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RESEARCH ON DRIVERS' REACTION TIME IN DIFFERENT CONDITIONS

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Проведені експериментальні дослідження дозволили визначити залежність між функціональним станом водіїв та часом їх реакції у лабораторних та реальних умовах. На основі цих досліджень можна визначити, наскільки формування часу реакції та його складових залежить від психофізіологічних особливостей водіїв та впливає на безпечні режими руху. Результати роботи необхідно враховувати для розробки автоматизованих систем управління дорожнім рухом

Ключові слова: функціональний стан, час реакції, швидкісний режим, автоматизована система дорожнього руху

Проведенные экспериментальные исследования позволили определить зависимость между функциональным состоянием водителей и временем их реакции в лабораторных и реальных условиях. На основе этих исследований можно определить, насколько формирование времени реакции и его составляющих зависит от психофизиологических особенностей водителей и влияет на безопасные режимы движения. Результаты работы необходимо учитывать для разработки автоматизированных систем управления дорожным движением

Ключевые слова: функциональное состояние, время реакции, скоростной режим, автоматизированная система дорожного движения

1. Introduction

Currently, the most unpredictable aspect of road safety is the driver's behavior. The information load and the road conditions have a significant effect on the driver, especially if the amount of information is scarce or excessive. The accuracy of accepting and producing actions, which is understood as the driver's reaction time, depends mainly on the psychophysiological state [1]. Among the main indicators that make it possible to analyze the functional state in detail, the important factors are the stress index (SI), the regulatory system activity index (RSAI), as well as the frequency and average amplitude of the rhythms of the electroencephalogram (EEG) [2–4].

The driver's reaction time is the manifestation of a complex mental process. Understanding, prediction, and management of this reaction are possible only after determining the psychophysiological mechanisms of the entire process of perception. In a study of the driver's response to stimuli, it is necessary to take into account the driver's functional state. Otherwise, it is impossible to explain the factors such as the ambiguity of the time of reacting to the same signal, a change in the response time, or a shorter duration of the reaction time [5].

The driver's reaction time largely depends on the speed and the accuracy of the appropriate actions to stimuli (pressing the brake pedal, turning the steering wheel, switching the gear, etc.), especially at a high speed [6–8]. The driver perceives increasing amounts of information about the road users, vehicles' regulation, the road condition and the environment, as well as about the work of the car's systems and parts. In addition, the driver needs to analyze continually any information input and to make decisions, often in shortage of time. Long and intensive work of a driver results in a hypertension in the driver's nervous system and requires constant discipline and attentiveness. This significantly affects the functional state. Often, it is just the latter circumstance that causes road accidents [4].

The reaction time of drivers in most cases determines the correct selection of the movement mode and affects road safety. Therefore, the results of the study of the psychomotor reaction with regard to the driver's functional state can help improve road safety. The findings of the study will facilitate a broader analysis of the driver's behavior under various conditions [7, 8].

2. Literature review and problem statement

The reaction time of drivers is an important indicator of their professional activities. In [5, 9], the researchers found that the driver's information processing is not a passive reflection of the statistical characteristics of the signal but an active search for the way of solving a problem. The driver's behavior in dangerous situations has been studied in [1, 5, 6, 8, 10, 11]. Each of the studies is dedicated to researching the driver's work under the influence of various factors both in real and laboratory conditions [1, 5, 6, 8, 10, 11].

Different countries have different regulations on the driver's reaction time. In particular, Western European calculations that are associated with urban traffic entail that the reaction time in town should be equal to 0.75 sec while the reaction time out of town should be 2.5 sec [9]. In Ukraine, the average emergency braking reaction time of drivers is about 1.16 sec [12]. The reaction time depends on the intensity of the driver's attention, that is, the degree of tension while perceiving simple and difficult traffic situations. In urban traffic, when the intensity of attention is high enough, the reaction time is much shorter. Czech and Slovak scholars argue that the preparation time for the braking reaction is about 0.6–0.8 sec, whereas for a distracted driver it increases to 1.1–1.7 sec [9, 12, 13].

