Pilot study of visual performance of drivers with the use of a driving simulator

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In city traffic, the driver's visual tasks are not just limited to observing the road. Visual information from the driver's immediate vicinity is also important for effective and safe driving. There may be objects of various luminance in the driver's field of vision, such as shop windows, conventional billboards and LED billboards. Excessive luminance of surfaces in the road's vicinity, especially at night, may lead to reduced visual performance of drivers. Special hazard comes from LED billboards that, apart from very high luminance levels, also feature large surfaces, high luminance contrast and colour contrast, and whose content (animated or video) is very dynamic. The article presents results of pilot study completed with the use of a driving simulator, analyses the obtained results and discusses the applied test method.

KEYWORDS: luminance distributions in the field of driver's vision, digital billboards, road safety

1. Introduction

1.1. Driver's visual tasks

To efficiently drive a vehicle, especially in city traffic, its driver needs plenty of visual information about the surroundings. The driver must be able to distinguish the outline of the road, pedestrian crossings, sidewalks, road traffic signs and lights, orientation points, the presence of other traffic participants, their location, speed and direction of movement. Moreover, all information must be received in the right moment, so that the brain can identify and process it and subsequently make a correct decision. Figure 1 presents an example of a road situation in municipal traffic, where the driver is to perform a visual task and only has a very limited time to make a decision.

The spotting of an object related to the process of driving results in driver's activities consisting in either just its observation or its observation followed by making a maneuver. Hence, three levels of performing the visual task should be applied to its investigation: the position level, the situational level and the navigational level [1].

The position level applies to maintaining the desired position and the correct course in a traffic lane. The situational level is connected to making maneuvers in the road and maintaining and adjusting the vehicle's speed. The navigational level is related to orientation in the surroundings and selection of the route. Each of the above levels requires special information from the visual analysis of the road and its vicinity, that allows correct execution of a specific task.

Fig. 1. Example of a typical road situation in municipal traffic

In order to maintain the right position in a traffic lane it is important to visually recognize changes in the roadway such as traffic lane lines, curbs, shoulders, etc. and to spot the relative movement of the surroundings. During daytime, this part of visual information is received automatically thanks to peripheral vision and does not require increased attention from the driver. Once dusk sets in, especially if only the vehicle's headlights are used, the field of vision is greatly limited and so is the volume of visual information that reaches the driver. In such conditions the driver's attention is generally focused only on the correct position in the lane and the driver's visual tasks are, out of necessity, limited to spotting changes in the road's vicinity. If, apart from the vehicle's headlights, the road's fixed lighting is operating, providing more information about its surroundings, additional, more complex driving related activities at the situational and navigational level can be performed. Visual tasks at the situational level are related to assessing the current position and speed in relation to other traffic participants. It is necessary to have visual information indicating the need to adjust the speed, driving direction or position in the road. The driver must recognize typical features of a given situation, relying, to a large extent, on previously gathered experience and knowledge and, if necessary, must make the right maneuver. Visual tasks at the navigational level are connected with finding and processing information from the direct or non-direct vicinity of the road - simple and quick recognition of characteristic points in the surroundings, traffic signs, information boards, street names and parcel numbers, etc., required to make decisions on the choice of route. In this situation, the illumination of areas adjacent to the road is important, since the driver's vision is also directed outside the road. The completion of a visual task at the navigational level is only possible in favourable vision conditions at the position and situational levels.

An efficient and safety implementation of these tasks depends on: the lighting conditions of the road and its surroundings, occur in the driver's field of vision glare sources, distracting and eye-catching sources eg outdoor electronic billboards (LED billboards), geometric and photometric properties of the obstacles, the conditions of observation and visual performance of drivers.

1.2. Hazards caused by outdoor LED billboards

Outdoor advertising billboards have become inherent elements of many Polish towns and cities. The lack of legal regulations specifying possible locations for outdoor billboards means that in every town or city, there are places where many various advertising billboards are located in limited area. This creates a visual chaos during the day; moreover, when the night falls, drivers have to deal with surfaces of various levels of brightness appearing in their field of view.

