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Study of visual performance of drivers in laboratory conditions

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Due to the safety of road traffic, the study of visual performance of drivers in real life conditions is often very difficult or downright impossible. Vehicle driving simulators turn out to be excellent testing equipment in such situations. A static driving simulator of a medium class passenger vehicle for carrying out drivers' visual performance test in nighttime conditions was built in the laboratory of the Lighting Technology and Electroheat Department of the Poznan University of Technology. During the tests a necessity was identified to formulate recommendations and guidelines on measuring drivers' visual performance with the use of a car driving simulator.

The article presents the examination procedure and the results of research aiming to determine the criteria and conditions of carrying out examinations of drivers' visual performance with the use of a car driving simulator.

KEYWORDS: visual performance, electronic billboards, driving simulator

1. Criteria and methods of evaluation of drivers visual performance

Visual performance is the performance of human optic system measured with, for example, the speed and accuracy of performing a visual task [1]. The level of visual performance determines one's ability to spot subtle changes in the field of vision, and for drivers it additionally affects the distance from which object can be spotted in the road. Visual performance depends on a number of personal factors, such as: sharpness of vision, age, level of adaptation of sight organ to lighting conditions, wellness, motivation, general health and physical conditions for performing the visual task: the angular size of the smallest details of the visual task, contrast (of luminance and color) against the background, time allocated for observing the object and lighting conditions.

The drivers' visual performance may be evaluated on the basis of: the distance of spotting, probability and ability to spot objects, speed of reaction or spotting relative movement, e.g. spotting changes in the angular dimensions of the rear of the car preceding the driver's car. The time criterion is most often used for laboratory tests of drivers' visual performance. The evaluation of visual performance is done on the basis of simple or complex time of reaction to light and sound signals. A person participating in the test of simple reaction time is required to react in the same way, e.g. by pressing the pedal of the measuring device for each type of stimulus. In the case of complex reaction time, the examined person is required to react to various stimuli in different ways, e.g. by stepping on the measurement's device pedal with their right leg for red light or by pressing a hand-held button with their right hand for sound signal.

Figure 1 shows a model of a device for testing simple and complex reaction time.

Fig. 1. A model of a device for measuring simple and complex reaction time [2]

Driving simulators are more sophisticated testing tools for evaluating drivers' visual performance on the basis of, among else, the reaction time in various road situations. Medium class simulators are used for research purposes most often. Such simulators feature: a large screen, very often with horizontal viewing angle of 180°, which serves to project computer generated image, a realistic passenger compartment with steering mechanism, a driving control system and a system for recording measured values. Medium class simulators include both static driving simulators, whose passenger compartment is fixed, and dynamic simulators with a moving passenger compartment [3].

Fig. 2 shows an example of a static and a dynamic medium class simulator.

Fig. 2. A model of a static driving simulator (left) [4] and a dynamic driving simulator (right) [5]

2. Car driving simulator built in the laboratory of the Lighting Technology and Electroheat Department of the Poznan University of Technology

A static car driving simulator was built during the research works related to the Ministry of Science and Higher Education grant no. N N510 666140, titled "The Examination of Impact of LED Billboards on Drivers' Visual Performance in Road Traffic" [6], performed at the Lighting Technology and Electroheat Department of the Poznan University of Technology. According to the classification found in literature [3], the simulator may belong to medium class. The simulator consists of the following basic elements:

