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Halszka SKÓRSKA[1]

A CONTROLLED PILOT STUDY IN A PRACTICE YARD TO ASSESS DRIVER PERCEPTION WITH CAMERA-MONITOR SYSTEMS VS. MIRRORS: EYE TRACKING INSIGHTS FROM A PILOT STUDY

Summary. Road accidents are an inevitable part of road traffic. Those involving trucks and vulnerable road users are especially tragic. Multiple solutions are proposed to deal with this problem. Among them is the idea of using camera-monitor systems instead of traditional exterior mirrors. The paper presents the results of a pilot study conducted in the practice yard using two trucks. One was equipped with the camera-monitor system replacing exterior side mirrors, and the other was equipped with traditional mirrors. The systems' usability was compared in the practice yard based on two scenarios. Eye tracking was used as a method of perception assessment to assess whether the driver noticed a potentially dangerous situation and objectively measure the time needed for the driver to scan the surroundings. The number and duration of detected eye movements were measured and analyzed. The results for both types of devices for indirect vision were compared. This made it possible to determine the number of obstacles that the driver overlooked. The results for both types of devices were similar and suggest the need to supplement existing devices for indirect vision with additional systems that could help drivers detect hazards. However, the comparison of indirect fields of view suggested a slight superiority of the camera-monitor system.

1. INTRODUCTION

The rapid development of passenger and truck road transport has drawn our attention to the problem of active and passive safety of vehicles as well as the protection of vulnerable road users who become accident victims. Unfortunately, accidents remain a part of road traffic. In 2018, the World Health Organization presented a report on global road safety showing that the number of road fatalities increases every year and that more than 50% of all victims are vulnerable road users—namely, pedestrians, cyclists, and motorcyclists [1].

The consequences of accidents involving heavy goods vehicles are tragic, especially if the abovementioned vulnerable road users are involved. The problem is global, and the circumstances and causes of events are similar worldwide [2]. Police statistics and sources point out many reasons for their occurrence. These issues were discussed in [3-11]. The main causes are presented in the Ishikawa diagram in Fig 1.

Limitations that emerge from insufficient visibility are important factors that influence the occurrence of accidents. However, the sources do not unequivocally define visibility. In [12], it was stated that an object is visible if it is noticed within the span of 0.25 s by at least 90% of examined participants. Thus, visibility can be defined as the ability to perceive objects in the field of view. Its degree and range of fields of view are both influenced by the following factors:

- the design of the vehicle's cabin, which affects the direct field of view
- the so-called devices for indirect vision (i.e., mirrors, camera-monitor systems, and Fresnel lenses); the image obtained with their aid is referred to as the indirect field of view.

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[1] Cracow University of Technology, Faculty of Mechanical Engineering; al. Jana Pawła II 37, 31-864 Kraków, Poland; e-mail: halszka.skorska@pk.edu.pl; orcid.org/0000-0002-7381-5484