Reactions may be simple or complex [4]. A reaction is simple if there appears a single and previously known irritant to which the driver responds with a single well-practiced movement.

However, drivers often find themselves in such difficult traffic situations when it is necessary to take into account the total number of objects in order to identify the most important ones at any given moment and to respond with an appropriate action to guarantee safe mode movement [13, 14].

Under normal circumstances, the value of the driver's reaction time varies from 0.2 sec to 1.5 sec. Research has disclosed that a driver's reaction depends on the complexity of the reaction itself, the driver's skill, as well as the physical and mental states of fatigue, illness, or intoxication [12].

The reaction time varies for different drivers. It declines with the acquisition of skills and an overall driver competence [7, 8]. Experienced drivers do most of the actions almost automatically, spending minimum time. The reaction time of one and the same driver may change due to various reasons. The driver's reaction time increases under complicated traffic conditions or their sudden changes. This increases the complexity of the response. If the driver predicts the emergence of some danger or obstacles in advance (i. e. if it he/she is psychologically prepared), it almost twice reduces the reaction time [4].

When driving a car, the driver may face all sorts of obstacles and dangers. To avoid danger, the driver must carefully evaluate it and choose the most effective action: stop the car, go round the object of danger, or drive past it at increased speed. This complex assessment and the choice of action constitute a complex reaction of the driver [1].

A complex reaction of a driver is associated with choosing the right number of possible steps. It requires much more time. The average response time of a complex reaction is assumed to be 0.8–1.0 sec. This time can vary from 0.4 sec to 1.5 sec [12].

The results of [15, 16] show the importance of psychophysiological research on drivers' behavior in dangerous traffic situations that are modeled for both real and laboratory conditions.

3. The purpose and tasks of the study

The purpose of the present study is to determine the patterns of changes in the driver's reaction time and its components under different conditions. The reaction time depends on the age and the driving experience [4]. To determine the effect of the information load on the functional state of drivers, the tests were conducted in laboratory and field (real) conditions.

The purpose was achieved by doing the following tasks:

– to specify the effect of different conditions on the drivers' reaction time;

– to determine changes in the reaction time of the tested drivers depending on their age and driving experience;

– to define the effect of the functional state of the tested drivers on the components of their response time.

4. Methods of studying the influence of the functional state of a driver on the formation of reaction time under different conditions

The job of a driver is always associated with dangerous situations where the speed of the sensorimotor response is essential. Most often, the response time refers to the time period that includes the time of the stimulus identification, decision-making, and appropriate action [5].

According to the present-day ideas about the mechanism of perceiving environmental signals, the driver's reaction time can generally be represented as a block diagram (Fig. 1).

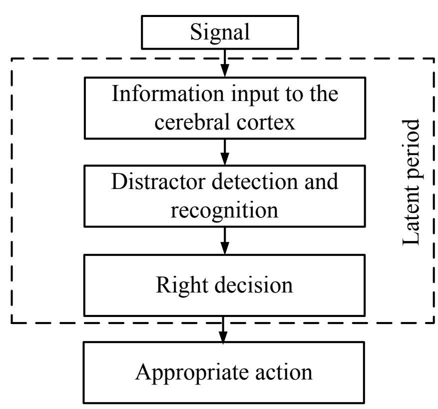


Fig. 1. A block diagram of forming the driver's reaction time

The interval between the time of the signal and the start of a respective action is the driver's response time.

The experimental tests were conducted in both laboratory and field conditions. They were based on the following requirements:

– implementation of professional motivation in the experiment;

– continuous registration of the drivers' functional state;

– performance of professionally specific tasks;
– reliability of the results [17].

