XX IMEKO World Congress
Metrology for Green Growth
September 9–14, 2012, Busan, Republic of Korea

EVALUATION OF THE MEASURING SYSTEM FOR RECORDING DRIVER REACTION TIME IN VIRTUAL ENVIRONMENT

J. Ogorevc[1], A. Čop[2], G. Geršak[1] and J. Drnovšek[1]

[1]University of Ljubljana, Faculty of Electrical Engineering, Slovenia, jaka.ogorevc@fe.uni-lj.si
[2]University of Zagreb, Faculty of Transport and Traffic Sciences, Croatia

Abstract: Measuring system for recording driver reaction time was built, where computer sound card was used as a data acquisition system. An experiment in virtual environment was performed to evaluate proposed measuring system. Measured values of reaction time were similar to reported values of studies in real-world on public roads. In addition, significant changes of recorded physiological parameters during experiment indicate that subjects responded similar to the real-world situations. From our results we can conclude that the built low-cost measuring system was sufficient to detect response of a driver to a hazardous situation and is ready to be tested in real-world situations.

Keywords: traffic safety, reaction time, evaluation, virtual environment, psychophysiology

1. INTRODUCTION

According to European Transport Safety Council (ETSC) outcome from June 2011, nearly 31,000 people were killed in road accidents in the European Union (EU) in 2010, which is almost 50 % less than in 2001. For such progress in traffic safety are the most deserved improvements in infrastructure, technological progress in means of transport, more stringent legislation and research in the field of transport and traffic safety [1]. A very important part of this research, are measurements in road transport, which are focused on driving performance and the role of the driver who is still a major cause of traffic accidents [2]. To achieve better road traffic safety there is increasing number of vehicles being equipped with Event-Data Recorder (EDR). These devices are so called “black boxes” in road transport. Such measuring system is connected to a computer in the vehicle and includes information on speed, acceleration, number of engine revolutions, pedal position, direction change, seat belt usage, vehicle skid, start and end time of a journey, time of activation of the brakes etc. [2, 3]. It also includes a camcorder and a GPS receiver. Also very important for traffic safety is the measurement of driver reaction time.

Reaction time (RT) (perception-response time) is the elapsed time between the presentation of a sensory stimulus and the behavioural response. Driver RT is an interval that starts when some object or condition enters the driver’s visual field and ends when the driver has made a discernible response (e.g., stepping on the brake pedal).

The time between the appearance of a hazard and the response is filled with certain activities. The detection interval starts when a hazard enters the driver’s field of view and ends when the driver has become consciously aware of that something is present. Having become aware of something, the driver must next acquire sufficient information to be able to be able to decide what action is appropriate (identification). In next stage (decision) the driver must decide what action is appropriate. Typically the choices come down to a change of speed and a change of direction. In the response stage the processed information is transmitted by the brain to the necessary muscle groups to carry out the intended action.

There are many papers dealing with the issue of driver RT. Driver RT has been measured in the assessment of Parkinson's disease, after various psychotropic drugs, in alcohol intoxication, in relation to pedal position, after total hip and knee replacement [5], after minor head injury [6], during mental workload [7], in relation to driver sleepiness [8]. It was reported that for situations considering healthy driver, not being tired nor affected by some chemicals or drugs, most individuals will respond in a range of 0.65 to 2.0 seconds [4, 7]. RT interval may be affected by many various influences. Elderly people have longer RT, while younger show lack of concentration [7]. Drivers respond later during mental workload, especially in detection stage [4, 7]. Fatigue or consumption of chemicals and drugs also lengthen RT [4, 8]. In case of injuries it was reported, that people with minor head injury have longer RT [6], while there was no significant difference by drivers after total knee replacement [5]. Poor visibility (fog, night time) may also have impact on RT, especially in identification stage [4]. Road signs normally increase attention of the driver and in case of marked crosswalks and school or playground area driver’s expectancy to a hazard. Increase in driver’s expectancy is reflected in shorter RT. Driver’s expectancy was reported to be the main reason why are RT intervals longer in real-world situations in comparison with research on simulators [7].

