# Measurement of Driver's Brain Activity within Truck Driving Simulator Laboratory

Mirko Novák, Josef Faber, Petr Bouchner, Stanislav Novotný, and Alina Mashko

***Abstract*—**Individual human behavior makes a significant impact to the road and traffic safety. The necessity of minimizing the human factor influence is rather obvious. A detailed study of different aspects of human-machine interaction shall make it possible to determine reasons of faulty human behavior and develop methods for its prevention. Complex approach for problem solution is suggested. A truck simulator laboratory described in this article shall suggest wide range of possibilities for the relevant research. Observation of various aspects of faulty driver behavior using different methods, namely combination of brain activity observations (EEG) together with data obtained from readings of other tools such as ocular movements, heartbeat, mimics, muscular activity, gestures, driving behavior and vehicle behavior is to be run for data collection and its further analysis. A set of pilot experiments has been relevant research of both electroencephalographic (EEG) and near infra-red (NIRS) signals analysis of drivers, exposed to influence of various kinds of attention load on adaptive driving simulator is presented. The results are expected to be a basis for recommendation for further deeper and wide scale analyses of various load influences on driver brain.

***Keywords*—** driving faults, driving simulation, EEG and NIRS analysis, truck simulator.

## I. Introduction

THE project "Advanced truck simulator laboratory" is a national project with Faculty of Transportation Sciences of Czech Technical University in Prague. The faculty is in charge of production of a truck simulator laboratory, namely, functional and constructional design, software and hardware parts of the simulator device itself, development of scenarios and the assembly of the whole system including installation of measuring equipment. The last includes the tools and devices to be installed in the laboratory for objective assessment of driver state in general and his/her behavior in particular scenario situations, ability to perform tasks etc. For objective evaluation both psycho-physiological and technical performance measures can be used. The first category includes taking measurements from human (body) directly, the obtained data are not stable and varies for each individual, analysis of such data requires knowledge in engineering, medical and informatics disciplines with deep research and analysis. EEG, EOG, skin impedance measurements, eye-tracking and other measurements can be related to this group. EEG is considered to be one of the most accurate among the mentioned measurement methods. However, more accurate data are obtained when it is combined with other tools (for taking physiological and technical measurements). A lot of research has been done in this field within the Faculty of Transportation Sciences for the past 10 years, some of the results can be studied in relevant resources [8,9,10]. One of the examples is examination of spatially located brain oxygen consumption and its influence on the performance (the study combined with NIRS – [3]).

The problems of unsatisfactory level of interaction reliability between a human subject and an artificial system exist in almost all areas of human activity [1,2]. This is of course a very important area, because the volume and density of road transport rises every day and the number of road accidents reaches tremendous level. According to data from EU on European roads more than 40000 people per year are killed, which is estimated to cause losses of about 200 billion Euros. To this figure one has to add the price of non-mortal accidents, which are cheaper in average, for sure, but are much more frequent. Suppose that the total price of these non-mortal losses reaches about the same level. These secondary losses, involving the necessary medical care, social expenses, losses of work capacity etc. are hard to determine via statistics and their estimations differ significantly. However, it is necessary to take them into account as well. Suppose that their total is of the same order as the two items mentioned previously. Therefore about several more hundred billion Euro due road accidents are lost every year.

Faults and errors of drivers are among the major causes of

This paper was realized on basis of data and knowledge obtained during work on (and utilized results of) finished grant Czech Technology Agency TACR, TA01030574 "Laboratory for training and education of professional truck drivers equipped with advanced truck driving simulator with ability of measuring and analyzing of psycho-physiological, psychological and performance data". The authors of this paper were ones key persons of the realization team of this project.

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these tremendous losses. The rough estimation is that the respective part is 60-70%. Therefore the need of its minimization is a challenging task.

For solution of this problem it is possible to try to eliminate the human factor in road transportation at a maximum possible rate. It is also important to understand the processes in human driver brain while it is being loaded with driving and related activities. In an attempt of more efficient solution we may also try to combine these two approaches.

Besides the extensive research and achievements of recent years in particular, it seems that maximal exclusion of human factor is applicable in special cases only. Wide-scale and complex application of robotic cars allowing full exclusion of human factor from driving procedure is still a future perspective.