The participants of the experiment were three groups of drivers. The first group included drivers aged 18 to 25 years with a driving experience of less than 5 years. The second group comprised drivers aged 26 to 40 years with a driving experience of 5 to 15 years. The third group included drivers aged more than 40 years with a driving experience of more than 15 years [4, 13]. Each group under consideration consisted of drivers to provide 95 % of reliability of the research results. 70 % of the selected drivers were sanguine. The group composition corresponded to the ratio of drivers in a real traffic flow [4, 7, 8].

The reaction time of the drivers in different conditions was determined by a computer program. Structurally, it is described as a block diagram (Fig. 2).

This program consists of two main parts: the main cycle of the program and the test. The main program cycle (Fig. 2, *a*) begins with the output of the information window and registration of each experiment participant. Further, the drivers are to choose one of the two tests provided by this program.

The two test programs are based on the flowchart test assembly (Fig. 2, *b*). The test begins with displaying its window and starting the test timer. Next, an image is displayed on the screen for each driver to react with a specific action. After the test, the driver is given the opportunity to take the test again or to go to the next test.

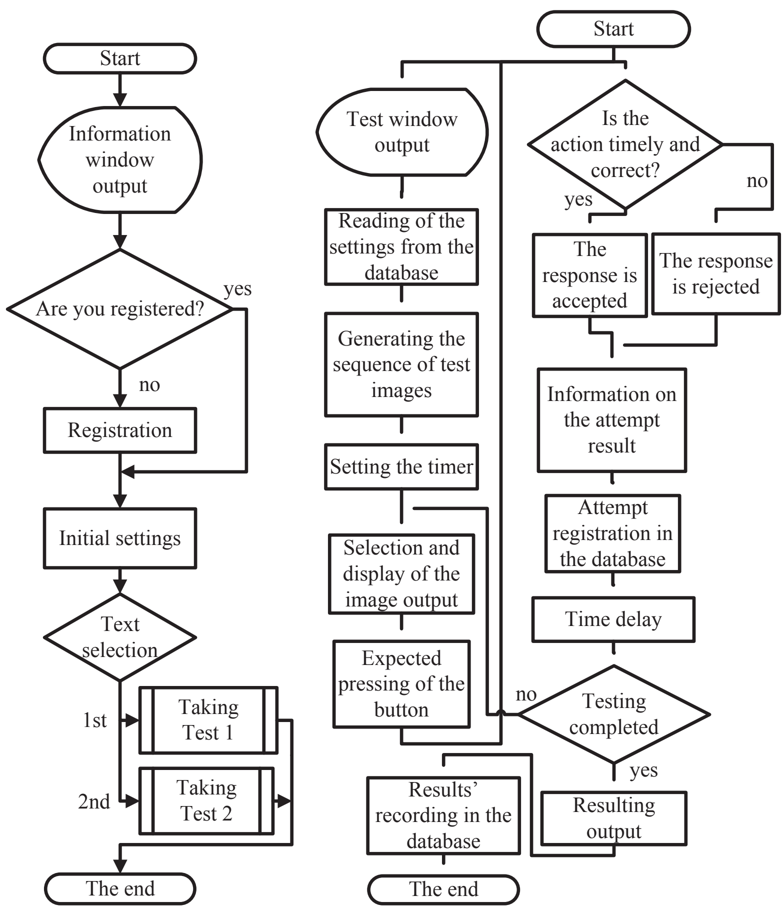


Fig. 2. A block diagram to determine the driver's reaction time: *a* – the main cycle of the program; *b* – the testing itself

The main window of the program to determine the reaction time of the drivers is shown in Fig. 3.