- a model of a passenger's car cabin with a classic dashboard including buttons, radio, a working ventilation system and a working speedometer indicating the current speed, a gearbox lever, accelerator and brake pedals. Additionally, a source of interfering glare, from road lighting system luminaires, was installed in the cabin. The external appearance of the cabin and its position in the laboratory as well as the interior view are presented in Fig. 3,
- the image projection is made from a screen, 3.90 m x 2.90 m, and two multimedia projectors, the main and auxiliary. The main projector displays the road between the angle 26.7º to the left and 25.8º to the right of the observer's optical axis. The auxiliary projector is used to complement the image under the LED billboard, an integral part of the laboratory test bed, and to facilitate taking right turns to drivers,
- the luminance in the driver's peripheral vision was simulated by illuminating the side walls of the laboratory with LED lines covered with dispersing, frosted glass panes and grey, translucent curtains. The use and control of LEDs allowed to obtain a constant value of average luminance, similar to the luminance of elevations of buildings in the vicinity of the road and changing luminance simulating the movement of vehicle in the environment (windows, shop windows),
- a control station, consisting of two networked PCs. The main PC is responsible for controlling the displayed road simulation and gathering data about the course of the experiment. The secondary PC controls the display of the image in the LED screen.

Fig. 4 shows the external appearance of the driving simulator. Examples of simulations displayed in the screen are presented in Fig. 5. The detailed description of the driving simulator and the method of calibration is described in literature [7, 8, 9].

The car driving simulator built in the Lighting Technology and Electroheat Department is the first simulator in Poland used for testing the impact of lighting conditions in the road after nightfall on drivers' visual performance.

Fig 3. Left: the external appearance of the cabin; right: the interior view

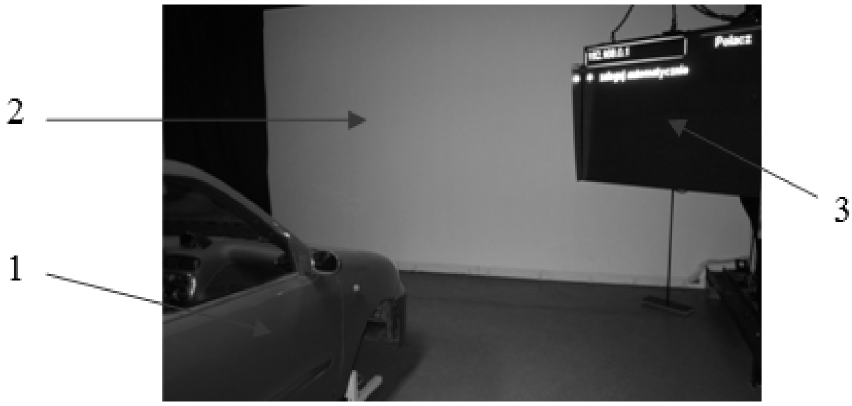

Fig. 4. View of the car simulator and the LED billboard module: 1 – view of a section of the driver's compartment, 2 – screen displaying road simulation, 3 – module of real LED billboard

Fig. 5. Examples of simulations displayed during driving

The methodology of tests on the drivers' visual performance with the use of a car driving simulator has not been described in literature, so it is necessary to establish conditions for carrying out such tests. Consequently, the laboratory of the Lighting Technology and Electroheat Department of the Poznan University of Technology has carried out pilot study aiming to determine the criteria and conditions of making tests on drivers' visual performance with the use of a car driving simulator.

3. Study of visual performance of drivers with the use of a driving simulator

3.1. Description of the test procedure

The visual performance was evaluated in the constructed test bed on the basis of the observer's reaction time to simulated road incidents. A road incident meant the appearance of obstacles in the road in front of the observer with no illuminated billboards in the road's vicinity, obstacles near illuminated billboards with specified luminance and illuminated billboards employed to mislead the observer. The reaction time of the driver was measured between the appearance of the obstacle on the road to the driver's reaction to this event. Pressing the brake pedal or a quick movement of the steering wheel to avoid the obstacle were considered reactions. The control system records reaction times and types of reaction, e.g. braking, turning the steering wheel, collision with an obstacle or the surroundings. The observer's reaction to all road incidents was recorded with accuracy of 1 ms.

Various types of obstacles were used during the study: a pedestrian, a dog, a ball on the ground, squares of various luminance: 0.7, 1.2 and 3 cd/m^2 (the road's average luminance was 1.5 cd/m^2). Fig. 6 shows examples of obstacles.

In order to unequivocally establish the observer's reaction time to the appearance of the obstacle on the road, it was assumed that the obstacle appears instantaneously, just like in previous studies [6, 10].