Fig. 2 shows an example of overcrowding of billboards in a very small area.

Fig. 2. An example of overcrowding of billboards in a very small area. View during the day and at night

Fig. 3. An example of an LED billboard located right in the driver's line of sight, also being a false background for traffic lights

The development of LED technology has brought billboards made up of light emitting diodes into our towns and cities. Such advertisement carriers are both large and very bright, in fact, much brighter than traditional billboards; they also display highly dynamic images (videos, animated content). By displaying content that resembles road traffics signs, such billboards often mislead the drivers. They are usually positioned to attract the attention of as many drivers as possible, e.g. in intersections, roundabouts, main traffic routes in towns and cities. It also happens that such billboards are placed directly in the driver's line of sight or act as false background for traffic lights. Fig. 3 shows an example of location of a billboard in the line of sight, also acting as background for traffic lights.

The threat to road traffic safety posed by LED billboards is discussed in finer details in literature [2, 3, 4].

2. Pilot of study of impact of LED billboards on visual performance of drivers

2.1. Description of laboratory test bed

Within a research project financed by the Ministry of Science and Higher Education Research, works are currently under way in the Institute of Electrical Engineering and Electronics of the Poznań University of Technology, to determine requirements for electronic billboards installed in the close vicinity of roads. A laboratory test bed for conducting subjective tests was built for examining the impact of LED billboards on visual performance of drivers. The laboratory test bed consists of a fixed passenger car simulator, a road simulator, a real-life electronic billboard module and a control device.

Fig. 4 shows the road simulator, the illuminated LED billboard and the vehicle simulator.

Fig. 4. The road simulator on the left, the working LED billboard and the vehicle simulator on the right

The detailed description of components of the test bed is presented in literature [5, 6, 7].

Striving to recreate in the test bed, in the most faithful manner, the visual conditions present in the actual field of view of drivers, examination of distribution of luminance in selected roads and in their vicinity was conducted. The streets selected for research were divided into three categories. The first category covered streets with densely developed buildings, the second category included streets which featured only a few buildings, usually located at a distance from the road edge, and the third category comprised city streets of significant importance to vehicle traffic, without buildings.

Fig. 5 shows an example of distribution of illumination present in the driver's field of vision.

Fig. 5. Photo of the road with prevailing high-density housing (on the left) and luminance distribution on the road and in its direct vicinity (on the right)

Ranges of average luminances $\Delta L_{śr}$ of surfaces surrounding the road were determined on the basis of the measured distributions of luminance. The detailed results of measurements were presented and discussed in literature [6, 7, 11].

In the subsequent stage of research works, average values of luminances of specific surfaces in the displayed road scene were reconstructed in the test bed, e.g. the luminance of the roadway, pavement, buildings, illuminated windows, shop windows, lighting posts, paint stripes on the roadway, the road's surroundings without buildings, horizon.

An example of distribution of luminance in the displayed road and in its direct vicinity is presented in Fig. 6.

Fig. 6. Distribution of luminance in the displayed section of the road and in its direct vicinity

2.2. Preparation of the experiment

The planned experiment concerned the evaluation of the test bed for purposes of examining the impact of LED billboards on the drivers' visual performance after nightfall. The driver's visual performance was evaluated on the basis of the observer's reaction time (braking, turning) to simulated road incidents. Six driving routes taking the driver through a virtual town were created for purposes of the project - two test routes and four basic routes. The route creator was designed so as to make it possible to create streets and intersections with various types of buildings and to simulate various road incidents, e.g. a vehicle braking in front of the observer, a pedestrian crossing, different types of obstacles, such as a man standing still, a jumping ball (a ball in motion), a cuboidal object.
Fig.7 shows an example of how a route is generated.

