Integrated System for Monitoring the Psychical and Physical Conditions of Road Vehicle Drivers

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ABSTRACT

From our previous research among bus drivers, in difficult, but not extreme situations, we observed an increase in blood pressure (up to 200mm Hg), cardiac arrhythmias, ischemia, etc. Such reactions may be dangerous to healthy people, but they are extremely risky for drivers with a history of cardiovascular or cerebrovascular incidents. Thus, certifying driving ability of such persons is a serious problem for the medical expert. In this case, tests in a driving simulator, where it is possible to arrange a variety of stressful situations and also to monitor the reaction of the cardiovascular system and brain electrical activity may be a great advantage. Therefore we developed a first-in-Poland integrated system for examination and training of road vehicle drivers, including model stand for simulating of driving vehicle under conditions of road traffic, and a set of methods of psychological and physiological tests to be applied for testing drivers. This simulator enables to assess physiological response to different traffic situations, to analyze the effects of work environment on psychical and physical abilities of drivers, to test the feasibility of the physiological methods for assessing the fatigue and drowsiness, to evaluate the effect of monotony and static loads on the development of driver's fatigue, to assess changes in psychomotor abilities of drivers resulting from exposure to harmful and noxious agents at workplace.

Keywords: driving simulator

INTRODUCTION

Driving a vehicle, and professional driving job in particular, is associated with a high risk of accidents.
In 2012, in Poland, there were **37046** traffic accidents in which

- ✓ **3 571** people were killed - the second highest traffic death toll in Europe;
- ✓ **45 792** were injured,

337 943 collisions were reported to the police.
Road accidents cost the Polish people over 12 billion zł per year.
Studies conducted in the United States and the United Kingdom indicate that 95% of all traffic accidents are classified as due to error committed by the road user (driver or pedestrian), and only 5% as due to defective vehicle, road or environment.

The main causes of crashes include:

- ✓ excessive speed,
- ✓ alcohol,

- excessive self-confidence and aggression,
- failure to obey the traffic rules,
- driver's inexperience,
- driver's fatigue

Dangerous errors are usually committed in cases of a sudden change in the traffic conditions, such as:

- a pedestrian walking suddenly into the roadway,
- unexpected change in the behaviour of other drivers,
- time pressure and the necessity to choose between performing the task in short time and violating traffic rules,
- difficulties due to high traffic intensity,
- change in traffic organization,
- limited visibility.

These situations are almost always associated with increased demands on the driver and are said to be difficult.
To meet the different and changing situations on the road, the driver must have certain special characteristics that allow him/her to maintain maximum dependability, i.e. the ability to drive with minimal risk of error.
Those characteristics include:

- expertise,
- experience,
- practical skills,
- suitable personality traits,
- acceptable cognitive function,
- satisfactory psychomotor performance.

The latter two items are adversely affected by stress, health problems, age and fatigue.
Literature data show that the most common causes of road accidents attributable to driver's poor health include:

- epilepsy (38%),
- hypoglycaemia in insulin-dependent diabetes (18%),
- cardiac disease (8%).

These data come from an analysis of 2000 traffic accidents caused by drivers, as reported by the UK police

Driver fatigue as the cause of traffic accidents

Traffic accidents due to fatigue represent one of the most common causes of death on the roads, preceded by drunk driving. A recent study conducted in the UK shows that every third traffic accident is caused by a professional driver (Clarke et al., 2009). Among those drivers, particular attention has been paid to the drivers of special-purpose/emergency vehicles who usually do not feel responsible for the accident, claiming that it is other road users that are to be blamed. Their driving style is usually sporty and aggressive which, combined with fatigue and emotional exhaustion, may increase the risk of accidents (De Graeve et al., 2003).

