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Research Article

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Drivers 'reaction time research in the conditions in the real traffic

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Abstract: The article presents the results of research on the total reaction time of drivers in real traffic conditions. The tested driver had to react to a complex signal by performing a braking manoeuvre. The measurements were based on the author's method combining the measurements of reaction time during the actual driving with their computer analysis. The research group consisted of 15 drivers with different seniority of driving licences. The study measured the time of perception and the time of leg transfer from the accelerator pedal to the brake pedal. The results were subjected to analysis and on its basis conclusions were formulated.

Keywords: drivers, real traffic conditions, reaction time

1 Introduction

In accident situations, where the sudden appearance of an obstacle may endanger safety, the consequences of the event are usually determined by the driver's reaction to the situation, *e.g.* taking a braking manoeuvre. The time that elapses between the occurrence of the hazard and the moment the vehicle stops is called the time of complete stopping. Its length is influenced by the following components: total driver response time, brake system activation time and braking time. While the latter two can be determined by knowing the technical aspects of the event, such as the speed of the vehicle, its technical condition or the type of surface, the response time is an individual parameter for each driver. Its length may be influenced by many factors, both those that characterize the driver, such as age or experience, as well as his current state, such as fatigue or stress.

The reaction time is used during the reconstruction of road events, but its value does not consist of fixed and quantifiable parameters. Therefore, during the analysis of events, the average value determined by experts is used. The research carried out in this field describes different methods of measurement, which differ mainly in the accuracy of measurement. We should mention research stations, used mainly during the research of professional drivers, driving simulators, which are versatile but leave the driver in the comfort zone, and research conducted on research tracks, which focus on the representation of real-world traffic conditions.

According to statistical data, *e.g.* [7], the most common cause of road accidents are vehicle drivers. It is estimated that about 70% of accidents in Poland are a consequence of a driver's wrongful action. The so-called reaction time is one of many features that characterize his or her action in a situation of a road accident hazard. In short, it can be defined as the period from the moment the danger occurs to the moment when the driver takes specific actions on the car's controls to avoid an accident.

The aim of the study was to examine the response time of drivers during a braking manoeuvre during actual driving. In the measurements, a universal test stand adapted to the assumed purpose was used. The research was preceded by an analysis of factors influencing traffic safety and the existing test methods.

The scope of the work consists of 4 chapters, which include a discussion of factors influencing the level of safety. The total time of stopping a vehicle in an accident situation and their influence on the stopping distance were defined. The factors influencing the reaction time are discussed, with particular emphasis on the driver's experience. The next chapter presents the methods used to date to measure the response time used in driver testing. Chapter 2 presents the adopted test methodology, the measurement system, the course of measurements and the method of analysis

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of results. Chapter 3 includes a summary of the measurement results, their presentation in graphic form and analysis of the obtained response time values. The last chapter includes a summary of the measurement results.

2 Factors influencing the level of road safety

2.1 The need to test the reaction time

In manuals and training materials for forensic and traffic experts, data on drivers' response times is one of the basic data. In many publications, their values are presented, often with significant differences. Meanwhile, as mentioned earlier, the final ruling on the possible guilt of the driver may largely depend on what values will be used in the analysis by the court expert. These differences are often due to different test methodologies (tool - test environment, test methodology, number and "composition" of the group of subjects, presentation of results). The assessment of response time in psychotechnical tests is one of a set of tests carried out in psychological laboratories for the general assessment of the test person's ability to drive. These tests are characterized by the methodology developed for many years and the way of evaluating their results, *e.g.* [10]. In the case of reaction time, so-called reflexometers are used. The response time is assessed as the period from the appearance of a given light or sound stimulus to pressing the appropriate button on the desktop. In the case of data from experiments on the road or test track, most often these are the results of tests of the reaction to the so-called simple stimulus (a single light or sound signal), while the way the driver's reaction is also simplified - it is supposed to act on one of the car control elements (service brake pedal, hand brake lever or steering wheel) [1, 2, 9, 15, 16].

The results of such studies are often published as a recommendation to experts, *e.g.* [1, 17]. In real road situations (apart from driving, *e.g.* in a column on a motorway, where the reaction occurs to the "stop" light of the preceding car) the driver reacts to complex stimuli. However, in the literature from 10-15 years ago, it is difficult to find data on reaction times in which both the stimulus and the driver's response are complex (similarly to real-life accident situations). So far, studies on the response to complex stimuli have been carried out, but these have often been highly simplified situations. For example, in the studies [2, 9], stimulator lamps glued to the windscreen of a car were used to study the response to a complex stimulus. In recent years, studies on roads or tracks have increasingly relied on the implementation of contractual accident scenarios, which were considered representative. The authors in their earlier works [3, 4, 14] presented such tests. The "observation" type tests in real traffic conditions should also be mentioned. These tests most often consist in the analysis of recordings from cameras (*e.g.* monitoring) placed near the roads [11]. However, the result of the assessment (reaction time) here is strongly dependent on the arbitrary assumptions of the observer as to the time of the initial threat situation, and thus also the stimulus. The development of simulation techniques, increased efficiency of computers and systems to generate images has made it possible to use a virtual environment for testing drivers - driving simulators. They are increasingly used in driver research. Their use increases the independence from weather conditions and favours the increase in repeatability of research conditions and results [3, 10]. It also enables the implementation of practically any accident situation scenarios in a way that does not endanger safety.