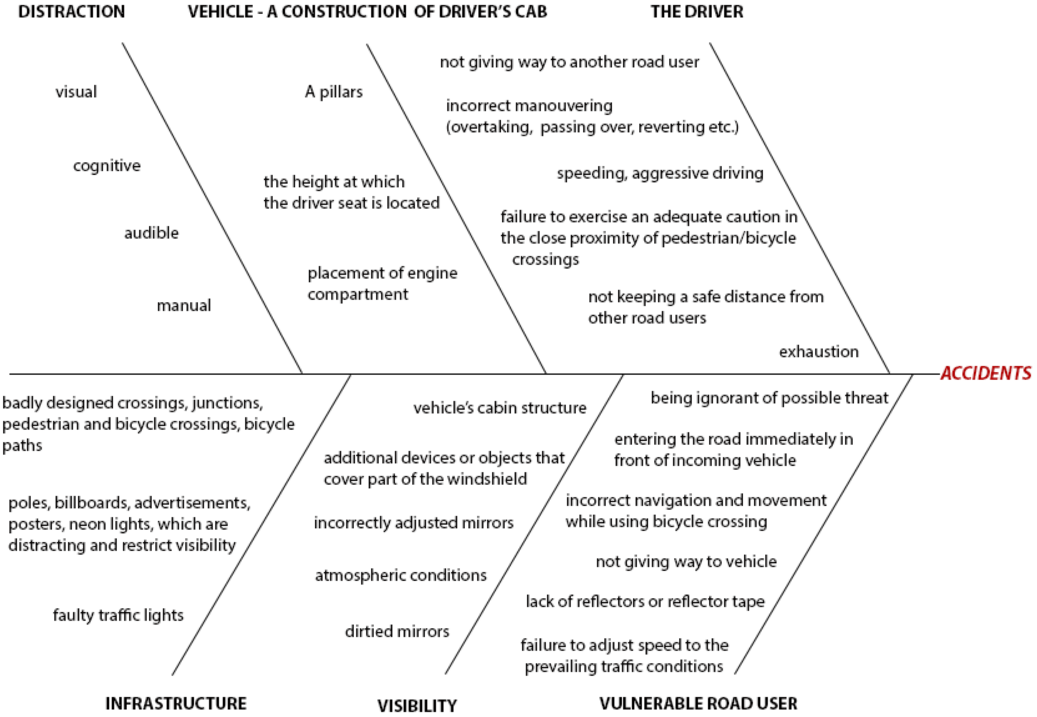

Fig. 1. Ishikawa diagram depicting the main causes of road accidents involving large trucks according to the literature

One important factor that contributes to accidents is the blind spots around a vehicle. Blind spots are areas that the driver cannot see. Objects, people, and vehicles can go unnoticed if they are located in a blind spot. The Directive 2007/38/EC of the European Parliament and the Council indicates that 400 people are killed annually due to blind spots and that most of these victims are vulnerable road users [13]. In theory, this problem could be partially solved by using camera-monitor systems.

Blind spots and visibility are related to drivers' perceptions. Every driver must react to various events, objects, and hazards while driving. For this to be possible, processes of perception must take place. Perception consists of three elements: detection (e.g., of an object or threat), identification (e.g., identifying an object or threat), and assessment (e.g., whether the driver needs to react). The final effect of the abovementioned processes is the driver's reaction. This is the last element in the chain of events that make up the driver's sensory perception.

Objects that the driver should effectively notice and identify and then respond to appropriately can be classified either as dynamic (e.g., vulnerable road users, other moving vehicles, animals) or static (e.g., parked vehicles, elements, or road infrastructure).

Governments and organizations have tried to address the problem of insufficient visibility and to improve the situation by introducing new legislation. In the member states of the European Union, the latest document regulating this issue (which took effect in July 2022) is Regulation 2019/2144 of the European Parliament and of the Council. The provisions on vehicle approval have been updated, with particular emphasis on retrofitting vehicles with advanced safety systems. As a result, the so-called Vision Zero should be achieved, which means that by the year 2050, the number of people killed or injured in road accidents should be reduced almost to zero. At the same time, the regulation identifies vehicle automation as the solution to most safety problems. It also orders the retrofitting of trucks with systems capable of detecting vulnerable road users on the sides and front of the vehicle and informing the driver of their presence [14-15].

Thus, car companies are trying to outdo each other while proposing ideas for an effective system. Among these are the use of sensors, radars, or even the redesign of vehicle cabins, as well as advanced systems based on the use of cameras that have recently appeared on the market and whose task is to assist the driver during maneuvers. Camera-monitor systems that fully replace Class II (main mirror) and Class IV (wide-angle) exterior rear-view mirrors, which are mandatory for all trucks, are already available on the market.

However, the use of this type of system raises important questions:

- Can it be a serious alternative to traditional exterior mirrors used so far in cars?
- Is this type of system safe?
- Will it improve the safety of vulnerable road users?

Research was conducted to answer such questions in an actual road traffic setting. A technique that can be used to assess the perception objectively is known as eye tracking, and an eye tracker was used during the research. The perception assessed was that of the users of the eye tracker (i.e., truck drivers).

2. EYE MOVEMENT, FIELDS OF VIEW, AND EYE TRACKING—BASIC INFORMATION

2.1. Eye movement

Eyesight is responsible for acquiring about 80% of information about our surroundings [16]. It is one of the reasons why humanity has been interested in both the anatomy of the eye and specifics regarding its functioning since antiquity. However, measuring instruments that would help track eye movements were not developed until the second half of the 19th century. Those first simple measuring devices were tasked with indicating the orientation of the eyes depending on the direction they were facing. Today, the device that is used to carry out this type of measurement is known as an eye tracker [17-18].

Human eyes are in constant motion, even while we are asleep. This distinctive feature means that we can distinguish many types of eye movement. The two primary movements are called saccades and fixations. A fixation is a state in which the eye is seemingly immobile for a specified period. The duration of a fixation is usually between 200 and 600 ms. During fixation, the brain processes the information that was noticed [19]. The longer the fixation, the greater the cognitive load [20].

A saccade is a rapid eye movement that was initially noted while observing what happens when people read. These movements occur between two fixations. It is the fastest motion made by the human body – its velocity reaches up to 500° per second, and sometimes even 800°. The duration of the saccade varies from 30 to 80 ms. The theory of eye movement usually assumes that a person cannot perceive things during most of that time [21-24].