Numerous statistics and studies have shown that long hours of driving result not only in the physical fatigue, but also in a slow-down of mental function (Philip P. et al. 2003). Drivers often have difficulty focusing their attention on the road, especially in the monotonous and uninteresting scenery (Thiffault and Bergeron, 2003, Ting et al., 2008). Fatigue is also increased by limited space for the legs, with the resultant restriction on the movements of the lower limbs. It is believed that the immobilization of the lower part of the body is one of the key causes of fatigue (Liang et al., 2008 a). Causes of fatigue are said to include also sleep disorders, such as e.g. sleep apnea (Boyle et al., 2007). Monotony, drowsiness and fatigue are factors that pose danger to road safety. The documents of the U.S. Department of Transportation (1995) comprise a statement that driver fatigue is a major problem among the professional drivers. Thus, particular attention should be paid to prevent fatigue in that professional group. Knowledge of the causes of fatigue, testing methods, preventing fatigue, ability to cope with the symptoms and the principles of rational recreation should be widely disseminated among drivers, because the consequences of driving despite fatigue can be dangerous not only to drivers but also to other road users, and thus they relate to public safety. Driver fatigue is a result of driver performing his/her job in the conditions of the traffic situation which comprises interaction between the four basic elements of this situation:

- ✓ driver,
- ✓ vehicle (technical fitness and ergonomic characteristics of workplace),
- ✓ behavior of other road users,
- ✓ road (traffic intensity, visibility, road surface characteristics, etc.,

Driver-related factors affecting the fatigue include:

- ✓ age,
- ✓ psychophysical condition,
- ✓ personality and temperament,
- ✓ health,
- ✓ driving time,
- ✓ number of hours of sleep before the driving task,
- ✓ individual course of circadian biological rhythms of the functions related to the psychophysical efficiency of the driver,
- ✓ medications,
- ✓ alcohol and other stimulants
- ✓

As to the complexity of the situation in which the driver works, there are four basic types of fatigue related to different areas of driver's job:

- ✓ muscle fatigue (static load associated with body posture while driving, holding the steering wheel),
- ✓ sensory fatigue, which involves reduced reactivity of the sensory organs,
- ✓ mental fatigue, involving deterioration of cognitive function as a result of the need for constant attentiveness and monotony of driving conditions,
- ✓ emotional fatigue caused by stressful factors (time pressure, conflicts with passengers, etc.).
- ✓

Fatigue leads to decreased vigilance and longer reaction time, can also cause erroneous interpretation of signals sent by other drivers and, consequently, inappropriate responses. Studies show that tired drivers drive:

- ✓ less smoothly
- ✓ perform often sudden steering maneuvers,
- ✓ often change the lane, causing a risk of collision with the vehicle traveling in the same or in the opposite direction,
- ✓

Fatigue also affects the mood of the driver, who is more prone to be anxious and react more aggressively. Professional drivers are under constant time pressure enforced by employers and the associated need to continue driving regardless of fatigue. Fatigue reduces the driver's ability for self-assessment of aptitude and endurance; alertness deteriorates as the fatigue and sleepiness become more severe.

Fatigue is an important occupational accident risk factor in drivers. Fatigue results from irregular working hours, night work, sleep deprivation. Accidents attributed to fatigue are, paradoxically, usually associated with excessive speed inadequate to the situation on the road (Copsey, 2010).

Study of fatigue as one of the major causes of accidents

Assessment of fatigue is a major element of risk management of accidents among drivers. So far, no sufficiently sensitive and specific method for testing of driver fatigue has been available. Most of the currently available methods are subjective, based on questionnaire surveys (e.g. Fatigue Symptoms List, developed by the Japanese Fatigue Study Team), in which the study subjects themselves assess the level of perceived fatigue. The results of such an assessment may be biased, since the examined persons may consciously rate their fatigue level as higher or lower than actual, depending on whether they think it desirable to prove that they are very tired or, to the contrary, well-rested. Therefore, search for an objective method to assess fatigue continues. To achieve that objective, it has been attempted to use the analysis of 24-hour recordings of electroencephalographic (EEG) data recorded while driving in the real world or in a driving simulator, the registration of facial expressions (analysis of changes in the position of the eyebrows, the lips, squinting and blinking), registering the diameter of the pupils, the analysis visual pathways (visual fixation on the individual control elements in the cabin, on the road and its sides), registering of 24-hour electrocardiograms (Holter ECG monitoring) combined with the analysis of heart rate variability (HRV)

(Lal and Craig, 2002) The most precise results can be obtained using all of these methods simultaneously, but this is difficult, especially in real conditions, because it largely restricts the freedom of the driver and may interfere with the driving job (Brookhuis and de Waard, 2010).