In the past few years, researchers have been working on the development of safety systems using different techniques. The most accurate techniques also include physiological measures [9]. One of the main reasons for road accidents is fatigue, leading drivers to fall asleep while driving. In relation to driver sleepiness face detection method [9] and measurements like electroencephalography (EEG) and electrooculography (EOG) [8] were proposed to achieve better safety. The majority of physiological measurements in the field of traffic safety appear in assessing the effect of mental stress on driver's psychophysiological state [10, 11, 12, 13, 14]. The most often used physiological measurements are heart rate [10, 11, 12, 13, 14], heart rate variability [11, 13], respiration rate [10], muscle activity [10, 13], skin conductance [10, 14]. Physiological measurements were also used to construct driver behaviour model [15].

Present study examines measuring system for recording driver RT. An experiment was developed in virtual environment, by means of playing a computer game. In addition to evaluate the proposed measuring system some physiological measurements were performed to investigate participants' immersion in experiment to simulate real-world situation as best as possible. Our hypotheses were: that because of unexpected occurrence of a hazardous situation significant change of physiological parameters should be detected; that in case of shorter RT the change of physiological parameters after occurrence of hazardous situation should be larger; that in case of larger absolute values of physiological parameters prior to occurrence of hazardous situation the RT should be shorter.

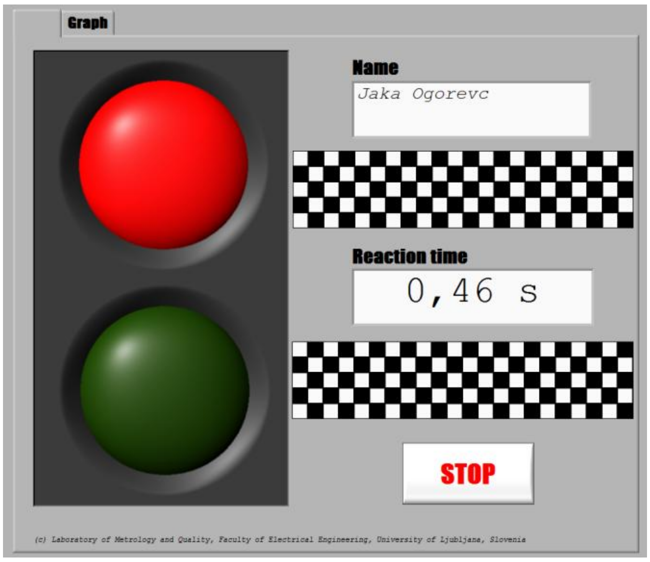

Figure 1: Front panel of the LabVIEW based virtual instrument for measuring driver reaction time. Subjects were instructed to step on the brake pedal when green light (lower light) of the semaphore changed to red (upper light) and an air horn sound was played. Measured reaction time was displayed. User friendly interface also contains graph of voltage signal measured by computer sound card.

2. EXPERIMENT

Previous studies concerning driver RT were examined as a simulation on virtual roads or in real-world on testing ground or actual roads. Most of reported studies were performed in virtual environment because of safety reason. Our research was carried out in virtual environment. Subjects were performing driving task by means of playing a rally computer game. To gain similar conditions as in actual driving the driving was realised by steering wheel and pedals gaming devices (by ACME, Lithuania).