2.2. Field of view

A person’s field of view can be divided into three parts: foveal field of view, parafoveal field of view, and peripheral field of view. In the foveal field of view, it is possible to notice details of a perceived image. It can be described as an open angle whose value is 2°. In Fig. 2, this angle is depicted as a small circle inscribed inside the larger one. The larger circle represents the para-foveal field of view in which shapes, colors, and contrast can be recognized. The angle for this field of view is 10°. Everything outside of these two zones is considered to be part of the peripheral field of view. In that area, the perception is very limited. Only strong stimuli, such as a flash or sudden movement are perceived.

Only after eyes are turned towards the stimulus does it become present in either the foveal or para-foveal field of view, which makes it possible to see details and recognize objects [19, 25]. In the present research, an eye tracker was used to gather data regarding the number and duration of both saccades and fixations.

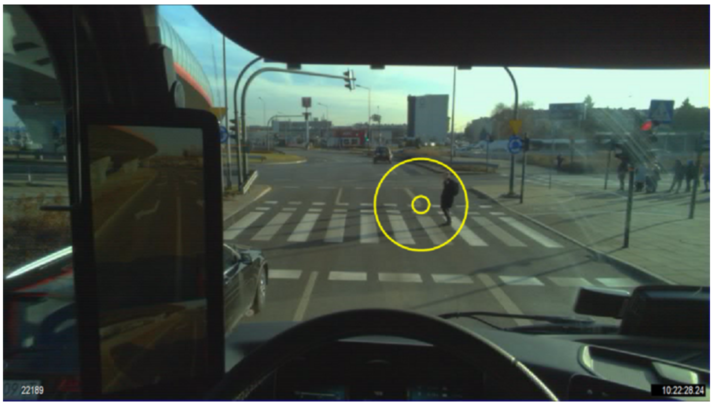

Fig. 2. Visualization of visual acuity generated by the Viewpoint System VPS16: central area of visual acuity – foveal perception (the smaller circle) and the area of parafoveal perception (the larger circle). The area outside those circles is the peripheral viewing area

2.3. Eye tracking and examining drivers

The first described cases of the use of eye tracking for examining drivers date back to the 1970s [21]. The research in the following years revealed many dependencies that currently impact the analysis of eye-tracking data. In 1980, M. A. Just and P. A. Carpenter formulated the so-called eye-mind assumption, according to which there is no significant delay between fixating eyes on the object and processing/understanding the information [26].

The assessment of the degree of visibility by drivers is subjective and is related to their perceptiveness, training level, and experience level. For this reason, registering eye movements is considered an objective method of examining perception [21]. Therefore, it is often used in research devoted to understanding the process of driving a vehicle. Eye tracking allows researchers to determine how much drivers can perceive, to what extent they focus their attention, what they notice, and what they ignore.

Eye tracking can be utilized during the psychophysical testing of drivers. The data collected by an eye tracker can be utilized in many ways (e.g., to assess driver alertness, fatigue, or drowsiness) [10, 27-28]. It is also possible to determine the level of their cognitive load in order to determine whether a driver is overloaded with information [25].

Indicators such as the number of fixations, average fixation time, and the exploration areas of the functional field of view can be treated as the basis for both diagnosis and assessment of operators' (i.e., drivers') perceptions as well as their psychophysical and functional states [29]. These three indicators were the first to be used for such a purpose as early as the 1970s [18]. However, they are not the only indicators that provide valuable information. For example, the frequency and duration of a driver's blinking allow researchers to assess a driver's concentration level [30]. The analysis of blinks also allows us to determine whether a driver has experienced information stress and its severity. High focus is indicated by the extended time between each blink. It also shows when the driver has fallen into a microsleep. An increased frequency of blinking indicates fatigue [27].

Eye tracking allows the analysis of perception techniques and drivers' visual strategies [31]. In [27], the types of information that can be obtained due to the abovementioned observation were discussed. These are, among other things, the data that allow us to decide whether there was a temporary loss of visibility that could have caused an accident and, if so, when that loss happened. The graphic representation of the main fixation points and the saccade paths between them makes it possible to see whether the traffic situation was a complex problem for the driver and to what extent. This, in turn, makes it possible to determine at which point the information was lost and what caused it to be lost (i.e., the high complexity of the perceptual process or the focus on information not related to traffic).