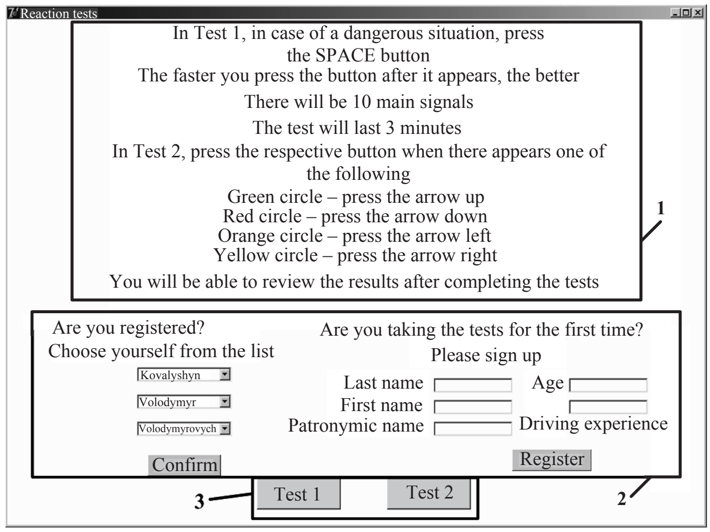


Fig. 3. The main window to determine the driver's reaction time: 1 – the block of the main conditions for the participant; 2 – the registration form; 3 – the choice of the test to determine a simple or complex reaction

The research results are entered into a database that contains the following information: the last name, the first name and the patronymic name of the driver; the age and the driving experience; the date and the time of the experiment; the functional state of the driver; the response time for each individual signal; the average response time in a test; and the percentage of correct answers.

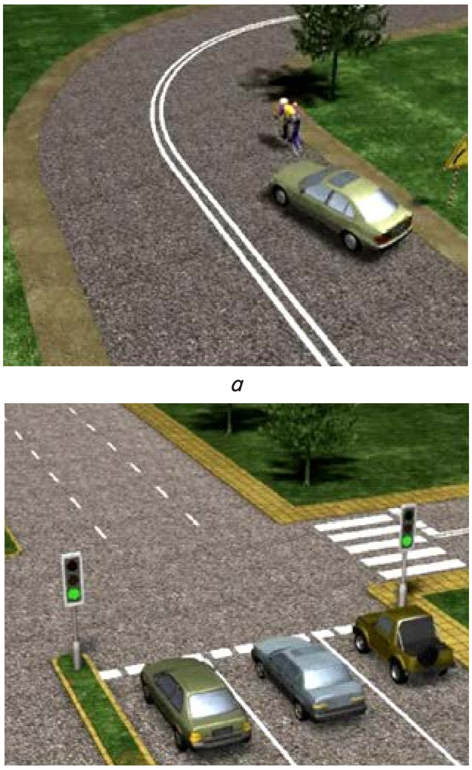
This computer program helps explore the reaction of drivers in difficult and simple situations. The first test of this program is built on the basis of dangerous situations that may happen to drivers. The main goal is to recognize a dangerous situation that appears among others and react to it (Fig. 4) [12].

The second test required to respond to every signal shown on the screen with an appropriate response action. This test reflected a complex reaction of the drivers to stimuli (Fig. 5).

The reaction time of drivers in real-life conditions is typically determined by the common methods of using wireless communication, video cameras, and assisted measurements [4, 12]. The components of the reaction time of the drivers at the wheel were determined while taking into account all the positive aspects of these methods.

The research did not entail arranging special training grounds. All work was performed on the road. The driving was conducted with a constant surveillance of the traffic situation. The drivers were given various signals to which they were to respond with an appropriate action. Meanwhile, the drivers were to comply with a given mode of movement [17].

This technique made it possible to define a simple reaction to the braking (in response to the red signal) and a complex reaction (when each of the signals required responding with an appropriate action). In addition, a complex reaction was associated with remembering the sequence of the appearing signals.



a

b

Fig. 4. The first test of the program to determine the driver's reactions: *a* — a dangerous situation to respond to; *b* — a safe situation to ignore

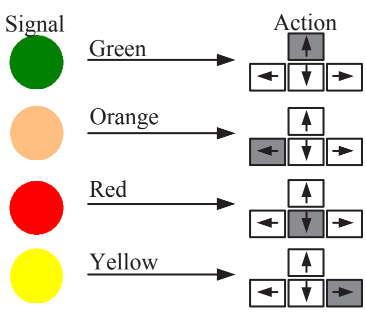


Fig. 5. The signals that elicited the driver's response and corresponding actions for determining a complex reaction

The research of the reaction time components of the drivers' reactions with regard to their functional states was conducted using the NeuroCom software package (Ukraine) [3]. This package is based on recording the electroencephalogram (EEG), which makes it possible to characterize the excitatory and inhibitory processes in the cerebral cortex. This package determines the duration of the inflow of information to the cerebral cortex as well as detects and identifies the stimulus to make the right decision [1].