Recording of heart rate variability (HRV) is the easiest way to asses driver fatigue, both in real life and on the driving simulator, because it can provide valuable information about the psychophysiological condition of the driver.

Analysis of heart rate variability (HRV) is used to assess the physical and mental effort. It has been shown that during the computer-aided tests, the high frequency (HF) spectral component of HRV (0.15–0.35 Hz) is significantly reduced, while the low frequency (LF) spectral component of HRV (0.05–0.15 Hz) remains unchanged. According to the commonly adopted interpretation, the HF power spectrum is parasympathetic-mediated, while the LF one is sympathetic-mediated. It has been also found that the heart rate variability is a more sensitive indicator than the changes of blood pressure. Assessment of HRV has been also used as a measure of mental load, stress, and fatigue in many studies conducted on flight simulators in order to evaluate the effectiveness of training, the stress experienced during the training, the difficulties associated with individual tasks performed by the pilots and the extent they perceive the simulated circumstances as real. It has been also found that the HRV accurately reflects the response to different tasks. Richter et al. (1998) observed that when driving in the city along the winding streets, the drivers showed reduced heart rate variability immediately after a difficult part of the route, which was probably a consequence of mental load after the difficult parts and the associated increased activity of the sympathetic system. Studies of fatigue during simulated driving show that the parameters describing heart rate variability correlate well with the assessment of fatigue and can be used to monitor fatigue in drivers.

By analyzing of HRV, it is possible to observe the impact of time of day on the changes in driver's susceptibility to fatigue. One of the first studies performed using the simulator compared the physiological changes associated with driving in the morning and in the afternoon. The study population consisted of 40 volunteers divided into 2 groups - morning (8:30-11:00) and afternoon (14:00-16:30). All of the subjects took a 90-minute test drive on a simulator. As a result of comparing the physiological indices recorded before and after the test, lower heart rate, increased heart rate variability and spectrum power in the very low frequency (VLF) - range 0.0167–0.05 Hz were recorded in both groups. In the morning group, increased activity of the sympathetic autonomic nervous system (LF) and decreased parasympathetic activity (HF) were noted. In the afternoon group, the reaction was reverse. The systolic blood pressure in the morning group did not change, whereas it decreased during the test in the afternoon group. By comparing the analyzed parameters of heart rate variability before the morning and the afternoon test ride, it was found that the parasympathetic activity (LF) and the ratio of LF/HF were significantly higher in the afternoon than in the morning group, which may indicate greater fatigue. This was confirmed by subjective feelings of the respondents. Volunteers from the morning group felt less fatigue than those of the afternoon group (Liang et al., 2008 b).

The analysis of heart rate variability has also been used in studies on the impact of the extended (up to 24 hours) working time of taxi drivers on circadian rhythm neurovegetative dysregulation and the associated risk of cardiovascular diseases. It was found that during the 24-h working time, blood pressure was significantly higher compared to the off-duty day, especially in hypertensive drivers. These changes were also accompanied by a decrease in parasympathetic activity, which has a protective effect on the cardiovascular system. The simulated driving studies have also shown that heart rate variability increased significantly after the programmed monotonous driving in drivers with sleep apnea syndrome compared with healthy subjects. Both groups had similar HRV levels at the beginning of the simulation. In drivers with known sleep apnea syndrome, the risk of accidents associated with fatigue and sleepiness while driving was higher.