In [32], the authors used a mobile eye tracker to examine drivers' perceptions of vertical and horizontal road signs in actual road traffic. The collected data were presented as heat maps. Similar studies were carried out in [33], in which the authors also checked the extent to which roadside advertisements and billboards distract the driver. It is also possible to use eye tracking to assess the degree of usability of advanced driver assistance systems (ADASs) [34] and graphical interfaces of head-up displays (HUD) [35]. It is also used to detect and measure levels of cognitive distraction [36]. Eye tracking has also helped assess the impact of motion cues on braking in driving simulators [37].

Some sources propose using eye tracking as a supporting tool in research regarding truck drivers. An example can be found in [38], in which eye tracking was used to determine drivers' techniques for checking surroundings before and during a right-turn maneuver. Eye tracking can also be used to learn more about the mirror search strategies used by truck drivers [39].

3. MATERIALS AND METHODS

3.1. Study aim and tools used

The tests and results presented here are part of a wider analysis. This study aimed to examine the perceptions of experienced drivers in static and dynamic conditions with the ultimate goal of creating a driver perception model. This paper presents the results of a static and dynamic test in a practice yard.

The experiment aimed to record drivers' eye movements while maneuvering in the practice yard and to check how often the potential obstacle was detected using devices for indirect vision. Recorded eye movements were saccades, fixations, and gaze paths. Information about those made it possible to determine the extent to which drivers use the vehicle's mirrors and the camera-monitor system and how often the obstacle was detected.

Tests were carried out using a Viewpoint System VPS 16 eye tracker. This eye tracker consists of two parts: eye-tracking glasses and a smart unit. The glasses have a built-in 256 MB RAM memory, a microphone, and a micro USB port, which makes it possible to connect the glasses to the central unit. Additionally, two types of cameras are built in: the front one has a resolution of 960x540 px, and the cameras directed at the eyes have a resolution of 320x240 px. Both types of cameras record 25 frames per second. A triaxial accelerometer, ambient light sensor, and four infrared LEDs are also built in. The weight of the glasses is similar to the weight of prescription glasses.

The smart unit has a Quad Core CPU of 1 GHz, 2 GB of RAM, and a 16 GB internal flash memory. The system is powered by two integrated lithium polymer batteries with a total capacity of 4000 mAh. The device can communicate with the environment via Bluetooth 4.0 and Wi-Fi. In addition, two micro USB ports and one HDMI port are built in, as are a loudspeaker and two control LEDs. A 4.3" LCD operates as a human-machine interface.

The results were analyzed using Fact Finder software, which was supplied with the VPS 16 eye tracker. The application allowed us to analyze static and dynamic visuals using one of eight visualization modes. Only a few are suitable for the interpretation of dynamic images, but all of them allow analyses in line with specific aims (e.g., searching for fixations after a wide saccade).

Two types of recordings were obtained: a recording of surroundings that users see and recordings of their eye movements. They were converted into a more understandable form for the purpose of the current analysis.

Fig. 3. Viewpoint System VPS 16 eye tracking device: glasses and smart unit

3.2. Conditions of the perception study: Research objects and participants.

The research objects were two trucks manufactured in 2019. All aspects of these two vehicles were identical except for the installed devices for indirect vision. The first was equipped with a traditional exterior mirror system consisting of Class II, IV, V, and VI mirrors, and the second was equipped with a camera-monitor system that completely replaced mandatory Class II and Class IV mirrors. Additionally, it was supplemented with obligatory Class V (close proximity mirror) and VI mirrors (front mirror).

The camera-monitor system consisted of three elements:

- cameras located in the arms mounted above the door on both sides of the truck cab
- two 15” screens mounted on the A-pillars inside the cabin
- a control panel located on the door

The screens allowed us to observe the area at a resolution of 720x1920 pixels. Their surfaces were divided into two parts corresponding to the Class II and Class IV mirrors. The upper part of the screen displayed an image corresponding to the Class II mirror (also known as the main mirror), and the bottom part corresponded to a Class IV mirror (a wide-angle mirror) [29].

Fig. 4. The placements of the camera (1a) and screen (1b) in the camera-monitor system, as well as the placements of exterior mirrors and (2): II – Class II main mirror; IV – Class IV wide-angle mirror; V – Class V close-proximity mirror; VI – Class VI front mirror

Tests in the practice yard were carried out on a cloudy morning in March. The eye tracker recorded the surroundings as seen by drivers, as well as their eye movements, which were visualized in the software as various graphic markers; this form is more understandable than other forms for analytic purposes. In addition, another camera placed in the parking lot in front of the truck tractor was used to record the surroundings around the vehicle and the behavior of vulnerable road users (i.e., pedestrians).