Prior to execute driving task all subjects were acquainted with procedure of the experiment. Afterwards, electrodes for recording physiological parameters were mounted. First stage of driving task was a 3-minute test drive on the road in virtual environment (Colin McCrae Rally 2.0, by Codemasters, UK), which served for subjects to get accustomed to the wheel and pedals gaming devices. Final stage of driving task was driving on the same virtual road, where RT and physiological parameters were recorded. Subjects were instructed to step fully on the brake pedal when green light of the semaphore on additional display changed to red and an air horn sound was played (fig. 1). Change of light of the semaphore and air horn sound appeared randomly. After the final stage of driving task participants had to answer the question how much they expected an occurrence of the hazard. They were given four possible answers (1 – Totally unexpected, 2 – Unexpected, 3 – Expected, 4 – Totally expected). Road in virtual environment was the same for all subjects. Duration of experiment for one subject was about ten minutes. Figure 1 shows front panel of the LabVIEW (by National Instruments, USA) based virtual instrument for measuring driver RT.

2.1. Subjects

Participants in the experiment were twenty healthy men, aged between 20 and 50. All the participants had valid driver's licence and were active drivers. Participants took part in the experiment voluntarily.

2.2. Measuring system for recording driver reaction time

In real-world situation the driver RT interval begins with occurrence of a hazard and ends with response or action of driver. Responding action may be steering the wheel or braking. In our experiment subjects had to respond by fully stepping on the brake pedal of the gaming device as soon as possible after the light of the semaphore changed and air horn sound was played. Red light on the semaphore and air horn sound appeared randomly between second and third minute of the final stage of the driving task. Random appearance of hazard was programmed to reduce subjects' expectancy of hazard and to increase subjects' immersion into driving task. For this purpose a pushbutton switch was mounted under brake pedal. An electrical circuit consisted of voltage source, voltage divider and pushbutton switch was connected to the microphone input of the computer sound card.

Computer sound card was used for data acquisition. While stepping fully on the brake pedal, a pushbutton switch was pressed, which could be detected as a change of voltage signal recorded by computer sound card. Voltage signal was recorded with sample rate of 44,100 Hz with resolution of 16 bits. Data acquisition, signal processing, synchronization and user interface with random appearance of audio and video signals used as a hazard was performed by means of LabVIEW (by National Instruments, USA) software (fig. 1).

Schematics of acquisition part of driver RT measuring system is shown on figure 2.

2.3. Physiological measurements

During the driving task physiological parameters skin conductance (SC) and heart rate (HR) were measured. These physiological measurements were performed to investigate driver's expectancy and immersion as a part of evaluation of measuring system for recording reaction time and to investigate dependence between reaction time and values of physiological parameters as well as dependence between reaction time and changes of physiological parameters.

SC was recorded from bipolar leads on the distal phalanges of the index and middle finger of the left hand. Biopac GSR100C and Biopac MPI150 acquiring system were used for SC measurements with sampling frequency of 1 kHz. Signal processing was performed using AcqKnowledge 4.1 software (by Biopac, USA).

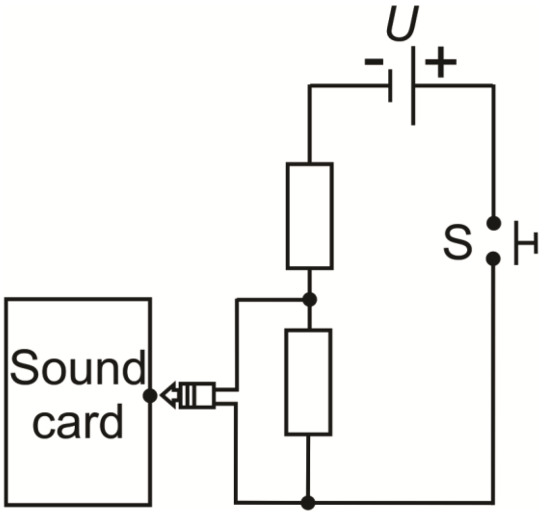

Figure 2: Scheme of driver reaction time measuring system. Driver's response was detected by computer sound card used as data acquisition system. An electrical circuit consisted of voltage source (battery), voltage divider and pushbutton switch (S) was connected to the microphone input of the computer sound card. While stepping on the brake pedal, pushbutton switch (S) was pressed and change of voltage signal recorded by computer sound card detected.