Though we should not neglect the progress in implementation of automated driving, for now and the closest future it makes more sense to concentrate the research at studying the processes of human brain of a driver during performing driving task, during training and other possible activities.

We are expecting that the results of experiments designed for the observation of driver brain activity may help to develop and adjust driver training methods, improve road management schemes by orienting them on human factor role in traffic excesses, namely the detection of risky and aggressive driving with proper regulations and penalization schemes, investigation of behavioral factors of drugs and possible development of new ones for improving human attention.

## II. Analytical Tools and Methodology

To perform measurements of driver brain signals for detection of faults that are caused by load of driving and related tasks a certain technical base for setting up the experiment will be required.

A satisfactory reliable adaptive driving simulator shall be available. For experiment setup it will be necessary to have:

1) representative simulation scenarios, preferably in 3D virtual reality,
2) measuring devices suitable for detection with possibility of on-time analysis of considered brain signals,
3) sufficiently large cohort of tested persons (so called probands, or testing group), representing with reasonable accuracy the sample of driving population in considered region,
4) acceptably large and well organized data-base,
5) suitable set of methods for analysis of experimental data.

As for the simulator system technology, it is quite convenient to operate with light simulators that are built of part of vehicle cockpit with simulation of visual and acoustic impacts. As for the EEG signals analysis, the investigation in NIRS region together with deep analysis of EEG signals in selected frequency bands (namely alpha and delta) [8, 9] is rather effective.

It is necessary to approach the selection and organization of the proband cohort with high care. The chosen sample must model with acceptable accuracy the respective driver population in certain region. Here also the influences of proband age, sex and health are to be taken into account. That's why it is rather important that groups have proper distribution of the drivers of various age, gender, driver experience etc. It is also desirable that all the probands participate in the experiment being in equal physical state, i.e. measurements run approximately at the same time of the day, drivers have been following equal rest schedule (they are equally fresh or equally tired), they are not under the influence of various substances (if not specified so by the conditions of experiment), are not under any significant stress etc. It is rather important to prepare probands for driving the simulator – spare adjustment time so that experiment participant could adjust to virtual reality, and to prevent negative influence (such as "simulator sickness", for example) on experiment data. Besides the precaution measures mentioned above the impact nevertheless appears and the respective part of measured data might be canceled.

Another important aspect for experiment design is a simulator scenario. It may be designed from scratch, or adjusted (modified) to fulfil particular needs of the experiment. Scenarios for measurement of driver fatigue and/or drowsiness are usually represented by long monotonous roads, or tunnels. Driver tasks for study of driver load can be incorporated directly into scenarios, which is especially useful when the external equipment (like in-vehicle monitors) are not applicable.

A significant contribution to research of these problems has been done by the experiments with EEG measurement.

EEG detects waves of brain activity and from frequency components of each wave it is possible to determine the kind of this activity. EEG has several frequency bands (waves) with their characteristic frequencies: delta (0.5–4 Hz), theta (4–8 Hz), alpha (8–12 Hz) and beta (12-30 Hz). Delta waves are normally characteristic for deep sleep, and only in particular cases for waking state. Theta waves are characteristic for meditation, level of arousal, meditation and creative inspiration. Alpha waves are present in a state of relaxed awareness and beta is associated with active thinking and concentration [13]. Particular ratio of each wave in its turn corresponds to a certain human brain activity. Thus, high ratio of each of the waves corresponds to the following:

1) for delta – sound sleep
2) for theta – drowsiness
3) for alpha – quiet
4) for beta – excitement.

Usually power spectrum of the waves (depends on the sensors of the device) is used to analyze the brain activity [12].

It is rather useful to combine EEG measurement with other tools for human behavior recording. For different kinds of brain wave frequencies characteristic to actual state corresponds certain muscle, eye, behavior, heart rate, set of gesture and mimics etc. That is why a complex approach to the problem is required. For example detected drowsiness state is characterized by slow muscle activity and occasional twitching. At sleep one may observe decrease of heart rate and body temperature. More detailed observations of characteristics of different sleep stages can be found in the related article [14].

