Driver sleepiness detection based on eye movement evaluation - a driving simulator study

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Abstract

The article provides a study of driver fatigue experimental research on interactive driver simulator. Visually available face features, movements of eyes and facial expression are followed with the help of distant eye tracker. The driver behaviour of sleep deprived participants is observed and compared to that of the rested drivers. This research targets sparing the key features of driver behaviour for further implementation in detection methods of driver fatigue in the human-machine interface of modern and future cars.

Introduction

Automation of many everyday processes is still a challenge – automation of driving is not an exception. Human agent is a soft element in any system. Human body is a system with not only physical properties. The cognitive processes running in human brain while controlling all their physical systems are individual, hard to define and predict. We have been learning to read human body and understand human brain, predict emotions and even imitate humane processes with the help of technology.

Interaction between a driver and a vehicle is a complex system. People have been driving cars for many years. Vehicles, transport infrastructure, cities and regions in general have become smarter, faster and at the same time more disturbed which makes human more vulnerable. Human reaction and response is crucial in the systems and interfaces one is involved. Study of driver behaviour is necessary for their safe interaction with the systems of modern world. Transport systems still depend on input of human agent, especially in-car systems. To improve prediction of driver crucial and dangerous behaviour we study their behaviour in simulated or real environment. Driving simulator experimental studies allow observing human behaviour in critical situations.

Sleep is quite well detected with the help of polysomnography where measurement of brain waves (EEG), eyelid movements (EOG) and muscle tonus (EMG) takes place. The detection of sleep using this technique is quite precise and has significantly contributed to the study of sleep; however because of their invasive nature measurements are only possible in experimental conditions. Non-intrusive measurement of sleepiness is possible with the help of video-based measurements of

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eye behaviour (blink frequency, duration, time of eye closure/opening, gaze fixations and saccadic movements). Quality of measuring using this method can be compromised by such factors as quality of detectors, lighting situation, or subject wearing glasses. Analysis and evaluation of behavioural sleepiness (body and head movements, face expressions and gestures) is another way of sleepiness detection, where video image analysis or observer rating methods are applied (Anund, 2009).

Our research is aimed at detecting visually available features of driver behaviour in drowsy or fatigued state with the help of tools for visual observation during experiments in a laboratory with driving simulator. The study provides analysis of eye behaviour, simulator obtained data and subjective evaluations. The purpose of research is to combine subjective (self-rating) and objective (eye movements and reaction times) measures for detection of best marginal measure for prevention of falling asleep at wheel.

Experimental measurement of driver fatigue

Research on the problem of driver drowsiness, fatigue and sleepiness is important. Worldwide organizations like National Sleep Foundation in America with project “Drowsy Driving”, National Traffic Safety Foundation, or project “Drowsy Driver” in Sweden have been leading extensive research programs in this area.

Experiments with fatigued drivers on driver simulators have been conducted at the faculty the authors are with for tens of years. A complex research has been done to assess driver physiological, psychological states and driving behaviour. Some results are presented in publications by Bouchner et al. (2006).

Experiment platform and measurement method.

Measurement of sleepy driver state is only safe in laboratory conditions. The suggested test is conducted in a laboratory on fixed-base light personal car half-cockpit simulator cut behind the driver seat. The visualization of virtual environment is a 270-degree projection on 3 screens (see Figure 1). Eye movements are recorded with the non-intrusive eye-tracker device Smart Eye Pro.

The driving track used here is a monotonous highway with minimal traffic (Figure 2). There are 9 triggered events (for fresh drivers) and 18 events (for sleepy drivers) in the scenario represented by a special signal that is supposed to engage driver to break till the light changes to green. For this experiment the signal is represented with a lane control red cross/green arrow light placed on roadside gantries (see Figure 3), with green signal set as default and red signal on some of the gantries, where per the given task drivers need to stop. The trigger event serves for measurement a time to reaction and subjective self-evaluation (for sleepy drivers) during experiment. Drivers were instructed to maintain stable speed (around 90 km/h) during the whole experiment.