HR was determined by processing the signal recorded by Biopac ECG100C and Biopac MPI150 acquiring system at sampling frequency of 1 kHz. Leads of the electrocardiography (ECG) device were placed on both wrists and above right ankle. Signals were processed using AcqKnowledge 4.1 software (by Biopac, USA).

Figure 3 shows sensor set-up of the experiment with placement of the electrodes for recording physiological parameters SC and HR.

3. RESULTS

The main goal of our study was to evaluate proposed measuring system according to how realistic the presented experiment is in virtual environment. The most successful way to simulate real-world situation is to achieve subject's full immersion in a driving task and to reduce subject's expectancy of the occurrence of the hazard. To determine driver's immersion physiological parameters SC and HR were measured.

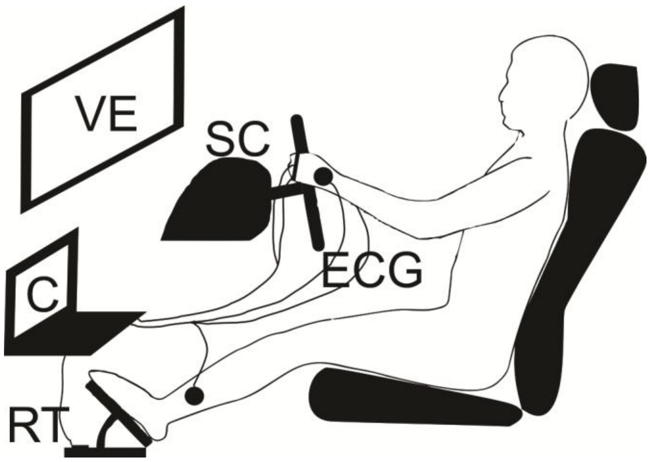

Figure 3: Sensor set-up of the experiment. Subjects were driving a car in virtual environment by means of playing a computer game (VE). Computer (C) was used for detecting driver reaction time (RT) and for recording physiological parameters skin conductance (SC) and heart rate (HR) by electrocardiography (ECG).

Mean value of measured driver RT was 0.81 seconds, which is similar to reported values of studies in real-world on public roads [4, 7]. Range of RT measurements was between 0.49 and 1.24 seconds. Physiological measurements show significant change of parameters skin conductance (ΔSC) and heart rate (ΔHR) after occurrence of hazard. Mean value for ΔSC was 0.44 microSiemens and for ΔHR 9.80 beats per minute. Mean values with respective standard deviations of measured variables are summarized in table 1. Figure 4 presents significant change of HR and SC after driver's braking action. Results of answering the question about hazard expectancy show that the occurrence of hazard was totally unexpected for 85 % of participants, unexpected for 5% and expected for 10 % of participants.

Table 1: Mean ± standard deviation values of measured variables reaction time (RT), change of skin conductance (ΔSC) and change of heart rate (ΔHR) (n = 20).

RT (s)	ΔSC (μS)	ΔHR (min^{-1})
0.81 ± 0.23	0.44 ± 0.26	9.80 ± 2.99

For investigating dependence between RT and physiological parameters Pearson (*r*) and Spearman (*ρ*) correlations were used. Results show correlation between RT and ΔHR (ρ = -0.425, p = 0.062), while there was no significant correlation between RT and ΔSC (ρ = -0.134, p = 0.573). Correlation was also between RT and value of skin conductance (SC_{prior}) prior to occurrence of hazardous situation (ρ = -0.412, p = 0.065). Smaller correlation with less significance was between RT and heart rate prior (HR_{prior}) to occurrence of hazardous situation (r = -0.326, p = 0.161).

From data acquisition point of view measuring system was not evaluated, while the sampling rate of 44,100 Hz turned out to be sufficient for our purpose. Measurement uncertainty for RT measurements was limited by resolution of display, which was 0.01 second as reported in most of reaction time studies [4, 5, 7].