Moreover, the authors' experiences indicate a strong correlation of research results in the simulator and in the real car on the test track [3, 5]. Summarizing this brief review of the literature, it can be concluded that research is necessary to determine the response times not to a stimulus or simple stimulus system, but to some simulated accident hazard situation. The number of results available in the literature for this type of tests is small and includes selected special cases.

2.2 Stopping distance

The stopping distance is an important parameter affecting the safety of vehicle traffic and the legal regulations concerning permitted speeds in particular areas. Its components include the distance covered by the vehicle with the same speed during the driver's reaction time and the distance covered by the vehicle from the brake pedal depression to the actual stop (braking distance) [8]. The total stopping time of the vehicle is the sum of the driver's reaction time and the braking time, which includes [6]:

- brake application delay time t_0 - time between the foot position on the brake pedal and the occurrence of braking force;
- increasing deceleration time t_n - the time that elapses between the driver applying the brake pedal and the full braking force of the braking system;
- time of full braking t_h - occurs from the moment when the braking system reaches full braking force to complete stopping of the vehicle.

The course of the braking process in total stopping time shall, taking into account the parameters of brake pedal force, deceleration and speed. This graph shows the change of individual parameters during the total stopping time, dividing it into individual components of reaction and braking times.

2.3 Driver response time

The driver's response time is critical to the braking process of the vehicle and therefore also has a significant impact on safety in critical situations. It can be defined as the time passing from the moment when a hazard occurs to the moment when the driver takes action to avoid it, by braking and/or turning the steering wheel [1]. When analysing the driver's response time, when the hazard occurs, one should distinguish [6]:

- perception time t_{r1} - the period between the moment the hazard appears in the driver's field of vision and the moment the driver focuses his attention on it and recognizes it;
- basic psychological reaction time t_{r2} - includes the time of analysing the situation by the brain and making a decision about the type of reaction (braking, bypassing an obstacle) and sending a signal by the nervous system about the start of the action to perform the manoeuvre (the beginning of foot movement in order to apply the brake pedal);
- t_{r3} foot transfer time - the time of the motor reaction consisting in transferring the foot from the accelerator pedal to the brake pedal.

The sum of the perception times (t_{r1}) and the fundamental psychological reaction times (t_{r2}) shows the mental reaction time; the transfer time (t_{r3}) shows the motor reaction time. When considering the driver's response time, the total psychomotor response time, being the total period from the onset of danger to the transmission of the foot from the accelerator pedal to the brake pedal ($t_r = t_{r1} + t_{r2} + t_{r3}$), should be taken into account [6].

The driver's response time parameter at the moment of danger has a direct impact on the safety of the driver and other persons involved in the accident. According to police reports from the years 2005-2015 [19], about 80% of accidents are caused by the drivers. The response time is an individual parameter for each driver and depends on many factors such as experience, fatigue and stress. The value of this parameter has a direct impact on safety when an accident occurs - often the degree of risk to the health and life of accident participants depends on the speed of the driver's reaction. This issue was described in detail by J. Unarski in the article "Driver's reaction time - standards and reality". [13]. He discussed the study of reaction time on the measuring track with the use of three different stimuli. The results of the tests in the form of reaction time intervals are presented in Table 1. The reactions to [13] have been taken into account:

Table 1: Average response times to different types of stimuli [13].

Type of stimulus	Response time interval [s]
Simple	0,7 – 0,85
Complex, expected	1 – 1,15
Complex, unexpected.	1,3 – 1,5

- a simple stimulus in the form of a lamp placed within the driver's field of vision;
- complex stimulus, expected stimulus - drivers were informed that at some point during the tests there will be a signal;
- complex stimulus, unexpected - the drivers did not know that there would be a signal while driving.

Reaction time studies are justified in the field of accident reconstruction. In calculations carried out by car technology experts and forensic experts, the adopted response time value may determine the results of the analysis of the circumstances of the event. The performed analysis influences the court's decision on the guilt or lack of guilt of the driver [3]. In the accident investigation, the braking time can be determined from known, constant and quantifiable parameters, while the psychomotor response time is an individual value for each driver, so the calculations should use the average value adopted on the basis of experience and research conducted by experts. An example of the formula used in the tests is the one presented in the book "Road accidents. Vademecum of the court expert". [12], showing in a simplified way the individual phases preceding the braking process of a passenger car (Figure 1).

Table 2 summarizes the times corresponding to each of the stages shown in the diagram. The quoted concept of "basic time loss" corresponds to the sum of the times of individual phases of the braking process - from the moment of recognition of an object to the beginning of the significance of braking tracks. Adding the perception time to this parameter, the concept of "basic time loss with peripheral perception" was obtained.