Participants for the experiment are being recruited mainly among the students and associates from faculty of transportation sciences at Czech Technical University in Prague. Seven people (all male) have participated in the experiment so far (age mean

25.7; SD = 27.6). One of the drivers could not complete the measurement because of simulator sickness, therefore measurements for six participants were available. Due to issues with eye tracker signal for one subject, eye behaviour of 5 drivers was observed. Subjective measure is available for 5 drivers. All participants are active drivers with valid driver's licence, average driving experience 6 years and with around 10 000 km of yearly mileage. Every participant came for measurement twice: once in normal state and a second time after sleep deprivation of at least 24 hours (24 hours since awakening from last sleep). All measurements for sleep deprived drivers took place in the morning hours (with a start around 8-9 am) with most subjects having been awake for the past day and night in a row, while measurements with fresh drivers could happen any time during the day. No energy drinks, excessive coffee intake, strong tea, alcohol or stimulating drugs were allowed during the sleep deprivation period. Simulator drive for fresh participants lasted for about 60 minutes and for sleepy participants – 120 minutes. The 60 minutes' drive is taken as a control state for each participant.

Figure 1. Driver simulator - left and eye-tracking device "Smart Eye pro" - right.

Figure 2. Driving track.

Figure 3. Driving scenario and triggered event realization.

Observation of eye movements

Eye movements may be characterized as saccadic movements being interrupted by fixations, or moving fixations – smooth pursuits (fixation on a moving target). During fixation, the brain is processing the information screened by the eyes. There are studies showing relation between fixation itself and the understanding of screened information during different kinds of activities like reading (Just and Carpenter, 1980), visual search (Hooge & Erkelens, 1997), scene perception (Rayner, 1998) etc. Some of possible measures for fixation are duration time, direction, or position, velocity. Evaluation of driver behaviour by means of measuring gaze duration is described in standard ISO 15007. Eye behaviour presented in this chapter relates to one experiment participant. Behaviour of drivers involved in the experiment was quite individual, besides, the number of participants of this experiment is small (at this stage) and therefore an expert approach was chosen for assessment and analysis of measured data.

Normally, fixation duration may last from 100 ms to over a second (Bergstrand, 2008). Eye behaviour has been followed in our sleepiness research, fixations and blinks analyses has been done over one hour for each 5 minutes' time section starting from the start of experiment. By fixation here a gaze intersection with front screen simulator projection (front scenery view) and with instrument cluster is understood. Analysis of one of the study participants is provided here. It has been observed that number of fixations increased in sleepy state (Figure 4). However, average fixation duration has noticeably dropped (Figure 5). Total time spent on fixations has shown no noticeable difference between sleep deprived and fresh states (Figure 6).

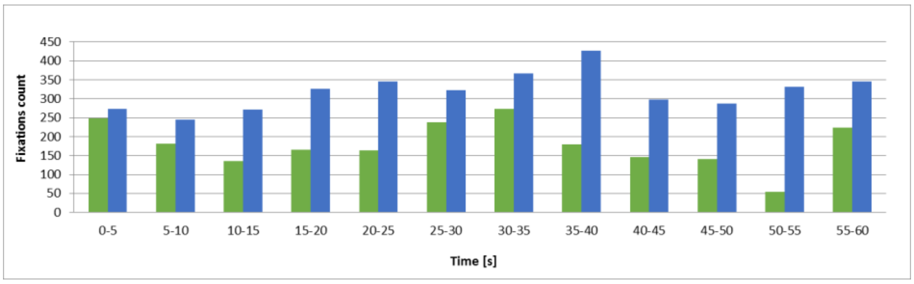

Figure 4. Fixation count analysis for one driver in fresh (green) and sleep deprived (blue) condition.

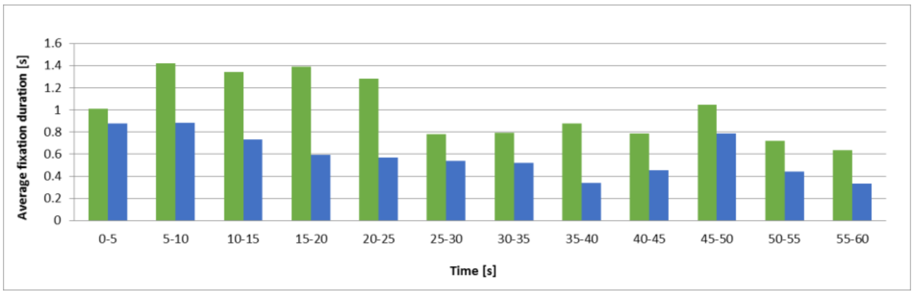

Figure 5. Average fixation duration analysis for one driver in fresh (green) and sleep deprived condition.