Assessment of heart rate variability was used as a measure of mental load, stress and fatigue in many studies conducted both on a flight simulator and a driving simulator (Veltman and Gaillard , 1993, Jang et al., 2002).
Jorna (1993) used the analysis of heart rate variability in pilots for evaluating the effectiveness of training, the stress experienced during the training, the difficulty of individual tasks of the pilot and the extent to which the pilot experienced the simulation as real, and found that HRV accurately reflected the physiological response to different tasks.

Liang (2009) analyzed the fatigue of drivers subjected to 120-minute simulated driving test depending on the simulated driving circumstances. One group were driving without a break (group A), the other (group B) had a 15-

minute break after the first hour of the test, during which the subjects performed physical (trot, neck and shoulder rotation, stretching the upper limbs and chest, knee rotations) and breathing exercises. During the test, the heart rate, blood pressure and heart rate variability were recorded. It was found that the group who were driving without interruption (A) showed lower heart rate, systolic blood pressure, sympathetic activity (decreased LF/HF ratio), and increased parasympathetic activity (HF), while Group B showed decreased heart rate, but increased sympathetic activity (LF). Thus, it seems reasonable to conclude that the activation of the autonomic nervous system associated with recreational exercise can help in overcoming some signs of fatigue resulting from driving a vehicle. Subjective assessment of fatigue after the test was better in group A. The authors conclude that the parameters describing heart rate variability, especially HF, LF and LF/HF ratio correlate well with the assessment of fatigue and can be used to monitor fatigue in drivers. Also Brookhuis and de Waard (2010) demonstrated in studies using driving simulators, the usefulness of HRV analysis in the assessment of both fatigue (tiredness) and stress among drivers.

Analysis of heart rate variability in older and younger volunteers during the test in a driving simulator that required visual and auditory attention showed no differences due to age. Both groups showed reduced HRV associated with mental load (de Waard et al., 1999). In contrast, Reimer et al. (2006) have shown that older (51-66) drivers have difficulty adopting to the conditions in the driving simulator, they also have a higher heart rate (HR) at the beginning of the test, which decreases more slowly during the test in comparison to changes in HR of young (19-23) drivers. The correctness of performing easy tasks in both groups was similar, but the difficult tasks were performed better by young drivers.

As stated earlier, drivers with diagnosed sleep apnea syndrome had a higher risk of accidents associated with fatigue and sleepiness while driving. Authors of some studies suggest that heart rate variability may be a simple, non-invasive screening test to evaluate the risk of sleep apnea syndrome, which is a major problem in drivers (Roche et al., 1999, Jo et al., 2005, Reynolds et al., 2007). Boyle et al. (2007) in studies on the simulator showed that heart rate variability increased significantly after the programmed simulated monotonous driving in drivers with sleep apnea syndrome compared with healthy subjects. Both groups had similar levels of HRV at the beginning of the simulation. Richter et al. (1998) observed that drivers, when driving in the city along the winding streets, showed reduced heart rate variability on the easier sections of the road immediately after the difficult part of the route, which was probably a consequence of mental load experienced on the difficult sections.

The study of heart rate variability seems to be an objective method of assessing driver fatigue, both in real life and in tests on simulators. By assessing neurovegetative regulation, i.e. the influence of the sympathetic and parasympathetic nervous system on the cardiovascular system in certain driving situations (real or simulated) it is possible to determine whether the response to these situations is correct, whether the stimulation of the body is too strong (the tendency to over-aggressive driving) or too weak (the tendency to snooze). Due to the fact that the neurovegetative regulation can be modified by suitable training, its monitoring by analyzing of heart rate variability can provide much essential information about psychophysiological adaptation to vehicle driving task. Currently, attempts are made to develop an algorithm for the assessment of the level of fatigue by analyzing heart rate variability (Rogado et al., 2009).

From the point of view of public safety, before first certifying one's qualification for profession of driver, or continue this job, it is necessary to precisely determine:

- ✓ knowledge of road traffic regulations,
- ✓ driving skills,
- ✓ health condition and psychophysical capacity.
- ✓

However, requirements of the Road Transport Act do not meet these expectations in all instances.

