ 1-2 times per week ❑$_3$ 3-5 times per week ❑$_4$

9. Are you charge and uncharged your truck? yes ❑ no ❑

10. How many kilometres are you driving in one year? .... km

11. How many years are driving trucks? .... year(s)

12. Profession

permanent employee❑1 self-employed ❑2

truck driving as secondary employment ❑3 in retirement ❑4 seeking work ❑5

13. Which truck are you most commonly using?

	1. Truck	2. Truck
Brand		
Model		
Year of construction		

14. How would you describe your experience in using the following trucks and systems?

	Non	little	ok	much	Very much
	1	2	3	4	5
1. Experience in using the Actros?	❑	❑	❑	❑	❑
2. Experience in using the speed control?	❑	❑	❑	❑	❑
3. Experience in using the ART?	❑	❑	❑	❑	❑
4. Experience in using the lane assistant?	❑	❑	❑	❑	❑

APPENDIX 4

Morningness-Eveningness-Questionnaire

Purpose:

With regard to circadian rhythm, the population consists of Morning, Evening, and Intermediate type categories. This factor has to be assessed in order to better classify the driver's assessed activation level over time as well as at different times of the day.

Reference:

Horne JA, Ostberg O (1976): A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. Int J Chronobiol. 4(2):97-110.

Approximately what time would you get up if you were entirely free to plan your day?

Select one of the following:

- 05:00 a.m. – 06:30 a.m.
- 06:30 a.m. – 07:45 a.m.
- 07:45 a.m. – 09:45 a.m.
- 09:45 a.m. – 11:00 a.m.
- 11:00 a.m. – 12:00 noon
- 12:00 noon – 5:00 p.m.

Approximately what time would you go to bed if you were entirely free to plan your evening?

Select one of the following:

- 08:00 p.m. – 09:00 p.m.
- 09:00 p.m. – 10:15 p.m.
- 10:15 p.m. – 12:30 a.m.
- 12:30 a.m. – 01:45 a.m.
- 01:45 a.m. – 03:00 a.m.
- 03:00 a.m. – 08:00 p.m.

If you usually have to get up at a specific time in the morning, how much do you depend on an alarm clock?

Select one of the following:

- Not at all
- Slightly
- Somewhat
- Very much

How easy do you find it to get up in the morning (when you are not awakened unexpectedly)?

Select one of the following:

- Very difficult
- Somewhat difficult
- Fairly easy
- Very easy

How alert do you feel during the first half hour after you wake up in the morning?

Select one of the following:

- Not at all alert
- Slightly alert
- Fairly alert
- Very alert

How hungry do you feel during the first half hour after you wake up?

Select one of the following:

- Not at all hungry
- Slightly hungry
- Fairly hungry
- Very hungry

During the first half hour after you wake up in the morning, how do you feel?

Select one of the following:

- Very tired
- Fairly tired
- Fairly refreshed
- Very refreshed

If you had no commitments the next day, what time would you go to bed compared to your usual bedtime?

Select one of the following:

- Seldom or never later
- Less than 1 hour later
- 1-2 hours later
- More than 2 hours later

You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week, and the best time for him is between 7-8 a.m. Bearing in mind nothing but your own internal "clock," how do you think you would perform?

Select one of the following:

- Would be in good form
- Would be in reasonable form
- Would find it difficult
- Would find it very difficult

At *approximately* what time in the evening do you feel tired, and, as a result, in need of sleep?

Select one of the following:

- 08:00 p.m. – 09:00 p.m.
- 09:00 p.m. – 10:15 p.m.
- 10:15 p.m. – 12:45 a.m.
- 12:45 a.m. – 02:00 a.m.
- 02:00 a.m. – 03:00 a.m.

You want to be at your peak performance for a test that you know is going to be mentally exhausting and will last two hours. You are entirely free to plan your day. Considering only your internal "clock," which one of the four testing times would you choose?

Select one of the following:

- 08:00 a.m. – 10:00 a.m.
- 11:00 a.m. – 1:00 p.m.
- 03:00 p.m. – 05:00 p.m.
- 07:00 p.m. – 09:00 p.m.