To determine the reaction time of the drivers by both the stimulus program and the EEG recordings, a remote control was designed to be connected in parallel to the NeuroCom package and the program of determining the reaction time [12].

One of the experimental stages of the laboratory tests is shown in Fig. 6.

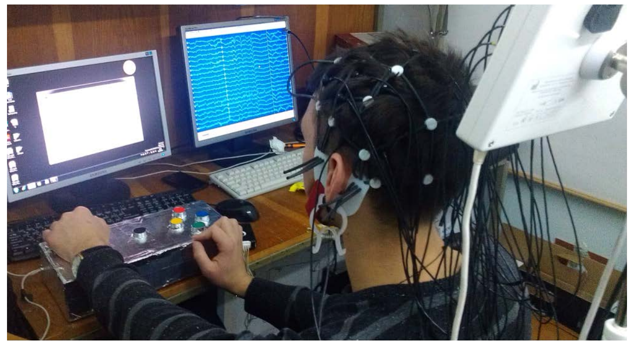


Fig. 6. The EEG recording under a load of information

The EEG recording was used to determine the functional states of the drivers during the experiment. The main characteristics of the EEG recording are the frequency and the average amplitude of α, β, θ, δ and γ rhythms [3, 18]:

– the alpha wave is expressed with closed eyes, at rest, and with relaxation of muscles. It is blocked at light stimulation, increased attention, and mental stress;

– the beta wave amplitude increases with attention to the situation, mental stress, or emotional disturbance;

– the gamma wave increases in solving problems that require the most concentrated attention;

– low-amplitude (20–30 mV) delta wave oscillations can be registered at rest in some forms of stress and under prolonged mental work;

– the theta rhythm is mostly observed during shallow sleep or a nap.

The research was conducted with parallel evaluation of each driver's functional state by means of the hardware and software Holter monitoring electrocardiogram Cardio Sens (Ukraine). The functional state was analyzed using indicators such as the stress index and the activity index of the regulatory systems [2, 4, 5].

The stress index is a measure that is used when assessing the degree of stress on the regulatory mechanisms, based on the frequency variations' spread of the heartbeat [4]. Its value is determined by analyzing the distribution schedule of the cardio intervals (heart rate), or the formula [2]:

$$IH = \frac{AMO}{2Mo \cdot \Delta X}, \qquad (1)$$

where AMO is the mode value, %; MO is the mode, sec; ΔX is the variation range, sec.

Individual states and characteristics of the heart rate regulation system were assessed by determining the RSAI in conventional units [4]. The RSAI helps differentiate between varying degrees of stress in the regulatory systems and assess the adaptation abilities. The RSAI is defined as the sum of five criteria:

$$RSAI = |A| + |B| + |C| + |D| + |E|, \qquad (2)$$

where A is the cumulative effect of regulation; B is the function of automatism; C is vegetative homeostasis; D is stability regulation; E is the activity of nerve centers.

5. The results of studying the drivers' reaction time in laboratory and real conditions

The results of the statistical tests on the latency and the response time of the drivers under various conditions are shown in Table 1.