There are many cases in which medical and psychological tests performed in an outpatient setting do not provide a complete understanding of the physiological response to extreme situations. For example, it is difficult to predict whether a collision or sudden event is dangerous to health of the driver because it could produce an undesirable response of the cardiovascular system (e.g. increase in blood pressure, cardiac arrhythmia, ischemia, myocardial infarction, cerebral ischemia). From our previous research among bus drivers in difficult but not extreme situations, we observed an increase in blood pressure (up to 200 mm Hg), frequent episodes of cardiac arrhythmia or ischemia, etc. Such reactions may be dangerous to healthy people, but they are extremely risky for drivers with a history of cardiovascular or cerebrovascular incidents. Thus, certifying driving ability of such persons is a serious problem for the medical doctors. In this case, tests in a driving simulator, where it is possible to arrange a variety of stressful situations and also to monitor the reaction of the cardiovascular system and brain electrical activity may be a great

advantage.
Similarly, during driver’s training, it is not feasible to teach trainees to respond in a proper way to stressful situations (e.g. accidents) that in real life occur occasionally. Such skills can be acquired by the trainees in a driving simulator, where it is in addition possible to assess trainees’ physiological response to different traffic situations.

In Poland, simulators fully imitating the actual driving conditions have not yet been used in the process of testing candidates’ fitness for the profession of driver, and until now they have been seldom applied in driver training.
So far, there has been also no possibility of psycho-physiological testing of drivers in simulated, but very realistic road traffic conditions.

INTEGRATED SYSTEM FOR MONITORING THE PSYCHICAL AND PHYSICAL CONDITION OF ROAD VEHICLE DRIVERS TO MINIMISE HAZARDS IN ROAD TRAFFIC IN NOFER INSTITUTE OF OCCUPATIONAL MEDICINE, LODZ, POLAND

General aim of the project was to develop a first-in-Poland integrated system for examination and training of road vehicle drivers, including:

1. model stand (a bus/truck cabin) for simulating of vehicle driving under conditions of road traffic,
2. a set of methods of psychological and physiological tests to be applied for testing drivers.

In Poland, simulators fully imitating the actual driving conditions have not yet been used in the process of testing candidates’ abilities for the profession of driver, and until now they have been seldom applied in driver training.

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The implementation of the project shall enable:

- ✓ diagnosing and certifying the ability to drive road vehicles in:
  - ➢ candidates for professional drivers,
  - ➢ drivers returning to work after cardiac, neurological and other incidents,
  - ➢ periodical examination of drivers,
  - ➢
- ✓ testing candidates’ abilities for the driver profession, with particular reference to candidates for special-purpose/emergency vehicle drivers,
- ✓ assessing the effect of fatigue, stress, urgency, drugs, on driver’s abilities to drive vehicle,
- ✓ analyzing the effects of driver’s participation in traumatic events (such as e.g. traffic accidents) on driving safety,
- ✓ psychological training of drivers after traumatic events,
- ✓ training of occupational medicine doctors and road traffic psychologists,
- ✓ training of road traffic instructors and managers of schools teaching how to improve driving technique,
- ✓ professional training of drivers, where under circumstances resembling as much as possible true road traffic conditions, the drivers shall acquire abilities and habits of responding correctly to various road traffic situations (slippery road, driving in the mountains, dazzling by vehicle lights or sunlight) difficult atmospheric conditions (fog, snow, night, rain).

Simulator stand

The simulator is equipped with two interchangeable driver cabins: truck and bus. Cabins are fully equipped (adjustable driver's seat, steering wheel, accelerator, brake and clutch and gear lever, together with a full simulation of loads that occur on these elements of control, signal lamps, buttons, levers and switches). The cabin is mounted on a movable platform with six degrees of freedom.