Since this is a pilot study, it was carried out with just two drivers who had the following characteristics:

- They were volunteers.
- They were experienced drivers.
- They agreed to participate in the experiment.
- They were informed about the purpose of the research and how the eye-tracking device works.
- They had valid medical check-ups confirming their ability to drive vehicles (one of them needed prescription glasses).
- They had never used a vehicle for which the traditional mirrors had been replaced with a camera-monitor system.

Before the research commenced, the eye tracker was calibrated to match the drivers’ gaze.

4. RESULTS

4.1. Stage I: Static tests at the practice yard

Static tests were carried out in the practice yard on a cloudy morning in March. For each driver, the experiment lasted three minutes. The task was to observe the vehicle's surroundings in mirrors and on monitors. Other participants circled around the cars, simulating the behavior of pedestrians unaware of the visibility restrictions of the truck's cabin. The initial and final parts of the recording, during which the subjects turned the eye tracker on and off, were excluded from the analysis. Since this is a pilot study, the results were analyzed for each driver separately because of our interest in the individual differences in perception. The types of eye movements and the duration of time for which they lasted were assigned by the eye tracker's software.

The camera-monitor system was examined first. The results of the eye-tracking examination of the drivers for the camera-monitor system are shown in Table 1. Most of the fixations registered for Driver A lasted for a short time (between 0.08 and 0.27 s). It should be noted, however, that in many cases, the observation of the environment on the screen's surface consisted of a sequence of many very short fixations connected by saccades. Therefore, the total time the driver spent observing the surroundings was much longer than indicated.

Table 1

Results of the eye tracking examination of the drivers for
the vehicle equipped with the camera-monitor system for Stage I

Camera-monitor system								
	Fixations detected	**Fixation time [s]**	**Number of fixations focused on either screens or Class VI mirror**	**Fixation time on screens/ mirrors [s]**	**Saccades detected**	**Saccades time [s]**	**Blinks**	**Blinks time [s]**
Driver A	235	56.08	187	44.08	322	59.84	115	20.4
Driver B	180	42.08	120	23.92	267	37.2	109	14.68

Fig. 5 shows an example of a driver's gaze path and the search pattern used to detect a potential hazard using the screen. The path was determined by the Fact Finder software. The path was generated for two seconds. Yellow lines mark saccades and indicate the direction in which the driver's gaze moved. Clusters of short fixations (marked as yellow points between saccades) were highlighted using red circles. The number above them indicates the order in which they occurred.

In case of detected long fixations (lasting for at least 0.6 s), the driver usually either observed surroundings in the monitors or a pedestrian who was passing by and was visible through the windows. The longest recorded fixation lasted for 1.08 s; this occurred when the driver was observing the surroundings on the screen located on the right side of the vehicle. A similar situation occurred in the case of the second longest fixation, which lasted for 1 s. In total, 17 long fixations were focused on the screens of the camera-monitor system.

Additional analysis of the recording taken from the camera located outside of the vehicle showed that pedestrians appeared in the vicinity of the vehicle 25 times in three minutes. Four of them were not detected by the driver. Moreover, it is difficult to state whether the driver was aware of their presence in two cases. For safety reasons, it was assumed they were not. This means that pedestrians were not detected in 24% of cases.

Similar results were recorded during the examination of Driver B. Most of the long fixations were detected on the surface of screens or while the driver was glancing at pedestrians visible through the window. As before, the recording was analyzed again for fixations lasting 0.6 s and longer. The longest recorded fixation lasted for 1.48 s and was detected on the screen on the left side of the vehicle in an area corresponding to a Class IV mirror. The two next-longest fixations (1.4 s and 1.24 s) were focused on the pedestrian visible through the windshield. Another one was once more located on the left screen. Ultimately, only five long fixations were detected on the screens' surface.

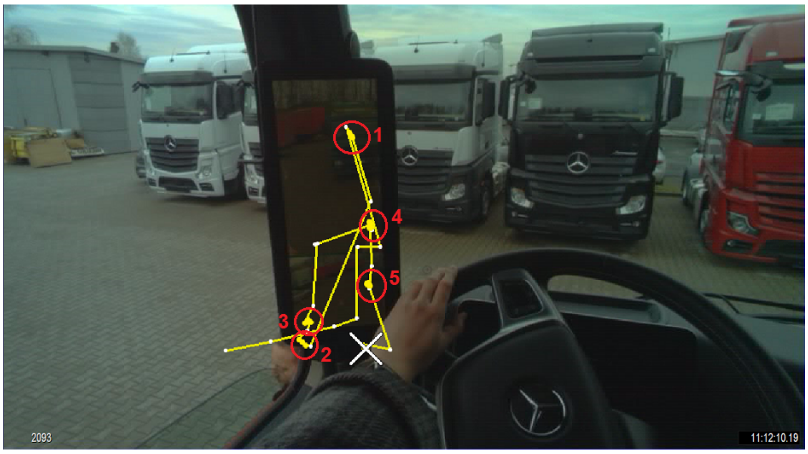

Fig. 5. Placement of the camera-monitor system and a two-second gaze path showing five consecutive short fixations: 0.16 s, 0.12 s, 0.24 s, 0.32 s, and 0.48 s (lasting for 1.32 s in total). The rest of the time was consumed by saccades that occurred between fixations