Fig. 7. An example of creating a town map in the route creator

The first test route is taken to learn the vehicle simulator's driving characteristics and the manner of travelling around the virtual town. The second test route includes obstacles emerging in the road and other vehicles present in the road.

The proper experiment consisted of the tested person navigating four routes, along which obstacles were placed in the traffic lane, both in places where working billboards were present and were such billboards were not located. The working billboards present in each of the four routes had other luminance values: 150 cd/m^2, 300 cd/m^2, 600 cd/m^2 and 1200 cd/m^2. Additionally, advertising billboards serving to deceive the driver's vigilance were present along each route. The illumination of these billboards was not taken into account when evaluating the driver's visual performance at all.

In order to maintain identical conditions for evaluating the impact of luminance of billboards on the tested person'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). The locations of LED billboards, places of appearance of obstacles and their type were exactly the same in each of the four routes. As it was necessary to definitively determine the time of occurrence of a potentially dangerous incident on the road, and by that determine the time of reaction to an incident and eliminate the time related to taking the decision by the driver, the appearance of the obstacle in the driving lane was decided to take place instantaneously, in close proximity in front of the vehicle. It was decided that such a situation may take place in real life traffic conditions when the driver spends a long time observing objects outside the traffic lane, and then looks at the lane onto which an obstacle has just moved.

Fig. 8. Appearance of obstacles without working electronic billboard (on the left) and with working electronic billboard (on the right)

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12/13/2012 4:39:09 PM
Nazwa pliku z wynikami:   01_trasa_1
Nazwa pliku trasy:        Trasa 1.txt
Nazwa ustawien:           1_5cd_m2.txt
Nazwa obserwatora:        01
pis trasy:                trasa 1_8

0:21:021   Skrecenie kierownicy przekroczylo prog
0:33:483   LED ON
0:33:651   Skrecenie kierownicy przekroczylo prog
0:50:420   LED OFF
0:59:083   Skrecenie kierownicy przekroczylo prog
1:09:413   Przeszkoda Pieszy w miejscu
1:10:595   Skrecenie kierownicy przekroczylo prog
1:11:312   Skrecenie kierownicy przekroczylo prog
1:17:523   Hamowanie przekroczylo prog
1:28:831   Skrecenie kierownicy przekroczylo prog
1:38:871   Hamowanie pojazdu z przodu
1:44:450   Hamowanie przekroczylo prog
1:50:829   Skrecenie kierownicy przekroczylo prog
1:59:757   Hamowanie przekroczylo prog
2:00:706   LED ON
2:00:923   Skrecenie kierownicy przekroczylo prog
2:03:769   Skrecenie kierownicy przekroczylo prog
2:14:813   Przeszkoda Pilka na ziemi
2:15:946   Skrecenie kierownicy przekroczylo prog
2:16:845   Skrecenie kierownicy przekroczylo prog
2:17:145   LED OFF
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Fig. 9. An example of a record in the event log

Along each route the appearance of 3 obstacles without working billboards in the road's vicinity was simulated, the appearance of 6 obstacles with LED billboards at specified luminance and the appearance of 3 illuminated billboards whose purpose was to deceive the observer. Altogether, for each observer, along the four basic routes, 12 reaction times of the observer to the appearance of an obstacle without an illuminated billboard in the road's vicinity was determined, 6 reaction times to the appearance of an obstacle with an illuminated billboard at specific luminance and 12 times when only the billboard was illuminated. Obstacles in the road included a standing pedestrian (designated as Pedestrian), a ball on the street (designated as Ball on the ground) and a jumping ball (designated as Ball in one place). Fig 8. shows the obstacles without working electronic billboard and with working electronic billboard.

The observer's reaction times to all road incidents were recorded with accuracy of 1 ms and stored, with the type of reaction (braking, taking a turn) in the so-called event log. Fig. 9. shows an example of a record in the event log.