If you got into bed at 11 p.m., how tired would you be?

Select one of the following:

- Not at all tired
- A little tired
- Fairly tired
- Very tired

For some reason you have gone to bed several hours later than usual, but there is no need to get up at any particular time the next morning. Which one of the following are you most likely to do?

Select one of the following:

- Will wake up at usual time, but will not fall back asleep
- Will wake up at usual time and will doze thereafter
- Will wake up at usual time, but will fall asleep again
- Will not wake up until later than usual

One night you have to remain awake between 4-6 a.m. in order to carry out a night watch. You have no time commitments the next day. Which one of the alternatives would suit you best?

Select one of the following:

- Would not go to bed until the watch was over
- Would take a nap before and sleep after
- Would take a good sleep before and nap after
- Would sleep only before the watch

You have to do two hours of hard physical work. You are entirely free to plan your day. Considering only your internal "clock," which one of the following times would you choose?

Select one of the following:

- 08:00 a.m. – 10:00 a.m.
- 11:00 a.m. – 01:00 p.m.
- 03:00 p.m. – 05:00 p.m.
- 07:00 p.m. – 09:00 p.m.

You have decided to do physical exercise. A friend suggests that you do this for one hour twice a week. The best time for her is between 10-11 p.m. Bearing in mind only your own internal "clock," how well do think you would perform?

Select one of the following:

- Would be in good form
- Would be in reasonable form
- Would find it difficult
- Would find it very difficult

Suppose you can choose your own work hours. Assume that you work a five-hour day (including breaks), your job is interesting and you are paid based on your performance. At *approximately* what time would you choose to begin?

Select one of the following:

- 5 hours starting between 4 a.m. and 8 a.m.
- 5 hours starting between 8 a.m. and 9 a.m.
- 5 hours starting between 9 a.m. and 2 p.m.
- 5 hours starting between 2 p.m. and 5 p.m.
- 5 hours starting between 5 p.m. and 4 a.m.

At *approximately* what time of day do you usually feel your best?

Select one of the following:

- 05:00 a.m. – 08:00 a.m.
- 08:00 a.m. – 10:00 a.m.
- 10:00 a.m. – 05:00 p.m.
- 05:00 p.m. – 10:00 p.m.

- 10:00 p.m. – 05:00 a.m.

One hears about "morning types" and "evening types." Which one of these types do you consider yourself to be?

Select one of the following:

- Definitely a morning type
- Rather more a morning type than an evening type
- Rather more an evening type than a morning type
- Definitely a evening type

APPENDIX 5

Epworth Sleepiness Scale (ESS)

Purpose:

The assessment of the individual sleep propensity is required to distinguish between sleepiness induced by monotonous driving and subject's daytime sleepiness.

Reference:

Johns MW (1991): A new method for measuring daytime sleepiness: the Epworth sleepiness scale. Sleep. 14(6):540-5.

How likely are you to doze off or fall asleep in the situations described below, in contrast to feeling just tired?

This refers to your usual way of life in recent times.

Even if you haven't done some of these things recently try to work out how they would have affected you.

Use the following scale to choose the most appropriate number for each situation:-

0 = would never doze
1 = Slight chance of dozing
2 = Moderate chance of dozing
3 = High chance of dozing

Situation	Chance of dozing
Sitting and reading	
Watching TV	
Sitting, inactive in a public place (e.g. a theatre or a meeting)	
As a passenger in a car for an hour without a break	
Lying down to rest in the afternoon when circumstances permit	
Sitting and talking to someone	
Sitting quietly after a lunch without alcohol	
In a car, while stopped for a few minutes in the traffic	
Total	

APPENDIX 6

Karolinska Sleepiness Scale (KSS)

Purpose:

The assessment of the subjective sleepiness is important for a better interpretation of the objectively assessed sleepiness level by means of physiological and behavioral measures.

Reference:

Akerstedt T, Gillberg M (1990): Subjective and objective sleepiness in the active individual. Int J Neurosci. 52(1-2):29-37.