Six routes were prepared for the purpose of the study - one route (the learning route) where the test participants learned the operation of the simulator, the types of road incidents, the look of obstacles and their method of appearance on the road, and five routes where various criteria of making the measurements were evaluated. The routes were designed to allow for analysis of the results considering the type of obstacle, the location of obstacle along the route (a straight section of the road, a curve), the applied scenario of the order of obstacles and billboards along the route (only obstacles intermingled with illuminated billboards or obstacles with billboards in the beginning and the end of the route, the same obstacles in the middle part of the route without billboards), the complexity of the task (simple task - observing the road and more complicated tasks - observing the roadside and searching for particular objects or observing and memorizing the advertising content), the method of enlarging the image of the billboard for simulating the process of observer approaching the object (quickly or slowly), the type of route (the route only with obstacles, but without illuminated billboards, or the route with not only obstacles, but also with obstacles appearing in the road while the LED billboard is illuminated).

In order to eliminate the impact of the design of the route itself on the observer's reaction time, the routes were designed to have the same number of turns, intersections and straight sections projected exactly in the same order, but with different scenery (different appearance of buildings).

In the beginning, each observer was informed about the objective and method of conducting the test and about the possibility of resigning from the study at any time. Then, learning how to drive in the simulator started (the learning route) and driving on the basic routes commenced. In order to eliminate the impact of order of the routes on results, all observers were divided into groups assigned various orders of taking routes during the study.

After the completion of the part of study related to driving in the simulator, the observers' sight contrast sensitivity was tested in mesopic conditions and their sharpness of vision was tested in photopic conditions. Then, the participants filled in personal forms with basic demographic data, a survey on the performed tests; a vision-motion coordination study was also carried out with the use of cross-validation.

Fig. 6. Models of obstacles appearing on the road during simulation

3.2. Results and analysis of laboratory tests

39 volunteers, aged 20 - 50, participated in the pilot study; the average age was 27 years. All test subjects were holders of at least category B driving licenses. Most of participants owned their driving license for no longer than 10 years. One person was a professional driver. Six of the tested persons failed to complete a full cycle of tests. The observers were diagnosed with symptoms of simulator sickness. The description of typical symptoms of simulator sickness are covered in literature [3, 11, 12].

Tables 3.1 – 3.3. includes results of investigations.

Table 3.1. Average reaction times of observers $t_{śr}$ in [ms] to various types of obstacles in the route, without active LED billboards, with specified locations in the road and reaction times listed from the shortest one to the longest one

Order of appearance of obstacles in the route	Obstacle type	Location of obstacle in the route	Reaction time $t_{śr}$ [ms]	Reaction time order
1	Pedestrian	Straight section	769	8
2	Square whose L = 3 cd/m^2	Straight section	800	10
3	Ball	Curve	695	3
4	Square whose L = 0.7 cd/m^2	Straight section	780	9
5	Square whose L = 0.7 cd/m^2	Curve	713	4
6	Dog	Straight section	753	6
7	Pedestrian	Curve	713	4
8	Square whose L = 1.2 cd/m^2	Straight section	762	7
9	Ball	Straight section	764	11
10	Square whose L = 3 cd/m^2	Curve	645	1
11	Square whose L = 1.2 cd/m^2	Curve	744	5
12	Dog	Curve	665	2

Table 3.2. Comparison of reaction times $t_{pśr}$ in [ms] of observers for obstacles appearing only in places without active billboards, regardless of the type of the route

No.	Applied distinction criteria		Average reaction time just for obstacles $t_{pśr}$ [ms]
1	Obstacle type on route without active billboards	Pedestrian	741
		Dog	709
		Ball	780
		Square whose L = 3 cd/m^2	723
		Square whose L = 1.2 cd/m^2	753
		Square whose L = 0.7 cd/m^2	747
2	Obstacle type on route where billboards are active too	Pedestrian	789
		Dog	769
		Ball	778
3	Type of route	Route only with obstacles, without billboards	742
		Route with active billboards	779
4	Location of obstacle in the route - route without obstacles	Straight section	788
		Curve	702