An additional analysis of the recording that was taken from the camera located outside of the vehicle showed that pedestrians appeared around the vehicle 20 times. The driver failed to detect them in the monitors four times. At that time, the driver monitored the situation either via a second monitor or Class VI mirror. This means that pedestrians were not detected in 20% of cases.

The same experiment was carried out on the same day and with the same drivers in another vehicle, this one equipped with conventional mirrors. The results of the eye-tracking examination are shown in Table 2. As before, a more detailed evaluation was carried out after that. Fourteen long fixations were detected—nine focused on the surfaces of mirrors and five focused on the surfaces of windows.

An analysis of the recording from a camera placed outside the vehicle showed that pedestrians appeared around the vehicle 35 times. The driver noticed pedestrians in most cases, missing them only seven times. In two cases, we could not determine whether the driver noticed them. For safety reasons, it was assumed they did not. In summary, pedestrians were not detected in almost 26% of cases. However, in several cases, mirrors were not needed for the driver to detect them because they were already visible in the direct field of view.

During the examination of the second driver, only one long fixation focused on the mirror was observed. The longest one, lasting 2.16 s, was located on the windshield. Just over half of the detected fixations were focused on the mirrors. However, it cannot be stated with certainty that the driver ultimately spent less time observing the surroundings in the mirrors—in many cases, long-lasting saccades were observed on the surfaces of the mirrors, followed by either no fixation at all or very short ones.

An analysis of the recording from an outside camera showed that pedestrians appeared in the immediate vicinity of the vehicle 33 times during the experiment. The second driver, like the first one, was usually able to notice them, as they were missed only seven times. In two cases, it was impossible to determine whether the driver noticed the pedestrian. As before, it was assumed he did not. This means that pedestrians were not detected in 27% of cases. As before, in several cases, the mirrors were not needed to detect vulnerable road users since they were visible in the driver's direct field of view.

4.2. Stage II: Maneuvers in the practice yard

During the second stage of the study, various maneuvers were performed in the practice yard: leaving the parking space, driving through a narrow gate, turning left, parking the truck tractor backwards, leaving the parking space again, and then entering the traffic from the side road to the main road. Because the main purpose of this part was to learn the extent to which the screens and mirrors would be used during the maneuvering, the data regarding various eye movements and their duration were no longer analyzed separately.

Table 2

Results of the eye-tracking examination of the drivers for
the vehicle equipped with the traditional external Class II and IV mirrors for Stage I

Traditional external mirrors								
	Fixations detected	**Fixation time [s]**	**Number of fixations focused on either screens or Class VI mirror**	**Fixation time on screens/ mirrors [s]**	**Saccades detected**	**Saccades time [s]**	**Blinks**	**Blinks time [s]**
Driver A	267	62.16	195	42.72	377	51.24	150	36.24
Driver B	234	52.08	118	19.48	368	72.44	163	21.2

The first examined system was the camera-monitor system. The results of the eye-tracking examination of the drivers for this system are shown in Table 3.

Table 3

Results of the eye-tracking examination of the drivers for
the vehicle equipped with the camera-monitor system for Stage II

Camera-monitor system						
Duration of maneuvering [s]	**Fixations detected**	**Fixation time [s]**	**Saccades detected**	**Saccades time [s]**	**Blinks**	**Blinks time [s]**
148.8	278	55.32	313	86.16	41	7.4

The average duration of registered fixations was 0.202 s. The longest one lasted for 1.2 s and was located on the surface of the right screen. In total, 40 fixations were detected on the left screen's surface, 63 were detected on the right screen's area surface, and seven were detected on the Class VI exterior mirror's surface. The rest were detected mainly on the surface visible through the windshield.

Fig. 6 shows the main areas where fixations were detected in the vehicle equipped with the camera-monitor system. They were grouped based on their duration. Regardless of the area of their detection, the vast majority of them are short fixations (0.08–0.28 s). Only some of them were long or very long. None of the 163 fixations detected outside the monitors and mirrors are shown. Of these, 133 lasted 0.08-0.2 s.

The results of the eye-tracking examination of the drivers for the vehicle equipped with the traditional exterior Class II and IV mirrors are shown in Table 4.