2.3. Description of the test procedure

The task of the test participants was to navigate, without collisions and observing traffic regulations, through a virtual town, every time in the direction of Poznań. In the beginning of the test, each observer was informed about the objective and method of conducting the test and its total duration. The time spent on the introduction to the test was also used to allow the observers' sight to partially adapt to mesopic vision conditions. All test subjects were informed about the possibility of resigning from the test at any point.

Each time, following the introductory part, the test participant took the two test routes, followed by the four basic routes. Between the second and third route a break took place, during which the test participants were subject to a psychological test. The purpose of the test was to obtain information on the test participant's general psychological condition. Due to the necessity to adapt to low luminance levels, the psychological test was conducted with the main lights switched off.

Upon completion of the measurement stage in the vehicle simulator (after completion of the four basic routes), the observers filled in a personal questionnaire with basic demographic information, a survey on LED billboards located in Poznań and they also answered questions related to the course of the experiment. Subsequently, the test participants underwent psychomotor coordination examination in a cross visual-motor tester and visual acuity examination in photopic conditions. The aim of the psychomotor examination was to evaluate the test participants' psychomotor abilities, while the visual acuity test aimed to eliminate any possible, significant visual acuity defects.

2.4. Results and analysis of laboratory tests

7 volunteers, aged 29 – 44, participated in the pilot study. Two of them failed to complete the full cycle of tests. These observers were diagnosed with symptoms of

simulator sickness. The description of typical symptoms of simulator sickness are covered in literature [8, 9, 10]. The test participants have had a B category driving license for at least 10 years. Neither person was a professional driver. All observers declared good or very good skills in driving passenger vehicles.

The observers were assigned numbers from 1 to 7. The measurement results are presented in tables 2.1 – 2.3.

Table 2.1. List of average reaction times t_{rav} of observers to appearance of an obstacle in the road

Observer no.	Averaged reaction times of observers to obstacles, depending on the road surroundings in the place of appearance of the obstacle t_{rav} [ms]					
	Test drive	Without billboards	Billboard 150 cd/m^2	Billboard 300 cd/m^2	Billboard 600 cd/m^2	Billboard 1200 cd/m^2
1	1009	1054	1036	1247	975	1194
2	900	731	724	736	728	758
4	1044	783	797	761	692	872
5	1011	906	823	794	766	819
7	900	729	755	812	775	686
Average	973	841	827	870	787	866
Standard deviation	68	139	123	213	110	196

Table 2.2. List of averaged reaction times T_{rav} of all observers, depending on the type of obstacle appearing in the road

Type of obstacle	Averaged reaction times of observers to obstacles, depending on the road surroundings in the place of appearance of the obstacle T_{rav} [ms]				
	Without billboards	Billboard 150 cd/m^2	Billboard 300 cd/m^2	Billboard 600 cd/m^2	Billboard 1200 cd/m^2
Pedestrian	831	827	830	762	818
Ball on the ground	807	781	833	774	799
Ball in motion	884	873	947	858	980

Table 2.3. Statistics concerning the observance of road traffic regulations

Observer no.	Average driving time t [s]	Red lights crossed	Permissible speed exceeded	Collisions with obstacles
1	519	3	17	7
2	772	1	5	3
4	762	0	4	7
5	773	1	9	9
7	678	1	6	1

Table 2.1 shows calculated average reaction times t_{rav} in [ms] of the observers to obstacles appearing in the road during the second test drive and the two basic routes. Table 2.2 shows reaction times T_{rav} in [ms] averaged from the times of all observers, depending on the type of obstacle appearing in the road. Table 2.3 shows the statistics of the average time of driving, observance of road traffic regulations and the total number of collisions with obstacles in basic routes.