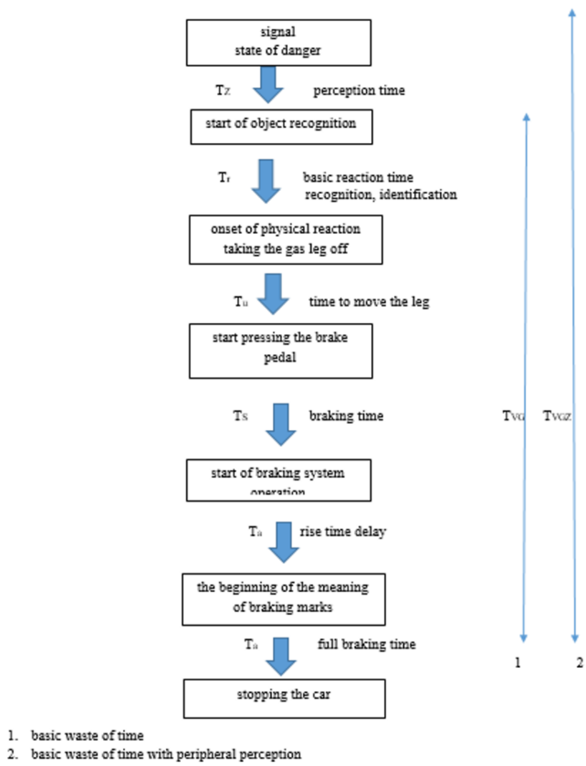

Figure 1: Diagram of the driver's reaction to the braking manoeuvre of the vehicle [12].

Table 2: Possible time values resulting from statistical analysis [12].

Phase of the braking process	Designation on the scheme	Reaction time value [s]
Time of perception	T_z	0,48
Basic response time	T_r	0,45
Time of leg postponement	T_u	0,19
Braking system response time	T_a	0,05
Time delay build-up	T_a	0,17
Basic waste of time	T_{VG}	0,86
Basic waste of time with peripheral perception	T_{VGZ}	1,34

2.4 Time delay build-up

The build-up time of the deceleration is one of the components of the stopping time and has a direct effect on the stopping distance. It can be defined as the time elapsing from the moment when the braking force is applied to the moment when the braking system reaches the value of deceleration expected by the driver or the full braking efficiency resulting from wheel lock-up [6]. The value of the rise time of the deceleration depends on the type of braking system. Examples of measured values for pneumatic and hydraulic systems, together with the name of the author of the tests, are presented in Table 3.

Table 3: Example of the delay build-up time [3].

Autor badań	Brake application time [s]	
	Hydraulic actuation system	Pneumatic actuation system
S. Arczyński	0,3	0,5
T. Wrzesiński	0,1 - 0,3	
A. Reński	0,05	
K. Studziński	0,02 - 0,05	0,2 - 0,5
L. Prochowski, J. Unarski, W. Wach	0,15 - 0,3	0,3 - 0,5

2.5 Full braking time

The full braking time is the last component of the stopping time, covering the period from the moment when the vehicle reaches the expected deceleration to the moment when the vehicle comes to a halt [6]. The distance covered by the vehicle during full braking is called the braking distance, the length of which depends on the length of the braking distance:

- the initial speed of the vehicle;
- the type of surface;
- the condition of the surface;
- the state of repair of the vehicle.

An important parameter in the braking process is the coefficient of adhesion. It is characterized by the properties of different types of tyres cooperating with surfaces

Table 4: Frequent ranges of the coefficient of adhesion [12].

Surface type	Surface condition	Coefficient of adhesion
Concrete	Dry	0,8 – 1,08
	Wet	0,25 – 0,75
Asphalt	Dry	0,7 – 1,08
	Wet	0,4 – 0,6
Stone blocks	Dry	0,6 – 0,7
	Wet	0,25 – 0,35
Ground road hard	Dry	0,5 – 0,6
	Wet	0,3 – 0,4
Gravel	-	0,45
Snow-covered road	-	0,1 – 0,4
The road is icy	-	0,05 – 0,15

Table 5: Comparison of reaction times in different traffic situations [12].

Road situation	Average response time [s]		
	Without using a phone	When using the phone	Difference [s]
Change of signal lights	0,80	1,13	+0,33
Falling of an obstacle on the road	1,06	1,69	+0,63
Pedestrian crossing the road	0,85	1,14	+0,29
Occupation of the road by another vehicle	1,02	1,41	+0,39
Rapid braking of the preceding vehicle	0,90	1,40	+0,50

of different types and condition. As the coefficient of adhesion decreases, the braking distance of the vehicle increases, so this parameter has a real impact on the safety of this manoeuvre. Average values used in the analysis of road events are presented in Table 4.