The average duration of the registered fixations was 0.186 s. The longest fixation lasted for 0.68 s and was detected on the surfaces of mirrors located on the left side of the cabin. In total, 57 fixations were detected on the surfaces of mirrors located on the left side of the cabin, and 29 were detected on the surfaces of mirrors located on the right side of the cabin. None were detected on the Class VI exterior mirror's surface. The rest were focused mainly on the area visible through the windshield.

Fig. 7 shows the main areas where fixations were detected for the vehicle equipped with exterior mirrors. These fixations were grouped based on their duration. The results are similar to those obtained for the vehicle equipped with the camera-monitor system. Most fixations were short, lasting 0.08-0.24 s, regardless of where they occurred. Only one long fixation was detected. Moreover, no fixations were detected on the surface of the Class VI exterior mirror – a situation that did not occur for the vehicle equipped with the camera-monitor system. The eye tracker detected only brief saccades in that area.

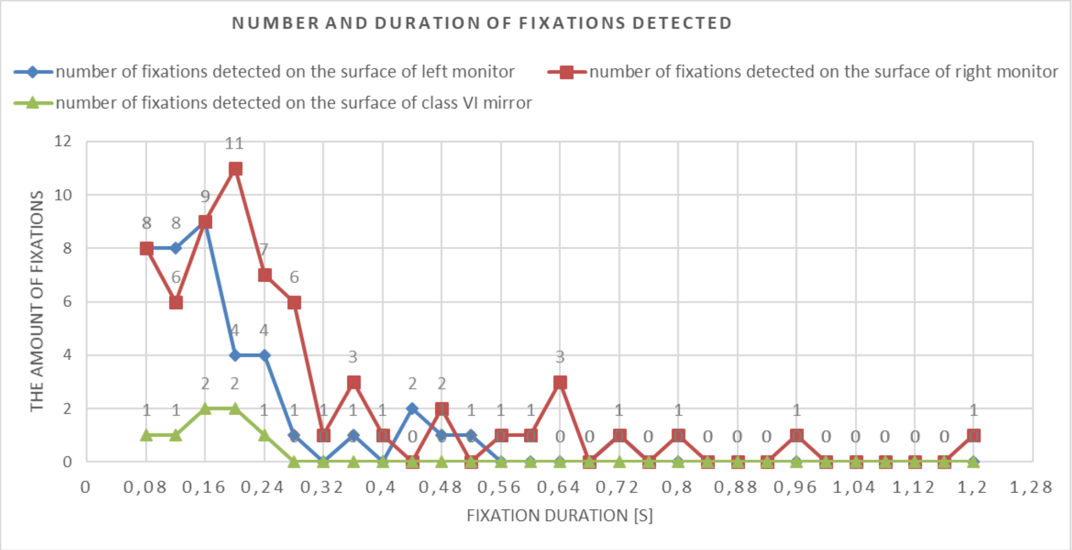

Fig. 6. Number and duration of fixations detected during the practice yard maneuvering in Stage II for a vehicle equipped with the camera-monitor system

Table 4

Results of the eye tracking examination of the drivers for
the vehicle equipped with the traditional external mirrors for Stage II

Traditional external mirrors						
Duration of maneuvering [s]	**Fixations detected**	**Fixation time [s]**	**Saccades detected**	**Saccades time [s]**	**Blinks**	**Blinks time [s]**
98.48	195	36.32	240	57.52	71	4.64

5. CONCLUSIONS

Modeling a driver’s perception of road traffic is vital, considering that blind spots affect a driver’s visibility and, consequently, reactions. We decided to use eye tracking to gather data regarding drivers’ gaze paths in order to create a model that would closely represent actual human reactions.

The analysis of the Stage I results revealed the extent to which drivers focus on indirect vision devices and how much time they devote to them.

It is widely accepted that fixations should be treated as evidence of ongoing perception processes. However, during this study, it was noticed that the time the driver spends observing the environment in devices used for indirect vision is much longer than the duration of detected fixation. Moreover, their observation often consisted of many short fixations lasting between 0.08 and 0.16 s, focused on the mirror/screen area and connected by multiple saccades. Therefore, the total time the driver spends observing the surroundings in indirect vision devices is longer than indicated by the results obtained using an eye tracker. However, the eye tracker and the software used do not allow glances at various areas of interest (screens and mirrors) and their duration to be properly examined, making their analysis difficult.

Additionally, in many cases, it was observed that the driver turned their attention towards the mirrors/screens, as evidenced by the recorded saccades. However, no fixation occurred, even though the gaze path of the driver followed the pedestrians visible in the mirror or screen, indicating that they noticed a potential source of danger. This may indicate that fixation, contrary to the belief presented in various sources debating the processes of perception, is not necessary for assessing the situation while driving. However, extensive quantitative research is needed to establish this fact with certainty.