The obtained results allowed us to formulate the following conclusions:

- The accuracy and commitment of observers had much impact on their reaction times to appearance of obstacles in the road. Observer no. 1 covered all basic routes in shortest time, but committed the most mistakes while driving and had the longest reaction times.
- The learning effect could be observed among the observers, with regard to driving in the simulator. The times of reaction of all observers to obstacles appearing in the test route were longer than when basic routes were navigated. The learning effect could also be observed when driving along basic routes. In almost all cases, driving along subsequent routes took less time.
- All observers showed the effect of attempting to anticipate an incident when they spotted the beginning of projection of advertising content on an LED billboard. After the first obstacle appeared in the road, while an LED billboard was working, the observers would slow down for other such situation, waiting for a similar incident to occur. This phenomenon was noticeable to such an extent that most of the observers were surprised (exhibited significantly longer reaction time or very often colliding with an obstacle) with the appearance of the last obstacle in the road, without a billboard in the road's vicinity.
- Regardless of the route or whether an obstacle would appear in the road at an working LED billboard or without it, a significantly longer reaction time of observers to an obstacle in the form of a jumping ball could be observed. This may be explained by the obstacle's different character, in comparison to the two other obstacles.
- The effect of fatigue and weariness caused by driving in the simulator could be observed with two observers (no. 4 and 5). During the last drive, the number of mistakes consisting in breaching the road traffic regulations increased.
- Interviews with test participants done after the experiment, concerning their subjective audio and visual impressions related to the driving simulator and the displayed road simulation brought to attentions several issues, among these the necessity to provide more realistic engine sound, use of more legible signs indicating the direction of driving, change the convergence point in the displayed road perspective, improve the realism of turns at intersections.
- During the pilot study it was concluded that it is necessary to introduce changes to the method of controlling the image displayed in the LED screen, to eliminate errors occurring during the road simulation, e.g. additional vehicles

running through pedestrians who unexpectedly stepped onto the road from the sidewalk, collisions between additional vehicles in the intersections, making it impossible to continue the simulation.

- Only a small group of observers participated in the pilot study, so at this stage it was impossible to formulate general conclusions on the impact of LED billboards in visual performance.

3. Summary

The pilot study of the impact of LED billboards on the visual performance of drivers was conducted in order to verify the applied testing methodology. During the analysis of test results and on the basis of observations made during the experiment, it was concluded that certain modifications and changes had to be introduced to the road simulator, the control of content displayed in the LED billboard, the vehicle simulator and the test procedure itself.

- The changes in the road simulator should cover the introduction of a dog as another obstacle, lowering the horizon in the displayed image, the introduction of more detailed control over the behaviour of other traffic participants and pedestrians, the introduction of pedestrian crossings before T-type intersections, with a pedestrian walking on such crossings, improving the legibility of direction signs, the introduction of changes to the roads' surroundings, such as changing distances between lamp posts, changing luminance distribution on buildings, the introduction of movements of the image while braking, starting to drive and sways during turning, thus simulating the effect of a vehicle swaying, the alignment of the viewing angle of the observer in the vehicle simulator to the viewing angle of the displayed image, widening of the displayed image to facilitate turning right.
- The changes in the control of displaying content in LED billboards should relate, first and most of all, to making the rate of displaying images in the LED screen fully dependent on the observer's vehicle speed and incidents occurring while driving along a route.
- The changes in the operation of the vehicle simulator should aim to calibrate the simulator's driving system and sound effects that would take, to a higher degree, the subjective impressions of test participants.
- The changes in the testing procedure should, first of all, consist in shortening the duration of the experiment by limiting the number of routes - one test route and two basic routes, in modification of the route's layout - fewer T-type intersections, more straight sections, in displaying billboards at all examined luminance level in one route, in increasing the diversity of the displayed advertising content and increasing the number of billboards, in eliminating the jumping ball serving as an obstacle, in

placing obstacles between the middle of the road lane and the middle of the road, in introducing rest breaks between basic routes.

The introduction of these changes will greatly help adapt laboratory conditions to real life road conditions and increase the possibility of objectively evaluating the impact of LED billboards on the drivers' visual performance.

Work completed from 2011 until 2013 is financed with Ministry of Science and Higher Education resources for academic purposes within the frame of own research project no. N N510 666140.

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