## III. Problem Solution

For testing the possibility of use of methodical and experimental tools at disposal the small size pilot experiment was realized in the frame of a thesis [4].

As the technical basis for all measurements the static adaptive car simulator, developed in 2012 at the Department of Vehicle Systems of the Faculty of Transportation Sciences in Czech Technical University in Prague, was used. This simulator (see Fig. 1) is equipped with 3 perpendicularly located large scale screens presenting the driver view ahead, right and left. There are virtual mirrors (i.e. within the left and right screens) allowing the driver watch the situation behind the truck tail. This setup conforms to arbitrary truck or van vehicle and could be parameterized to various loads, engine strengths and driver's sight virtual height (observer's view point in virtual reality). It was developed within the project as a smaller variant of the full truck simulator ("Laboratory for training and education of professional truck drivers equipped with advanced truck driving simulator with ability of measuring and analyzing of psycho-physiological, psychological and performance data") which is being used for development of simulator software parts as well as measuring methods with in this project.

The tested driver controls the movement of simulated 7 ton truck in the virtual reality scenarios, in visual perception close to real-world environment. Simulation of acoustic signals is provided as well. The simulator is steady; the motion stimuli are not simulated. Since it is not essential for particular type of the performed measurements, the results should not be affected.

Per the designed experiment, driver faces various driving situations. From his/her reactions projecting in brain signals above all the EEG and NIRS were measured.

Before starting the experiment itself, reaction times for each proband are to be recorded. The values differ for individual driver, and also during the course of experiment. One example of such dependence is shown in Fig. 2. This reaction times measured before the experiment are so called model data and are used to be compared with when experiment data are obtained.

The EEG signals can be analyzed using different methods and visualizations. One of the most expressive methods seems to be the amplitude domain in alpha and delta frequency bands mapped on the proband head surface in artificial colors. An example is shown in Fig. 3 and 4.

Fig. 1: View on used truck simulator and the NIRS and EEG measuring set (upper) and driver's view on virtual environment (bottom).

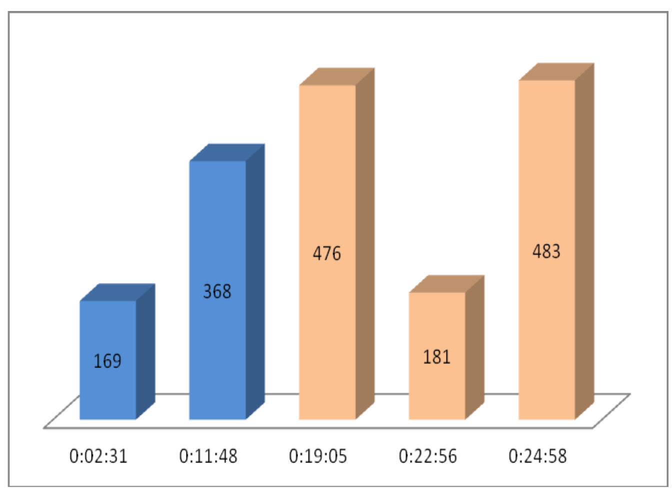


Fig. 2: Proband J.'s reaction times for various length of experiment. Blue in static state, yellow while on simulator.

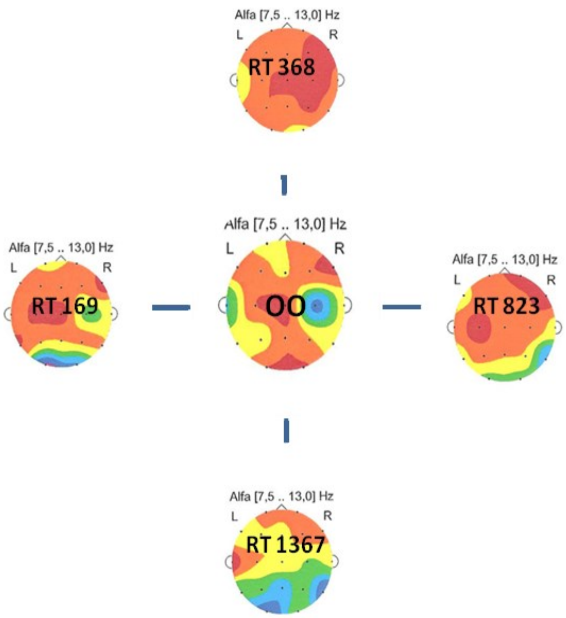


Fig. 3: Amplitudes of EEG alpha component for different values of reaction time RT. OO means open eyes.