2.6 Factors worsening the reaction time

The driver is exposed to a number of distractions while driving. This can lead to an accident situation that endangers the driver, passengers and bystanders. Lack of focus on driving is associated with a loss of control over the perception of the road scene. Any additional activity can distract the driver, which, when a hazard occurs, can significantly increase the response time and lead to an accident. The most common distractions are:

- talking to the passengers;
- controlling the behaviour of transported child/animals;
- use of a mobile phone;
- operation of devices in the car (air conditioning, radio, navigation);
- stress;
- alcohol;
- malaise or ill-health;
- food or drink while driving;
- road surroundings;
- reverie;
- looking for something in your car or environment;
- stress from inexperience in driving.

Distracting the driver’s attention from the road scene delays the response time and increases the overall response time. A distraction can be considered as a distraction:

- a diversion of the pattern from the road,
- a picture of the hands on the steering wheel,
- stop consciously thinking about driving a vehicle [12].

Examples of differences in response times in different dangerous traffic situations when using a mobile phone and without one are presented in Table 5.

Averaging the values of the reaction time presented in Table 5, the average difference of 0.43 s was obtained. Taking into account the permissible speeds on Polish roads, it is easy to determine the distance a vehicle will travel before the reaction time of a driver talking on a mobile phone. These values are as follows:

- in the built-up area with a limit of 50 km/h - 5.98 m;
- in an un-built area with a limit of 90 km/h - 10.75 m;
- on the expressway with a limit of 120 km/h - 14.33 m.

As the speed increases, the distance travelled by the vehicle increases before the driver reacts to the emergency situation and, consequently, the total stopping distance of the vehicle increases. Any driver distraction can therefore have a significant negative impact on safety and reduce the chance of accident avoidance or mitigation.

2.7 Driver experience

One of the main factors influencing the driver’s behaviour while driving is his or her experience. It sets out all the skills and knowledge acquired between the time of obtaining the driving licence and the present. Together with the experience gained, the driver improves his or her judgmental skills, improves his or her driving technique and learns to respond to emergencies. In an accident, the driver’s experience can be crucial to the driver’s progress and the way and timing of his response will help to reduce the damage involved.

Drivers’ experiences cannot be clearly divided, as they are influenced by several factors. The main criteria taken into account are the duration of the driving licence and the number of kilometres driven. The difficulty in determining the distribution parameters lies in the lack of dependence between these criteria - both are individual for each driver.

When considering the experience of drivers, “young drivers” are the most frequently mentioned group. In Poland, they include persons aged 18-24. This is the most numerous age group of victims in the annual reports of the National Road Safety Council [18].

Drivers in this age group have many features that may have a negative impact on safety, which may disappear with the acquired experience. Such features include:

- overestimating one’s own skills;
- the desire to impress others;
- lack of driving skills;
- looking for excitement;
- inadequate/error risk assessment;
- no learned reflexes, too slow a response’
- lack of self-confidence and/or driving stress;
- fixation of incorrect behaviour caused by the lack of a person suggesting errors.

With the acquisition of experience by the driver, such characteristics may weaken or even disappear altogether, being replaced by positive characteristics. Drivers with longer experience already know their capabilities and feel more confident behind the wheel, and their driving technique improves as well. Experienced drivers are more knowledgeable and able to cope with difficult situations, and some activities are carried out with a reflex without having to think about how to react.

Assuming that the driver’s response time decreases with experience, the impact of age-related psychophysical changes should be taken into account. Such changes may include, but are not limited to, poor perception or delayed reflexes, which may result in longer response times for older drivers. This leads to a situation where one of the parameters shortens the response time while the other one lengthens it. This means that up to a certain age these values may be tolerable [4].

3 Testing methodology

3.1 Measuring system

In the research carried out, a time measurement station was used. It is constructed in such a way that it is possible to conduct tests according to various measurement scenarios and to install them in any vehicle in such a way that it is possible to conduct tests.

The measurement system consists of three main components:

M9S Dual Cam dual channel video recorder (Figure 2) - two lenses recording synchronized images of equal resolution and frequency; the length of the cable connecting both lenses and the power cable, amounting to 6 m and 3.5 m respectively, allow for almost any location of the lenses in the vehicle; the main technical parameters:

- resolution: 1920 × 1080;
- the frequency of reprimands: 30fps;
- angle of view: front 170 degrees, rear 140 degrees;
- compound Stimulus Indicator (Figure 3) - two green and red LEDs, mounted on a flexible cable, which allows to be mounted anywhere in the car - together or separately,
- call buttons (Figure 4) - separate for each colour, mounted on a long and flexible cable, this allows the control person to occupy any position in the vehicle.

Figure 2: Lens set with the necessary cables [20].

Figure 3: Compound stimulus siren [18].

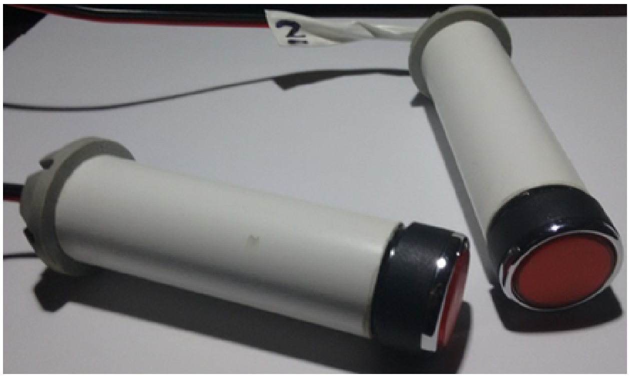

Figure 4: Light signal call control buttons [18].