The purpose of the platform is to simulate the movements felt by the driver when driving the vehicle in the real world. In the cabin is also installed a camera designed for continuous transmission of the image to the instructor stand, as well as a radio communication system. The simulator uses a modern visualization system equipped with a screen with a field of view of not less than 180 degrees horizontally and 40 degrees vertically, and high-quality projectors. The visualization system of the simulator generates and displays a realistic view as seen from the cabin of the vehicle. This allows the examined driver to see the road and its environment in a very realistic manner similar to the real circumstances (varied terrain types provided with natural and complete road infrastructure). In addition, the generated image is also visible in the rear-view mirrors. The monitors installed at the instructor stand show a real-time representation of:

• the image seen by the driver,
• situational map of the area involved in the training session,
• simulator control interface,
• image captured by the camera in the cabin,
• mapping of the current position of the instruments and controls in the cabin.

Analysis of driving parameters: speed, acceleration, brake, clutch, wheel position etc.
During preparation of the exercise scenario, it is possible to select:

• vehicle type and its configuration
• the size and type of cargo
• exercise area (type of terrain: mountains, lowlands, urban or rural environment),
• season (winter, summer) and time of day (day, night, twilight),
• weather conditions (rain, snow, visibility - such as fog, blizzard; temperature, wind speed and direction),
• type and volume of traffic

Group and Study Protocol

The subjects were 48 drivers of municipal bus transportation service (MPK) in Lodz. All tests were performed on a day off from work. The study included three steps: I. *Basic examination, II. Psycho-physiological testing in the real conditions and III. Psycho-physiological examinations using a driving simulator*

I. Basic examination included: medical examination with anamnesis and questionnaire, standard ophthalmological examination, neurological examination, 24-hr Holter recording with analysis of heart rate variability (HRV), 24-hr ABPM blood pressure monitoring, psychological tests - in addition to the standard tests, included also the Vienna Test System to assess driver's psychomotor skills and perception.

II. *Psycho-physiological testing in the real conditions* were carried out among the same drivers as in Phase I, in two kind of real conditions:

- ✓ on the day when the driver was leading the bus in conditions of heavy traffic
- ✓ on the day with monotonous driving conditions (suburban route)
- ✓

The examinations included: rating of fatigue before and after work, psychological tests before and after work, 24-hour Holter recording with HRV analysis, 24-hour blood pressure monitoring

III. *Psycho-physiological examinations using a driving simulator*

The following methods are using in the simulated driving tests

- ✓ EEG recoding prior to, during and after the test on the simulator (neurological diagnosis, assessment of the possible changes attributable to the simulated driving, the reaction of different areas of the brain to the specific challenges that may occur during driving and to stressful situations as well as fatigue, sleepiness etc),
- ✓ eye-tracking and Facelab (full face and eye tracking capabilities, eye movement; head position and rotation; lip and eyebrow movement , pupil size, the number of fixations, percentage of area in the total field of view during fixation, the average fixation time, exploration areas of the functional vision field - Recording and analyzing eye movements provide important elements for understanding the nature of the task of driving a vehicle. Results of these measurements make it possible to optimise driver training strategy and prevent accidents
- ✓ 24-hour blood pressure monitoring (assessment of blood pressure response to specific traffic situations),

- ✓ 24-hour Holter recording with heart rate variability (HRV) analysis (assessment of heart rate, arrhythmias and ischemia in different driving situations and analysis of the autonomic nervous system response to stress, fatigue, hazards - HRV)

Up till now we have no results of these studies, because they are on-going. The results will be analyzed to evaluate usefulness of the driving simulator with a discussed methods in assessing the psychophysiological state of drivers. and abilities to drive. Comparison of the results of the tests on the simulator with results in real conditions enables to choose the most reliable protocols and methods for drivers examinations.

CONCLUSIONS

Our studies shall provide an useful tool included simulator and a set of methods (24 -h ECG with analysis of heart rate variability, 24-h blood pressure, impedance ECG, EEG, eye-tracking, facial expressions) for testing the influence of different factors and conditions such as fatigue, stress, personality, urgency, drugs, alcohol, weather, road etc. on driver's abilities to drive vehicle. It could improve the process of qualification, diagnosing and certifying the ability to drive road vehicles.

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