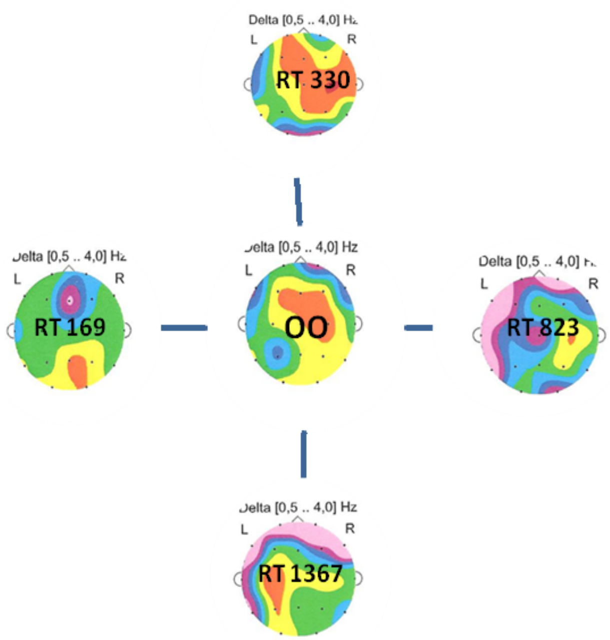


Fig. 4: Amplitudes of EEG delta component for different values of reaction time RT. OO means open eyes.

In the majority of EEG records the so called alpha spindles can be found in the time-development of alpha components. Examples of alpha spindles are shown in Fig.5.

This is an extremely interesting phenomenon, which after more detailed analysis (see [5] e.g.) can be a source for formulating a hypothesis on dual iteration in data processing in the thalami-cortical reverberation system (TCRS) of the brain: One can expect that two main stages exist

1) MIA (multilayered iterative algorithm) according to A. G. Ivakhnenko, (see [6] e.g.)
2) "Ordinary" iterative stage with convergence to the target solution in the second phase of data processing. In vigilance, the brain's electric activity comprises primarily the alpha rhythm (8-13 Hz) of variable amplitude responsible for the fusiform spindle-like shape of those alpha waves - described as the alpha spindle.

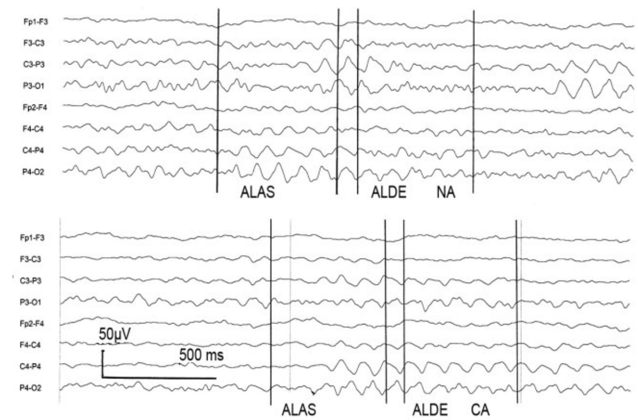


Fig. 5: Example of twice eight EEG curves from the medial leads of proband XVIII. The graph, expanded in amplitude and in time, represents each time one alpha spindle divided into a first half with the amplitude increasing (ALAS) and a second half with the amplitude decreasing (ALDE). The top and bottom parts of the graphs show merely minor optical differences despite the fact that the upper 8 curves relate to the resting (native, NA) state, and that the lower 8 curves were recorded during the test, - the addition of two-digit numbers (CA). Each part (ALAS and ALDE) were analyzed separately and then compared against each other or to different states.

Generally, until now it has been assumed that the ascending part of the alpha spindle (ALAS) is almost the same as the descending part (ALDE).