3.2 Testing location

The place chosen for the research was a car park around the Arena Lublin stadium, located between Stadionowa and Lubelski Lipca ’80 Streets. A large space with a good surface allowed the research to be carried out at speeds comparable to real city driving. The lack of other traffic participants was conducive to the safety of conducting the research and free riding on the parking space and performing any manoeuvres related to the maintenance of traffic.

3.3 Respondents’ group

15 drivers of different ages and sexes, marked with letters A to O, took part in the research. The number of kilometres driven was not taken into account, but it was assumed that the persons surveyed were active drivers. The shortest time of possession of certificates was 2 years for driver A and the longest - 11 years for driver O. The universal design of the measurement station allows to install them in any vehicle.

3.4 Methodology for conducting research

The test method closest to the test method quoted above is the one on roads or test tracks, but with greater emphasis on the method of reaction time measurement itself. The research was carried out on the basis of free driving within the research area and performing any manoeuvres. The route was not imposed, so the driver focused on driving, instead of reconstructing the route. The test site allowed the driver to drive at a speed corresponding to urban traffic of approx. 40 km/h. While driving, the person sitting in the passenger seat at any time triggered one of the light signals in red (Figure 5) or green (Figure 6).

Figure 5: Red light signal [18].

Figure 6: Green light signal [18].

The task of the tested driver was to react to the red signal by shifting his foot from the accelerator pedal to the brake pedal, braking the vehicle (not to a complete stop) and then continuing driving. In order to make it more difficult, a composite signal in the form of an additional green light (stimulus) was introduced, on which the driver was not supposed to react. The measurement ride lasted about 5 minutes, during which the cameras recorded at least 10 correctly performed measurements, *i.e.* those in which the driver held his foot on the accelerator pedal when the red light was on, then he put it on and pressed the brake pedal. Samples that did not record the full braking sequence were not taken into account.

3.5 Methodology for analysing the results

Analysis of measurement materials recorded during the research was conducted using Lightworks version 12.6.0. It is a freeware program for editing video files. It was used to open two synchronized video files from both lenses at the same time (Figure 7). The next step was to find on the material the moment when the red light turned on and play it back frame by frame. An important stage was to count the number of frames passing from the signal to the first move-

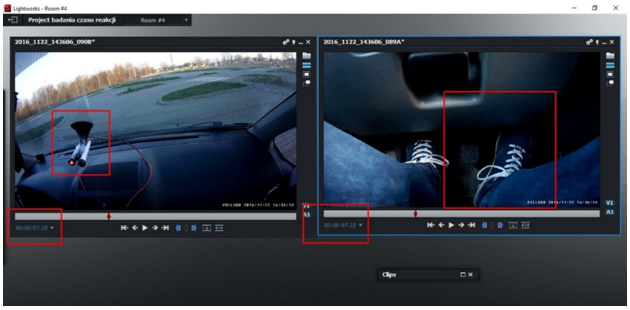

Figure 7: Example of a screenshot from a sample analysis program with the selection of relevant areas [18].

ment of the foot and then to the position of the foot on the brake pedal. Knowing the camera recording frequency of 30 fps, the next step was to divide the number of frames by 30. This way the perception time of t_{r1} and the time of transfer of t_{r3} were obtained. The sum of the results obtained is the total response time of the driver. Calculations were made for each sample and the results were rounded to 0.001 s.

4 Results

The results of individual samples of reaction time measurements obtained during the tests are presented in Tables 6 - 20. Drivers were ranked according to their driving licence possession time, starting with the shortest one.

Table 6: Summary of the results of driver A.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,500	0,300	0,800
2.	0,267	0,267	0,534
3.	0,500	0,300	0,800
4.	0,500	0,233	0,733
5.	0,367	0,267	0,634
6.	0,333	0,300	0,633
7.	0,367	0,200	0,567
8.	0,600	0,300	0,900
9.	0,533	0,333	0,866
10.	0,500	0,267	0,767
11.	0,500	0,233	0,733

Table 7: Summary of the results of driver B.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,267	0,400	0,667
2.	0,600	0,333	0,933
3.	0,500	0,367	0,867
4.	0,433	0,333	0,766
5.	0,500	0,333	0,833
6.	0,333	0,267	0,600
7.	0,600	0,300	0,900
8.	0,300	0,300	0,600
9.	0,267	0,300	0,700
10.	0,600	0,367	0,900
11.	0,500	0,300	0,667
12.	0,267	0,200	0,900
13.	0,600	0,300	0,733
14.	0,500	0,267	0,634