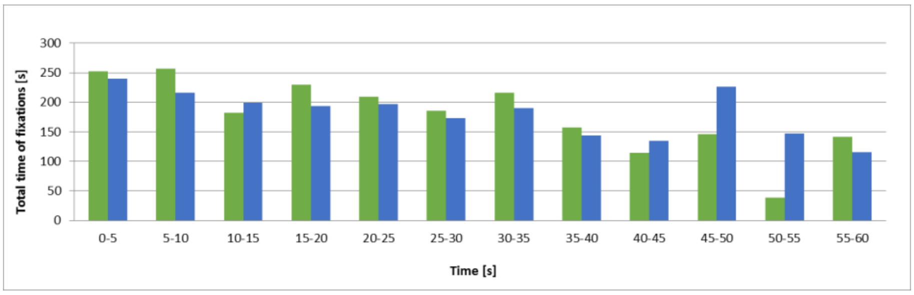

Figure 6. Total fixation duration analysis for one driver in fresh (green) and sleep deprived condition.

Blinks were also analysed for frequency, average and total duration during one hour of measurement (first hour in case of sleep deprived drivers) per 5-minute time sections. At this stage, no typical schemes of blink behaviour can be observed as behaviour of each participant is individual. In Figure 7, one can see that different tendencies of blink frequency are observed through one hour for one of the drivers (same participant, whose fixation analyses are suggested above): noticeable increase in blinks count for sleep deprived state. Blink measure provided in eye tracker data is an eyelid closure of duration under 700 ms. This could mean that in the sections with blinks count drop we may be facing sleep events. However, further analysis needs to be done for more solid assumptions. Total blinking time values per each time section are represented in Figure 9. In general, total blinking time over the whole period (60 minutes) hasn’t changed between states as compared within 1 hour. Average blink duration is somewhat shorter for sleep deprived drivers (see Figure 8), however difference is not very representative, besides, the longer eye closures could be not detected due to blink measurement parameters described above. Further research will be concentrated at correlation of eye behaviour to driving behaviour measures as well as sleep events detection for better understanding of eventual behaviour changes observed here.

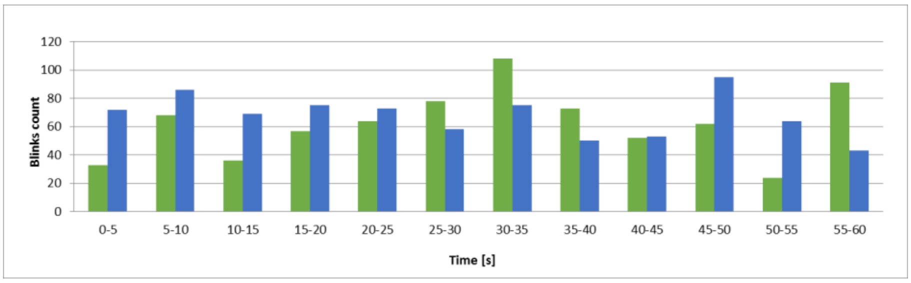

Figure 7. Blinks count analysis for one driver in fresh (green) and sleep deprived (blue) condition.