1. Sleepiness via KSS

How would you describe you state since the last request?

1	2	3	4	5	6	7	8	9
Extremely alert	Highly alert	Alert	Little alert	Neither alert nor sleepy	First signs of sleepiness	Sleepy, but no difficulty remaining awake	Sleepy, difficulty remaining awake	Extremely sleepy, fighting sleep

2. Attention on driving

How attentive have you been driving since the last request?

1	2	3	4	5	6	7	8	9
Extremely attentive	Highly attentive	attentive	Little attentive	Neither attentive nor inattentive	First signs of inattentive	Inattentive , but no difficulty remaining vigilant	Highly inattentive	Extremely inattentive

3. Monotony of driving

How monotone has the driving been since the last request?

1	2	3	4	5	6	7	8	9

Extremely varied	Highly varied	Varied	Little varied	Neither varied nor monotone	Little monotone	Monotone	Highly monotone	Extremely monotone

APPENDIX 7

Handedness Questionnaire

Purpose:

In order to obtain comparable results, all subjects have to operate the response button with the thumb and index finger of the dominant hand. Therefore, it is important to assess subject's handedness.

Reference:

Oldfield RC (1971): The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia. 9(1):97-113.

Instruction:

Please mark the hand with which you prefer most performing the following activities. Place a + in a box for each question that describes you best.

When you extremely prefer one hand and can only use the other hand with trouble, please mark a ++ in the column for the preferred hand.

If you are not sure, which hand you prefer, please place a + in both column. Please answer all questions.

Most people are either right-handed or left-handed. However, there are different "degrees" of handedness. Some people use one hand for jobs that require skill and the other hand for jobs that involve reaching. Other people use the same hand for these different jobs. Use this "Handedness Questionnaire" to measure the strength of handedness. Place a mark in a box for each question that describes you best.

Activity	LEFT Hand	RIGHT Hand
1. Which hand do you use to write?		
2. Which hand do you use to draw?		
3. Which hand do you use to throw a ball?		

4. Which hand holds scissors when you cut things?		
5. With which hand do you hold a toothbrush?		
6. Which hand holds a knife (without a fork)?		
7. Which hand holds a spoon?		
8. Which hand holds a broom?		
9. Which hand holds a match when you light it?		
10. Which hand holds the cap when you open a box?		
TOTAL		

APPENDIX 8

CAT-M Post-Test Vehicle Operator Survey

Instructions:

Please circle the response that best answers each question.

1. Which vehicle did you operate during the road test?

Lead Vehicle	Middle Vehicle	Last Vehicle

2. How focused were you on the task of driving as you participated in the road test?

Very Distracted	Substantially Distracted	Slightly Distracted	Slightly Focused	Substantially Focused	Very Focused	I choose not to answer this question

3. What percentage of the time were your eyes focused on the forward roadway?

10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	I choose not to answer this question

4. What time of day was it easiest to concentrate on driving?

1000 – 1100	1100 – 1200	1300 – 1400	1400 – 1500	1500 – 1600	1700-1800	I choose not to answer this question

5. What percentage of the time were you distracted from the driving task?

10%	20%	30%	40%	50%	60%	70%	80%	90%	100%	I choose not to answer this question

6. What time of day was it most difficult to concentrate on driving?

1000 – 1100	1100 – 1200	1300 – 1400	1400 – 1500	1500 – 1600	1700-1800	I choose not to answer this question

7. How often did you experience boredom while driving?

Never	Very Rarely	Somewhat Rarely	Somewhat Often	Very Often	Constantly	I choose not to answer this question.

8. Please express your level of agreement with the following: "There were a lot of distractions while I was driving."

Completely Disagree	**Substantially Disagree**	**Slightly Disagree**	**Slightly Agree**	**Substantially Agree**	**Completely Agree**	**I choose not to answer this question.**

9. How well rested did you feel at the beginning of the road test?

Totally Exhausted	Substantially Fatigued	Slightly Tired	Slightly Rested	Substantially Rested	Totally Rested	I choose not to answer this question

10. How often did you feel drowsy while driving?

Never	Very Rarely	Somewhat Rarely	Somewhat Often	Very Often	Always	I choose not to answer this question.