Table 8: Summary of the results of driver C.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,467	0,367	0,834
2.	0,433	0,200	0,633
3.	0,467	0,300	0,767
4.	0,667	0,367	1,034
5.	0,367	0,300	0,667
6.	0,467	0,267	0,734
7.	0,433	0,233	0,666
8.	0,367	0,167	0,534
9.	0,433	0,200	0,633
10.	0,533	0,333	0,866
11.	0,500	0,267	0,767
12.	0,433	0,300	0,733

5 Analysis of results

Analysing the results of the tests carried out (Table 21 and Figure 8), it can be seen that the total response time is not dependent on the length of time the vehicle has been licensed to drive. Both the lowest and the highest scores were obtained by drivers with driving experience, which differs only by a few months. Driver H obtained the lowest average response time of 0.541 s and his measurement results were in the range of 0.433 s - 0.8 s. Driver G had the highest average score of 0.833 s with a standard deviation

Table 9: Summary of the results of driver D.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,333	0,267	0,600
2.	0,333	0,233	0,566
3.	0,300	0,233	0,533
4.	0,367	0,300	0,667
5.	0,333	0,200	0,533
6.	0,367	0,267	0,634
7.	0,500	0,233	0,733
8.	0,333	0,300	0,633
9.	0,367	0,200	0,567
10.	0,300	0,267	0,567

Table 10: Summary of the results of driver E.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,233	0,300	0,533
2.	0,400	0,200	0,600
3.	0,267	0,233	0,500
4.	0,300	0,333	0,633
5.	0,400	0,233	0,633
6.	0,333	0,200	0,533
7.	0,433	0,233	0,666
8.	0,300	0,200	0,500
9.	0,367	0,233	0,600
10.	0,267	0,300	0,567

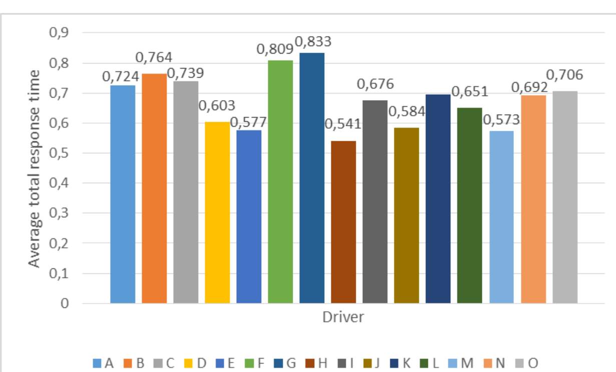

Figure 8: Summary of results of the average total reaction time.

of 0.171 s indicating a high time dispersion. The most repeatable measurements were observed during the passage of driver E, whose average total reaction time was 0.577 s with a deviation equal to 0.059 s. The most repeatable measurements were observed during the passage of driver E, whose average total reaction time was 0.577 s with a deviation equal to 0.059 s. Furthermore, the performance range of this driver was the narrowest and ranged between 0.5 s and 0.666 s, so it can be assumed that even though he did not obtain the lowest result, he reacted best.

Table 11: Summary of the results of driver F.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,400	0,333	0,733
2.	0,867	0,233	1,100
3.	0,467	0,267	0,734
4.	0,533	0,267	0,800
5.	0,733	0,233	0,966
6.	0,300	0,267	0,567
7.	0,300	0,400	0,700
8.	0,433	0,367	0,800
9.	0,733	0,267	1,000
10.	0,467	0,267	0,734
11.	0,333	0,300	0,633
12.	0,600	0,233	0,833
13.	0,333	0,233	0,566
14.	0,767	0,400	1,167

Table 12: Summary of the results of driver G.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,233	0,633	0,866
2.	0,333	0,400	0,733
3.	0,567	0,300	0,867
4.	0,567	0,233	0,800
5.	0,433	0,267	0,700
6.	0,400	0,333	0,733
7.	0,800	0,300	1,100
8.	0,467	0,267	0,734
9.	0,467	0,233	0,700
10.	0,500	0,267	0,767
11.	0,767	0,367	1,134
12.	0,300	0,300	0,600
13.	0,700	0,233	0,933
14.	0,867	0,267	1,134
15.	0,433	0,267	0,700

The average total response time of all tested drivers was 0.680 s. Although the signal was complex, the result obtained is lower than the lower limit of the response time

Table 13: Summary of the results of driver H.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,400	0,267	0,667
2.	0,267	0,200	0,467
3.	0,300	0,133	0,433
4.	0,600	0,200	0,800
5.	0,367	0,233	0,600
6.	0,233	0,200	0,433
7.	0,367	0,200	0,567
8.	0,200	0,233	0,433
9.	0,300	0,233	0,533
10.	0,300	0,233	0,533
11.	0,400	0,200	0,600
12.	0,233	0,233	0,466
13.	0,333	0,167	0,500

Table 14: Summary of the results of driver I.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,500	0,233	0,733
2.	0,300	0,400	0,700
3.	0,300	0,267	0,567
4.	0,267	0,300	0,567
5.	0,533	0,233	0,766
6.	0,300	0,333	0,633
7.	0,400	0,233	0,633
8.	0,333	0,233	0,566
9.	0,633	0,233	0,866
10.	0,200	0,400	0,600
11.	0,500	0,300	0,800

to the simple stimulus discussed in the literature [18]. This discrepancy may result from the application of methods with different measurement accuracy and differentiation of the studied groups of drivers. The standard deviation of 0.145 s indicates a high dispersion of individual measurements, confirming that the response time parameter is an individual feature for each driver.