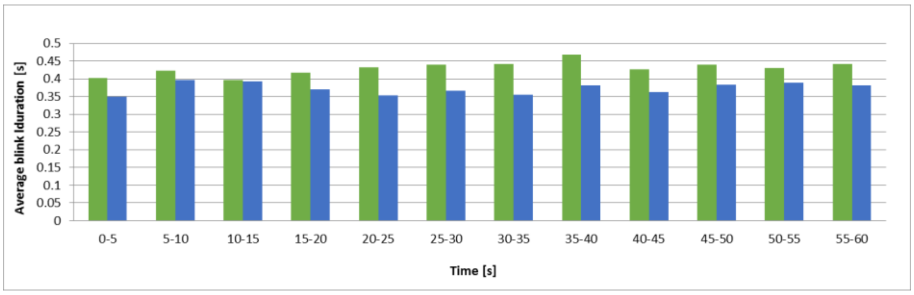

Figure 8. Average blink duration analysis for one driver in fresh (green) and sleep deprived (blue) condition.

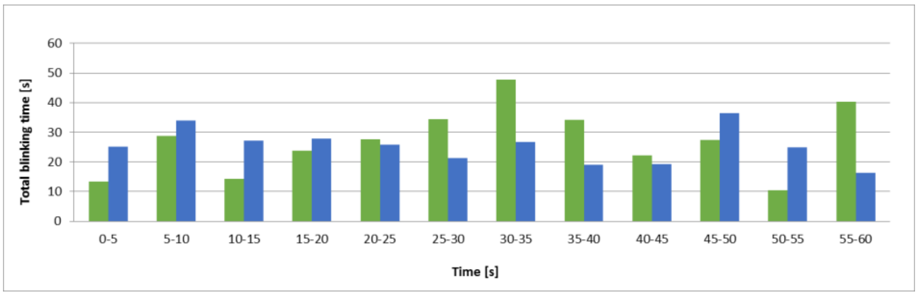

Figure 9. Total blinking time analysis for one driver in fresh (green) and sleep deprived (blue) condition.

Analysis of driving data

The incident method for experiments with sleepy drivers on a driving simulator is described by Baulk et al. (2006). The research shows that longer time spent on task by drivers after sleep deprivation was resulting in increase of reaction times.

The outcomes of experiment described here show that even though no significant differences have been noticed for drivers in fresh state (mean 1220 ms; SD 500 ms) as compared to sleepy state during the 1st hour (mean 1414 ms, SD 711 ms, t= 1.6, p=0.1) and 2nd hour (mean 1315; SD 447 ms, t=1.03, p=0.3), however, it is worth of noticing that the overall grow of time to react grew further in the course of the sleepy experiment – the tendency can be tracked in Figure 10, where mean reactions among all subjects are displayed per each trigger event in fresh state, sleep deprived state (first and second hours of driving in sleep deprived state are displayed separately). For many drivers the abrupt breaking at trigger zones has been observed. Further research will be concentrated on more driving characteristics parameters.

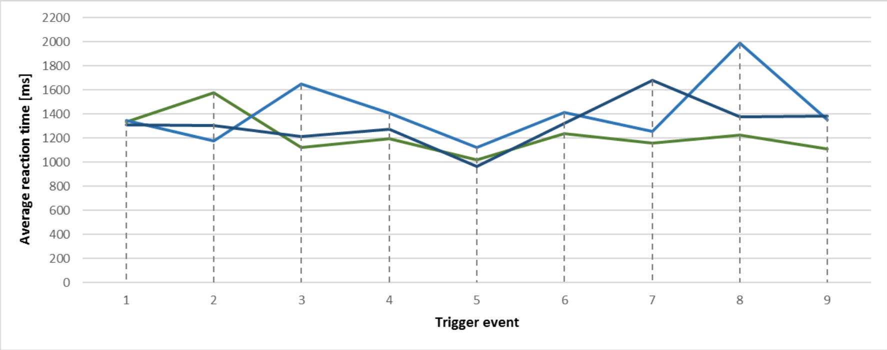

Figure 10. Average reaction time for each trigger event in each state: green - fresh, light blue - sleep deprived 1st hour, dark blue - sleep deprived 2nd hour.