One of our aims was to find out whether our hypothesis of differences between the ALAS and ALDE phases is acceptable. The set of pilot experiments that have been made, seems to be in correspondence with it.

The combined measurement of EEG and NIRS (see e.g. Fig. 6) seems to support the validity of prediction possibility hidden in deep analysis of these both kinds of brain signals [16].

While the dominant information on the projection of driver faults seem to appear in the alpha and delta bands of EEG signals, the signals in NIRS band inform about the energy exchange and load in the respective part of the frontal cortex. However, much more precise measurements are to be made.

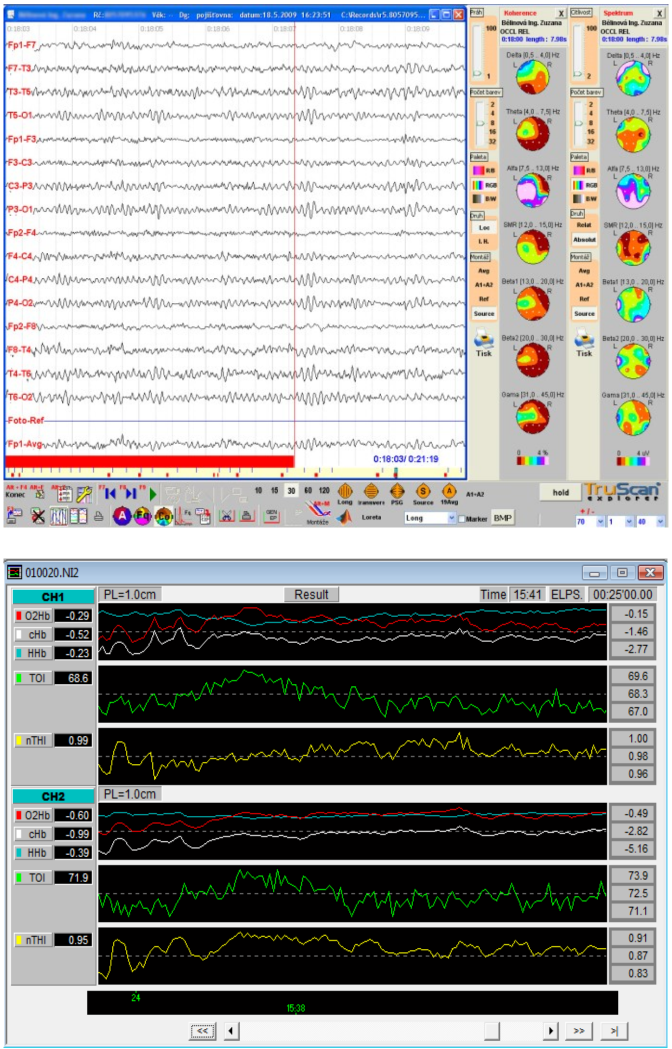


Fig. 6: Combined analysis of EEG and NIRS in the state of proband relaxation

## IV. Conclusion

Pilot experiments prove that for more through exploration of driver errors and as a result, their minimization and decreasing the losses in traffic accidents caused by human factor with possible development of effective methods and tools, a bigger number of experiments (or sets of experiments) with detailed study of processes in human driver brain need to be done. The possible tools may include both infrastructure traffic management applications, methods and implementation of in-vehicle applications to help monitoring the driver state, warn his/her faulty behavior as well as communicate to infrastructure, or supervising authority monitoring the traffic. It is a complex and challenging task that requires multidiscipline approach, especially when dealing with human subjects and their individuality in all the related concerns like influence of various effects and conditions, namely stress, time variance, perception of situations etc.

However we believe that coordinated approach to experiments being held recently and in present in several countries (see [7] or [15] e.g.) in the same field could be of a good help.

As it has been described in a book published during the project realization period [11], initial and primary purpose of truck simulator laboratory being mentioned in this article is training of professional drivers. The intention of the training is to improve the road safety level in the EU and other developed countries. Besides that, we are pursuing further research and exploration of driver behavior for its better understanding, which shall provide a scientifically based contribution to the development or improvement of teaching professional as well as other categories of drivers on a long-term basis.

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