The measurements carried out, despite the objective to investigate the total response time, also provided data on its components. The mean perception time was 0.416 s and ranged from 0.2 s to 0.867 s. The mean perception time was 0.416 s and 0.2 s to 0.867 s. The mean perception time was 0.416 s and 0.2 s to 0.867 s. The mean perception time was 0.416 s and 0.2 s to 0.867 s. The mean perception time was 0.416 s and 0.2 s to 0.867 s. The mean perception time was 0.2 s to 0.867 s. The mean perception time was 0.416 s. On the other hand, the mean time of transferring the foot from the accelerator pedal to the brake pedal was 0.265 s, and the minimum and maximum values were 0.133 s and 0.633 s, respectively.

Table 15: Summary of the results of driver J.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,267	0,300	0,567
2.	0,267	0,367	0,634
3.	0,300	0,300	0,600
4.	0,433	0,267	0,700
5.	0,300	0,200	0,500
6.	0,300	0,233	0,533
7.	0,333	0,233	0,566
8.	0,300	0,333	0,633
9.	0,267	0,233	0,500
10.	0,367	0,233	0,600
11.	0,333	0,200	0,533
12.	0,267	0,233	0,500
13.	0,533	0,233	0,766
14.	0,367	0,233	0,600
15.	0,267	0,267	0,534

Table 16: Summary of the results of driver K.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,300	0,267	0,567
2.	0,567	0,333	0,900
3.	0,267	0,400	0,667
4.	0,367	0,267	0,634
5.	0,633	0,267	0,900
6.	0,467	0,267	0,734
7.	0,500	0,300	0,800
8.	0,400	0,467	0,867
9.	0,333	0,300	0,633
10.	0,533	0,233	0,766
11.	0,433	0,233	0,666
12.	0,333	0,267	0,600
13.	0,333	0,267	0,600
14.	0,300	0,267	0,567
15.	0,300	0,300	0,600
16.	0,367	0,267	0,634

Table 17: Summary of the results of driver L.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,367	0,200	0,567
2.	0,467	0,300	0,767
3.	0,300	0,267	0,567
4.	0,333	0,167	0,500
5.	0,400	0,200	0,600
6.	0,433	0,200	0,633
7.	0,667	0,200	0,867
8.	0,433	0,200	0,633
9.	0,367	0,233	0,600
10.	0,267	0,233	0,500
11.	0,400	0,167	0,567
12.	0,633	0,167	0,800
13.	0,433	0,200	0,633
14.	0,400	0,233	0,633
15.	0,667	0,233	0,900

Table 18: Summary of the results of driver M.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,533	0,300	0,833
2.	0,367	0,200	0,567
3.	0,400	0,200	0,600
4.	0,333	0,233	0,566
5.	0,300	0,200	0,500
6.	0,300	0,200	0,500
7.	0,367	0,200	0,567
8.	0,333	0,200	0,533
9.	0,367	0,200	0,567
10.	0,300	0,233	0,533
11.	0,367	0,200	0,567
12.	0,300	0,233	0,533
13.	0,467	0,200	0,667
14.	0,300	0,200	0,500
15.	0,333	0,233	0,566

The results of all the measurements of the total reaction time were divided into 12 intervals every 0.1 s, and then the number of results in each of them was summed up (Table 22). The obtained distribution, in the form of a histogram, is shown in Figure 9. The lowest result obtained in the studies was 0.433 s, while the highest was 1.167 s. The most numerous range, containing 60 results, was from 0.600 s to 0.699 s. The next, in terms of numbers, was the range by 0.1 s lower. It included 52 measurements. Out of the whole set of 196 results only 5 were less than 0.5 s, and 7 were in the last two ranges, with the time exceeding 1 s.

Table 19: Summary of the results of driver N.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,333	0,300	0,633
2.	0,267	0,300	0,567
3.	0,333	0,300	0,633
4.	0,233	0,300	0,533
5.	0,667	0,233	0,900
6.	0,300	0,233	0,533
7.	0,700	0,267	0,967
8.	0,333	0,267	0,600
9.	0,500	0,300	0,800
10.	0,500	0,233	0,733
11.	0,433	0,200	0,633
12.	0,567	0,233	0,800
13.	0,500	0,233	0,733
14.	0,400	0,233	0,633

Table 20: Summary of the results of driver O.