Subjective measurements and some experiment findings

Normally people are aware of their sleepy state. However, studies show that they aren't capable of predicting crash or inability to drive (Watling et al., 2015; Horne & Baulk, 2003). It has been shown by Howard et al. (2014) and Åkerstedt et al. (2014) that self-rating increases with longer awake hours. Though not considered to be a sufficient measure of sleep prediction, self-rating is still worth of being taken into consideration especially when combined with objective evaluation techniques of sleepy driver behaviour. There are several sleepiness scales for subjective measure, such as Stanford Sleepiness Scale (Hoddes et al., 1973), Karolinska sleepiness scale (Kaida et al., 2006). Another self-rating scale has been developed at author's faculty, also mentioned by Bouchner et al. (2006), for driver self-assessing of their state. In this study, sleepy drivers were self-rating themselves during 18 stops designed as trigger events in simulation scenario. The scale itself is a result of researchers' observations during numerous experiments of driver fatigue. The outcomes of participants' self-ratings in the current study are presented in Tables 2 and 3.

Changes in subjective feeling of sleepiness are individual. The following tendencies have been noticed here: participants 3, 4 and 5 reported to be at the highest stages of going into sleep at the early stages of the experiment; at the same time, one participant reported to be in an average sleepy state. It is important to collect more data for detecting typical tendencies. Comparison to real driving behaviour by analysis of vehicle outputs is important here.

During after-experiment moderated conversations with drivers we were seeking to find possible personal perceptions on questions about feeling, mood, and physical state. Most drivers have either expressed a desire to use an air conditioner or radio, some drivers tried to sing or read poems by heart. Such countermeasures were found by some researchers, such as, for example, Reyner and Horne (1998) and Schwarz and Ingre (2012) to be of little or zero effect on level of sleepiness. However, one might consider those as behavioural features of drowsy state for visual observations during driver sleepiness experiments.

Table 1. Sleepiness scale. Faculty of transportation Sciences CTU in Prague

Score	***State description as perceived by driver***
1	*I feel fine/fresh & driving does not make me any problems.*
2	*I feel drowsy & driving does not make me any problems.*
3	*I feel drowsy & I notice some problems.*
4	*I feel very drowsy & I need excessively concentrate to drive correctly.*
5	*I experienced 'blackouts' & losing of control over the car.*

Table 2. Self-rating scores provided by 5 participants during sleep deprived state.

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*
p1	2	3	3	5	4	5	5	5	5	5	5	5	5	5	5	5	5	5
p2	1	2	3	3	4	4	4	4	4	4	5	5	5	5	5	5	5	5
p3	2	3	4	4	3	4	4	4	5	5	4	3	3	3	4	3	3	4
p4	2	4	5	5	5	5	4	5	5	4	5	5	5	5	5	5	5	5
p5	4	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	4

<u>Note:</u> Self-evaluation scores of 5 participants during 2 hours of driving (columns 1 to 9 correspond to the first hour, columns 10 to 18 correspond to the second hour). Scores from 1 to 5 are given per scale presented in Table 1. Light green cell colours (weak shading) represent lower score of drowsiness, blue colour (strong shading) represent higher score of drowsiness.

Discussion and future work

The versatile approach to driver drowsiness is explained by the different character of human behaviour in similar situations. Individual approach in human behaviour research shall be applied therefore. The provided research has analysed behaviour of sleepy drivers as compared to that in fresh state. The goal of the research is developing an efficient technique, based on visually available parameters, to detect a dangerous behaviour. The extensive study of broad data collection from the experiments includes objective data collected from simulator driving outputs to subjective evaluation of driver with the help of self-evaluation tests. Separate observations show some tendencies in deterioration of driver eye behaviour, determined by visual behaviour changes, such as decrease in average duration of gaze fixation count and increase of fixation count. It was also possible to observe increase of blinking frequency, however blink length average values didn't display noticeable difference between two compared states. The results differ per individual and solid conclusions require measurement of bigger cohort. Calibration of analysis of eye behaviour is needed for specification particular conditions of certain behaviour and for better correlation of visual behaviour to objective data results and subjective evaluation. Each type of obtained results is depending on different parameters, such as time, i.e. time from last sleep, physical condition of each individual, driving experience, collection of quality visual data is complicated by various structure and in-cabin behaviour habits (body movements, gestures), not to mention the aspects of sleepy driver face relaxation and eyes half-closures. Obtained objective measures showed insignificant statistical differences. However, separate critical values of reaction times were noticed in several cases. Further cross analysis of experimental data and research shall continue.

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