Table 3.3. Comparison of reaction times of observers for obstacles appearing in the road where active billboards were located $t_{rśr}$ in [ms] and without billboards $t_{pśr}$ in [ms] for the analyzed distinction criteria

No.	Applied distinction criteria		Average reaction time just for obstacles $t_{pśr}$ [ms]	Average reaction time for obstacles appearing when the billboard is illuminated $t_{rśr}$ [ms]
1	Applied scenario of events	Obstacles with billboards in the beginning and end of the route; only obstacles, without billboards, in the middle section of the route	779	864
		Obstacles without billboards intermingled with illuminated billboards	761	807
2	Type of visual task	Observation of road	809	861
		Observation of vicinity	856	879
		Observation of billboards	827	1007
3	Experience of observers in driving in the simulator	No experience	793	888
		Already participated in a study at least once	725	807
4	Method of enlarging the image of the billboard	Slowly	770	861
		Quickly	774	836

The author believes the following conclusions can be drawn from the conducted pilot study:

- The observers exhibited shorter reaction times to obstacles emerging when there was no active billboard on the shoulder of the road for trips during which only obstacles would appear, than if obstacles with active billboards (mixed road events) were encountered in the route.
- When travelling along a route where only obstacles were present, without active billboards, the shortest reaction time was achieved for the dog, and the longest time for the ball. The maximal difference between times was 71 ms. For the route along which only obstacles appeared and where obstacles and illuminated billboards appeared, the shortest reaction time was measured for the dog, and the longest one for the pedestrian, but the type of obstacle affected reaction times to a lesser degree. The difference between the shortest and the longest time was 20 ms.
- For squares whose appearance in the road lane was simulated only for the route without illuminated billboards, the shortest reaction time was

achieved for the square with positive contrast in relation to the background. This may be explained by the human eye's higher contrast sensitivity within positive contrast range, than for negative contrasts. In the case of the lowest contrast of the square against the background, the results confirmed that observers had the worst visual performance.

- Shorter reaction times of the observers were achieved for each case where the obstacle was situated in the road's curve. The reason behind this may be the drivers' better concentration on the road's curve or lower speed of driving.
- The applied scenario of obstacles appearing in the road affected the average reaction times. Longer reaction times were achieved when road events were mixed, the appearance of obstacles without active billboards was intermingled with obstacles with illuminated billboards.
- The observers' reaction times to obstacles appearing when a billboard was illuminated were influenced by the speed of enlarging of the billboard, for the purposes of simulating the car approaching the billboard. The longer time of enlarging of the billboard resulted in longer reaction times of the test participants. This may be explained by the fact that glare was affecting the sight organ for a longer time, resulting in lower visual performance of the observers. The conducted test did not confirm the hypothesis formulated during the research [6], concerning the anticipation of the moment of appearance of the obstacle in the road on the moment of beginning to display the billboard on the LED screen. According to this hypothesis, the longer time of displaying advertising content should result in focusing the attention of the observers on the road and making them await obstacles to appear, thus resulting in shorter reaction times. The shortening of the time of expanding the billboard to the full size of the LED screen should come as a surprise for the observers and consequently their reaction times should be longer. Very similar results were achieved when only obstacles would appear on the road - this may be a testament to the high repeatability of results of measurement done in similar conditions.
- A fact was confirmed that the type of the task entrusted to the observers affects the obtained results to a large degree. A harder visual task, consisting in observing the route and the road's immediate vicinity, resulted in extended reaction time to obstacles appearing in the road. In the case of an additional visual task, which was to observe the advertising content, the longest reaction times to obstacles appearing in the road while a billboard was illuminated were obtained. This was caused by the glare originating from high luminance of the billboard's surface and longer time of regaining visual performance by the examined persons.
- The experience of the study participants in driving a car simulator is important in terms of the obtained results of measurements. The observers

who already participated in test knew how to carry out the test procedure, had more confidence in operating the simulator, were accustomed to the way of appearance of obstacles in the road and knew what to focus on - hence their lower reaction times.