To sum up, 30 long fixations (lasting at least 0.6 s) were detected for the truck equipped with the camera-monitor system, and 26 such fixations were recorded for the truck equipped with conventional Class II, IV, V, and VI mirrors. Of these, 73% were focused on the monitor area. In comparison, only 38.5% of such fixations were detected on the surfaces of mirrors. These results may be related to the fact that mirrors are the typical device used for observations in cars, while the camera-monitor system is a novelty.

During this study, vulnerable road users were not detected in 22.22% of cases for the camera-monitor system and in 26.47% of cases for the conventional mirrors. This happened even though the drivers observed the surroundings with particular attention, as they were aware that other road users would unexpectedly appear around the vehicle throughout the experiment.

The results obtained for both types of devices were comparable. This indicates the need to supplement existing devices with additional systems that would additionally warn the driver about a vulnerable road user detected in the immediate vicinity of the vehicle. A comparison revealed that camera-monitor systems give drivers an enlarged indirect field of view, thus it seems no further improvement in this regard is needed.

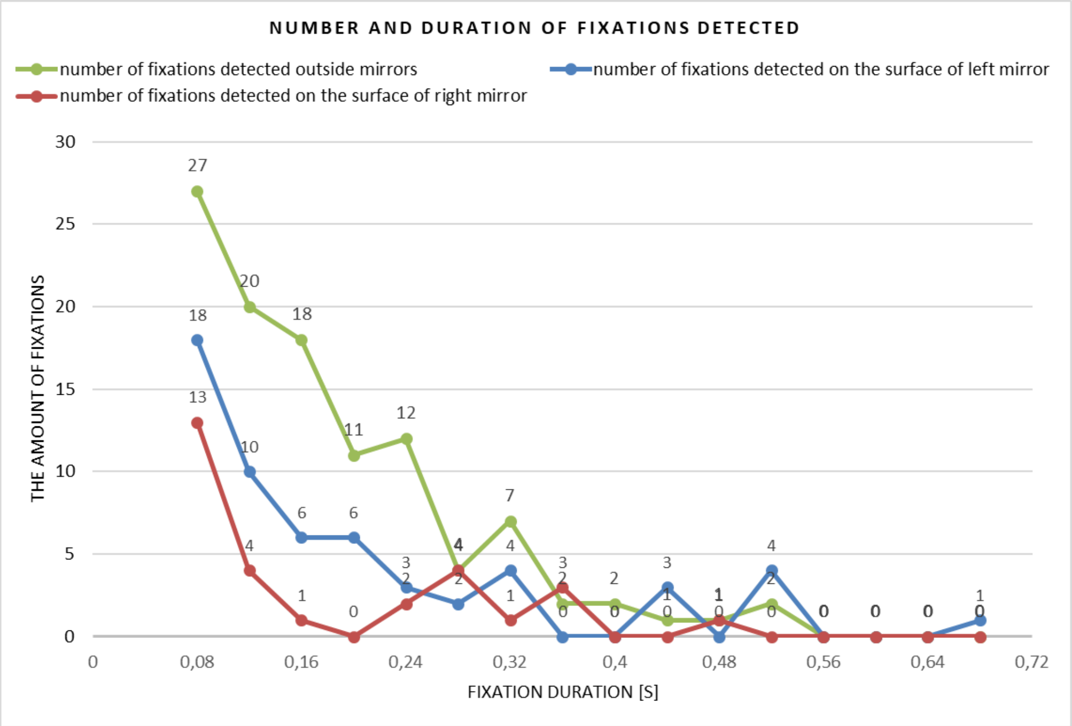

Fig. 7. Number and duration of fixations detected during practice yard maneuvering in Stage II for a vehicle equipped with traditional Class II and IV exterior mirrors

The Stage II results show no significant difference in the number of fixations focused on two vastly different types of devices for indirect vision. For the vehicle equipped with the camera-monitor system, 39.57% of all registered fixations were concentrated on both the surfaces of screens and the Class VI mirrors. Meanwhile, for the vehicle equipped with the traditional exterior mirror system, 44.1% of all registered fixations were concentrated on the surfaces of Class II and IV mirrors.

This preliminary research allows us to tentatively state that camera-monitor systems could be viable alternatives to traditional exterior side mirrors in cars. However, the safety of such systems requires more testing on a much larger sample.

Further research will determine the differences between the driver’s perception in actual road traffic and a truck simulator based on a full-size truck cabin.

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