11. How often did you momentarily fall asleep while driving on the road course?

Never	Very Rarely	Somewhat Rarely	Somewhat Often	Very Often	Constantly	I choose not to answer this question.

12. What time of day did you feel the drowsiest?

1000 – 1100	1100 – 1200	1300 – 1400	1400 – 1500	1500 – 1600	1700-1800	Not applicable	I choose not to answer this question

13. How much sleep did you get before driving?

less than 4 hours **4 hours** **5 hours** **6 hours** **7 hours** **8 or more hours** **I choose not to answer this question.**

14. Which of the following did you do to stay awake? (Circle all that apply.)

Drink caffeinated beverage	Shake head and/or appendages	Chew gum	Sit in an uncomfortable position	Sing	Roll down the window	Change vehicle speed	Hold breath	None of the above	I choose not to answer this question.

15. Please circle <u>all</u> activities listed below that you performed while driving:

drink water or beverage(s)	look at pedestrian(s)/ hiker(s)	look at an object of interest outside vehicle	listen to the radio	eat food	look at other drivers	look at road construction equipment	adjust dashboard controls
smoke	adjust radio settings	brush or floss teeth	shave	groom hair	trim fingernails	Not applicable	I choose not to answer this question

APPENDIX 9

List of questions fort the phone call conversation (for G-Wagon driver)

History:

What are your feelings about the fall of the Berlin Wall in 1989?

What do you think of the hostage situations in Afghanistan in the past?

What occurs to you when you think of terrorism?

What comes to your mind regarding the GDR?

What was a very meaningful experience in your life? Explain about it!

What did you particularly enjoy while attending school, what did you dislike?

What music or which song has influenced you the most? Why?

What age do you look back upon particularly fondly? Why?

Geography:

Is there a country in which you particularly enjoy traveling or to which you would like to travel? Which one, and why?

In which countries would you never travel and why?

What are the advantages and disadvantages of the opening of the borders in Europe?

What are your feelings concerning climate changes?

What occurs to you spontaneously regarding natural catastrophes?

What occurs to you regarding the topic nature? Perhaps a special experience?

Politics:

What do you think about the introduction of the Euro? In your opinion what are the advantages and disadvantages of the new currency?

At some public areas in large cities there are video cameras which tape the everyday happenings. What do you think of such monitoring activities?

There have recently been price increases for staple foods like mild and butter. What do you think about the price increases?

Some time ago it was decided to expand the European Union to include eastern countries such as Bulgaria and Poland. What do you think about this eastern expansion?

What do you think about a possible inclusion of Turkey in the European Union?

Over the past months there have been recurring reports about the possibilities of strikes at the German rail. What do you think about strikes of the public transportation system?

Technology:

What do you think are the advantages and disadvantages of the invention of the mobile telephone?

What do you think about nuclear energy and its safety?

What do you thing about the increasing air transportation of goods and passengers?

Compared to our grandparents' generation, there are many more technical devices in the modern household such as mobile telephones, microwaves, CD players etc. What effect does the larger amount of technical devices have on your life? Are there more advantages or disadvantages?

What do you think of spontaneously when you think of passenger cars?

Sports:

How do you feel about the doping scandals during the Tour de France?

The last soccer world championship was held in Germany. What were your feelings about that time and about the Germans during this time?

What occurs to you when you think of hooligans?

Do you follow the soccer games of the national league and what is your favorite team?

What sport event had a special meaning for you in your childhood and why?

What is your favorite sport?

Every day experiences

How would you react if you hit the jackpot in the lottery on Saturday? What would you do with the money, what would you buy?

Some people are afraid of snakes. How about you, do you have a fear of certain animals? Why?

What do you like to watch in TV? Where do you stop while channel-surfing?

Which magazines do you most enjoy reading? Why?

If you were the chancellor, what would you do about unemployment?

What are the every-day problems you encounter in your job?

Which home repairs do you perform by yourself?

How do you prefer to spend your free time; what would be the perfect day off for you?