Table 2: Pearson correlation (r) and Spearman correlation (ρ) with probabilities (p) of obtaining results (two-tailed significance) for correlations between reaction time (RT) and change of skin conductance (ΔSC) and heart rate (ΔHR) after driver's response and for correlations between reaction time (RT) and values of skin conductance (SC_{prior}) and heart rate (HR_{prior}) prior to occurrence of hazardous situation (n = 20).

correlation		ΔSC	ΔHR	SC_{prior}	HR_{prior}
RT	r	-0.099	-0.308	-0.382	0.326
	p	0.677	0.186	0.096	0.161
	ρ	-0.134	-0.425	-0.412	0.070
	p	0.573	0.062	0.065	0.770

4. CONCLUSION

Low-cost measuring system for recording driver RT was proposed, where common computer sound card was used for data acquisition. Such method was sufficient to detect response of a driver to hazardous situation. In comparison with data acquisition cards the computer sound card presents a much cheaper solution, especially because you can find it in every PC. It was very useful for research purpose in simulated environment because of easier synchronization of hazard occurrence and driver's response detection. Values of the measured reaction times were comparable to the RT values from previous studies. Evaluation of measuring system was performed by means of driver's immersion and driver's expectancy examination. Answers to the question about hazard expectancy and significant changes of recorded physiological parameters after occurrence of a hazardous situation and reaction of the driver proved that subjects were immersed in driving task and did not expect a hazard, which is similar to the real-world situations.

After occurrence of a hazard and after driver's reaction, there was significant change of physiological parameters SC and HR, which proves our first hypothesis. By calculating correlations, it turned out that subjects with larger ΔHR responded quicker, which was our second hypothesis, but it was proved only for ΔHR, while there was no dependence between RT and ΔSC. It was also proved that subjects with larger values SC_{prior} had lower RT, which was our third hypothesis. And again it was only proved for one physiological parameter, while the results of correlation between RT and HR_{prior} showed that drivers with larger HR_{prior} had larger values of RT.

Proposed measuring system for recording driver RT is ready to be tested in real-world situation on test ground and public roads. Further study in the field of traffic safety could investigate the effect of driver RT on the behaviour of the vehicle in various conditions. Such research would include measurements of RT and traffic parameters, introducing Event Data Recorder as a measuring device. For better traffic safety examination physiological measurements should be included to study effect of psychophysiological state of the driver on reactions to a various real-world situations. For further studies physiological parameters' sensor set-up should be as unobtrusive as possible. To achieve unobtrusiveness electrodes will be mounted on steering wheel or on seat. Some additional sensors could be employed, such as eye tracker to investigate how driver's point of gaze affects driver RT.

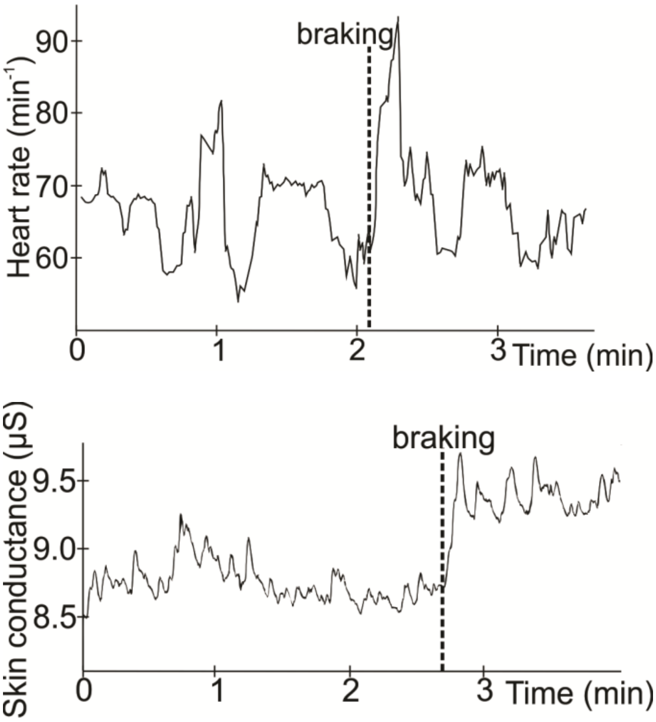

Figure 4: Recorded heart rate (top) and skin conductance (bottom) signal during the experiment. Significant change of heart rate and skin conductance signals were detected after driver's response. Braking action is marked by dashed line.