- On the basis of answers to questions from the survey filled in by test participants after the study, we can conclude that:
- For most of the observers the brightness of billboards displayed during the trips interfered with the correct execution of the visual task; also, the brightness of the surface was as arduous as the contrast of the displayed colors. Still, most of the test participants did not pay much attention to the content of the displayed billboard.
- Most of the test participants anticipated that obstacles would appear in the road in characteristic situations. Most often, they expected obstacles to appear in the road when the billboard was illuminated, especially when its brightness was higher than in other situations. The fact stems from the knowledge of the purpose of the experiment and memorizing specific situations.
- Most of the tested persons controlled driving speed, which may indicate that they participated in the study consciously and adhered to the general recommendations of the experiment administrator.

On the basis of the conducted pilot study the following recommendations can be formulated concerning the methodology of conducting tests of the drivers' visual performance with the use of a car driving simulator:

1. The study of visual performance of drivers with the use of a driving simulator should be preceded by a practical course in the operation of a driving simulator. Preferably, such preparations should be held on a different date than the test itself. A trial trip, serving as a way to remind how to operate the simulator, should be completed before the study itself.
2. Due to the impact of previous participation of observers in the same type of test on the results of measurements, the test of visual performance should be done on a group of observers with the same experience in such studies.
3. In order to avoid the impact of the order of routes on the results of measurements, a given group of observers should be divided into smaller sub-groups, tasked to take the routes in various orders.
4. During the study, different types of obstacles, in varying numbers, should be used along the route, to ensure the type of the obstacle has no significant impact on the obtained measurements.
5. To avoid the impact of anticipating the location of an obstacle on the road on measurement results, the obstacles should be placed on the route's straight sections. Also, due to the possibility of anticipation of the appearance of an obstacle on the road in a characteristic situation, the luminance of billboards used to mislead the driver should be identical to the

luminance of billboards active when an obstacle appears on the road. Additionally, the number of active billboards serving to mislead the driver's vigilance should be higher than the number of billboards active when an obstacle appears on the road.

6. To avoid the effect of surprise coming from the appearance of an obstacle on the road in a situation where there is no active LED screen on the shoulder of the road, obstacles without active billboards and obstacles with active billboards should not be placed on the same route. Separate routes should be used for each type of event.
7. Due to the fatigue and weariness of the test participants, the study of visual performance with the use of a driving simulator should not last longer than 30 minutes (this applies to the time spent on actually driving the simulator).
8. The driving simulator test should be taken by well rested persons in good mental condition.

3. Summary

The use of a driving simulator in drivers' visual performance studies allows to approximate the external conditions to real conditions and allows to recreate the effect of driving a vehicle in a city. Conducting the experiments in the simulator allows to eliminate numerous additional factors which may have an impact on the final result of the experiment that are found in real road conditions i.e. unpredictable behavior of other road users, different traffic loads or weather conditions. By using a sudden intrusion of an obstacle into the road, it is also possible to test the driver's real reaction times to obstacles appearing on the road. The use of such solutions makes it possible to eliminate the time related to making a decision on making any maneuver. It would be impossible to create such a situation in real conditions. The most important downside of laboratory experiments is conducting the measurements in conditions that are an approximation of real conditions i.e. the sensation of driving a car as well as the visual task - in reality, while driving through a city, the driver is rarely focused solely on the lane, and especially on spotting obstacles appearing on the road. Therefore, correct calibration of the laboratory test bed and correct preparation of the study are of significant importance.

The related literature gives no principles according to which drivers' visual performance studies should be held with the use of car driving simulators. The obtained results and the analysis showed a major impact of numerous factors on the obtained measurements. Hence the need to carry out more research work to determine conditions, principles and criteria of conducting tests of drivers' visual performance with the use of car driving simulators.

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