The number of the measurement	Perception time t_{r1} [s]	Transfer time t_{r3} [s]	Total response time t_r [s]
1.	0,467	0,267	0,734
2.	0,433	0,233	0,666
3.	0,400	0,233	0,633
4.	0,667	0,200	0,867
5.	0,333	0,300	0,633
6.	0,333	0,300	0,633
7.	0,333	0,367	0,700
8.	0,567	0,267	0,834
9.	0,500	0,267	0,767
10.	0,333	0,333	0,666
11.	0,400	0,233	0,633

The analysis of the results of the research showed that there is no relation between the period of possession of a driving licence and the total reaction time parameter. The driver with the highest average response time was authorized to drive only a few months shorter than the driver with the lowest average test result. The difference between them was 0.292 s. For comparison, the difference between the driver with the shortest driving time and the driver with the longest driving time was 0.018 sec. In order to analyze the data distribution, samples were divided into time inter-

Table 21: Summary of test results.

Driver	Average total response time $\overline{t_r}$ [s]	Deviation σ_{tr} [s]	Minimum $t_{r\ min}$ [s]	Maksimum $t_{r\ max}$ [s]
A	0,724	0,119	0,534	0,900
B	0,764	0,122	0,600	0,933
C	0,739	0,131	0,534	1,034
D	0,603	0,064	0,533	0,733
E	0,577	0,059	0,500	0,666
F	0,809	0,187	0,566	1,167
G	0,833	0,171	0,600	1,134
H	0,541	0,107	0,433	0,800
I	0,676	0,104	0,566	0,866
J	0,584	0,076	0,500	0,700
K	0,696	0,117	0,567	0,900
L	0,651	0,125	0,500	0,900
M	0,573	0,084	0,500	0,833
N	0,692	0,134	0,533	0,967
O	0,706	0,084	0,633	0,867

Table 22: Distribution of results in the individual response time intervals.

Response time interval [s]	Number of results
0 - 0,099	0
0,100 - 0,199	0
0,200 - 0,299	0
0,300 - 0,399	0
0,400 - 0,499	5
0,500 - 0,599	52
0,600 - 0,699	60
0,700 - 0,799	35
0,800 - 0,899	25
0,900 - 0,999	12
1,000 - 1,099	2
1,100 - 1,199	5

vals with a span of 0.1 s. It was observed that most of the results were located in the range of 0.600 - 0.699 s. In order to analyse the distribution of data, samples were divided into time periods with a span of 0.1 s. In order to analyse the distribution of data, samples were divided into time periods with a span of 0.1 s. In order to analyse the distribution of data, samples were divided into time periods with a span of 0.018 s. The average total reaction time for all the measurements was 0.680 s. The standard deviation of 0.145 s indicates a high dispersion of the results.

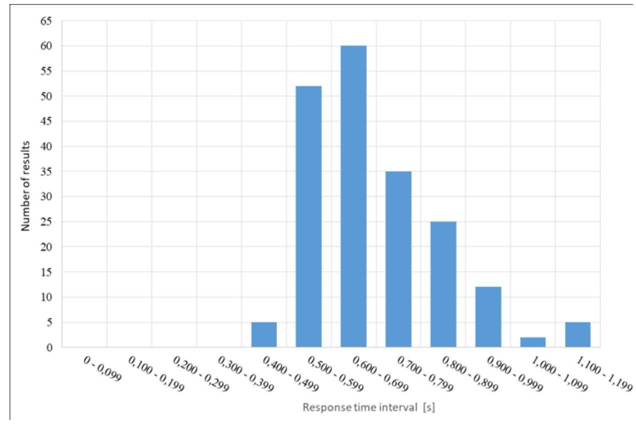

Figure 9: Distribution of results in the individual response time intervals.

6 Conclusions

The driver's response time is important both for the course of the accident and for its subsequent analysis. At the same time, this parameter cannot be accurately determined. Each event is characterized by a number of parameters, which in the case of response time are variable and individual for each driver. In the reconstruction of traffic events, the average values determined for a situation with similar conditions as the analyzed event are used. Methods used to determine this parameter differ from each other in accuracy and the way the driving conditions are represented, so it is not possible to unequivocally determine which of them is the most appropriate.

The aim of the study was to investigate the total response time of the driver in real-world driving conditions. They used a method combining representation of traffic conditions by free driving and computer analysis of the obtained measurements. In this way, the advantages of the two most popular test methods were combined. The measurements confirmed the correct functioning of the research station and provided important data for the analyzed issue.

The results of the study showed that there is no correlation between driving seniority and total response time. The research group consisted of 15 drivers, different in terms of age and gender The drivers with the lowest and highest score had the same period of time. The applied test stand can be used not only to measure the reaction time, but also to evaluate the driver's behaviour during an accident. The described method has a wide range of possibilities to adapt it to the scenario of conducted tests. Measurements carried out at work included 5 minutes of free driving by each driver, during which he had to react to a stimulus in the form of two lamps in different colors. In order to obtain more accurate results, it is possible to extend the time of each test and the period between individual measurements. This way, the driver will be less likely to expect the signal. Moreover, it is possible to extend the stimulus by adding more lamps or a sound signal. This will make it more difficult to recognize the appropriate signal assigned to individual reactions. Another factor influencing the accuracy of measurements is the size of the research group.

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