5. REFERENCES

[1] G. Jost, R. Allsop, M. Steriu, M. Popolizio, "2010 Road Safety Target Outcome: 100,000 fewer deaths since 2001", 5th Road Safety PIN Report, European Transport Safety Council, 2011

[2] G. Zovak, Ž. Šarić, I. Šiško, "Benefits of Event Data Recorder system on traffic safety in the Republic of Croatia", X. International Symposium Road accidents prevention, pp. 139-145, 2010.

[3] H. C. Gabler, C. E. Hampton, J. Hinch, "Crash Severity: A Comparison of Event Data Recorder Measurements with Accident Reconstruction Estimates", SAE Paper 2004-01-1194, 2004.

[4] R. E. Dewar, P. L. Olson, Human Factors in Traffic Safety. Lawyers & Judges Publishing Company Inc., Ch. 3, pp. 43-76, 2002.

[5] T. J. W. Spalding, J. Kiss, P. Kyberd, A. Turner-Smith, A. H. R. W. Simpson, "Driver reaction times after total knee replacement", The Journal of Bone and Joint Surgery, vol. 76-B, no. 5, pp. 754-756, September 1994.

[6] G. MacFlynn, E. A. Montgomery, G. W. Fenton, W. Rutherford,"Measurement of reaction time following minor head injury", Journal of Neurology, Neurosurgery, and Psychiatry, vol. 47, pp. 1326-1331, 1984.

[7] H. Makishita, K. Matsunaga, "Differences of drivers' reaction times according to age and mental workload", Accident Analysis and Prevention, vol. 40, pp. 567-575, November 2008.

[8] S. D. Baulk, L. A. Reyner, J. A. Horne, “Driver Sleepiness – Evaluation of Reaction Time Measurement as a Secondary Task”, Sleep, vol. 24, no. 6, pp. 695-698, 2001.
[9] L. M. Bergasa, J. Nuevo, M. A. Sotelo, R. Barea, M. E. Lopez, “Real-Time System for Monitoring Driver Vigilance”, IEEE Transactions on Intelligent Transportation Systems, vol. 7, no. 1, pp. 63-77, March 2006.
[10] J. A. Healey, R. W. Picard, “Detecting Stress During Real-World Driving Tasks Using Physiological Sensors”, IEEE Transactions on Intelligent Transportation Systems, vol. 6, no. 2, pp. 156-166, June 2005.
[11] W. C. Liang, J. Yuan, D. C. Sun, M. H. Lin, “Changes in Physiological Parameters Induced by Indoor Simulated Driving: Effect of Lower Body Exercise at Mid-Term Break”, Sensors, vol. 9, pp. 6913-6933, 2009.
[12] R. W. Backs, J. K. Lenneman, J. M. Wetzel, P. Green, “Cardiac Measures of Driver Workload during Simulated Driving with and without Visual Occlusion”, Human Factors, vol. 45, no. 4, pp. 525-538, 2003.
[13] D. de Waard, “The Measurement of Drivers’ Mental Workload”, PhD Thesis, University of Groningen, Traffic Research Centre VSC, 1996
[14] J. Engström, E. Johansson, J. Östlund, “Effects of visual and cognitive load in real and simulated motorway driving”, Transportation Research Part F: Psychology and Behaviour, vol. 8, no. 2, pp. 97-120, 2005.
[15] T. Vaa, “Cognition and emotion in driver behaviour models: Some critical viewpoints”, Proceedings of the 14th ICTCT Workshop, pp. 48-59, October 2001.