Table 1

Statistical values of the latency and the reaction time of the drivers in laboratory and real conditions

Range, sec	Research conditions							
	Laboratory conditions				Real conditions			
	Frequency, %		Frequency accumulation, %		Frequency, %		Frequency accumulation, %	
	LP	RT	LP	RT	LP	RT	LP	RT
0...0.25	2.50	–	2.50	–	–	–	–	–
0.25...0.50	78.76	1.50	81.26	1.50	13.04	–	13.04	–
0.50...0.75	16.12	9.35	97.38	10.85	75.70	–	88.74	–
0.75...1.00	2.62	40.77	100.00	51.62	10.00	1.50	98.74	1.50
1.00...1.25	–	30.29	–	81.91	1.26	4.21	100.00	5.71
1.25...1.50	–	12.65	–	94.56	–	43.25	–	48.96
1.50...1.75	–	3.82	–	98.38	–	33.51	–	82.47
1.75...2.00	–	1.62	–	100.00	–	14.1	–	96.57
2.00...2.25	–	–	–	–	–	2.94	–	99.51
2.25...2.50	–	–	–	–	–	0.49	–	100.00

Note: LP is a latent period, sec; RT is the drivers' reaction time, sec

The results were processed to build cumulative curves of the interval distributions of the latency and response times in the laboratory and real conditions (Fig. 7).

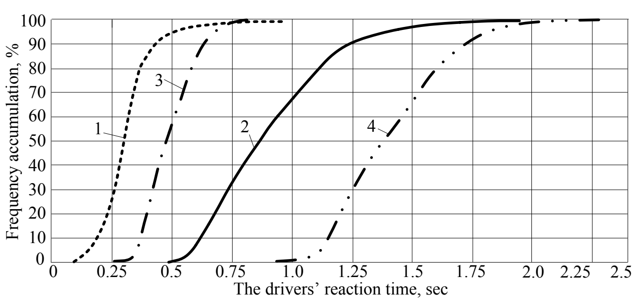


Fig. 7. The cumulative curves of the interval distribution in the driver's performance: 1 – the latent time in the laboratory conditions; 2 – the reaction time in the laboratory conditions; 3 – the latent time in the real conditions; 4 – the reaction time in the real conditions

If the overall reaction time is considered with no regard to the complexity of decision-making in the laboratory conditions, the latency period is on average 30 % (0.58 sec) (Fig. 7). It means that in some difficult situations the time to make an adequate decision is longer than the reaction in a simple situation.

The drivers' reaction time was statistically analyzed for car driving in real conditions. The duration of a simple reaction to the braking was the shortest. The duration of a complex reaction as its complexity increased was twice as long. The duration of the latent period in real terms varied from 0.25 sec to 1.07 sec. The average proportion of the latent period was 45 % of the total length of the drivers' reaction time.

Table 2 shows the research results on the duration of the drivers' reaction time components, registered by means of the NeuroCom package, the designed remote control (Fig. 6), and the specially designed computer program (Fig. 2).

Table 2

The components of the drivers' reaction time in different conditions

The duration of the response time components		The place of the experiment			
		Laboratory		Real conditions	
		Simple reaction, sec	Complex reaction, sec	Simple reaction, sec	Complex reaction, sec
The latent period	The flow of information to the cerebral cortex	0.034			
	The detection and identification of the stimulus	0.109	0.290	0.151	0.312
	The right decision-making	0.127	0.465	0.295	0.724
Appropriate action		0.503	1.131	0.710	1.360
The overall response time		0.773	1.920	1.190	2.430

The frequency and the amplitude of the EEG rhythms were recorded by using the NeuroCom package for each experiment; the results are shown in Table 3.

Table 3

The frequency and amplitude of the rhythms

Type of the test	The EEG values	The EEG rhythm				
		Alpha	Beta	Gamma	Delta	Theta
At rest	Frequency, Hz	9.28	13.67	40.34	0.73	7.81
	Amplitude, mV	23.15	10.58	3.32	15.96	8.42
Taking the test in simple situations	Frequency, Hz	10.33	18.10	41.22	2.18	7.26
	Amplitude, mV	9.31	11.13	6.92	17.21	8.07
Taking the test in difficult situations	Frequency, Hz	10.45	19.16	40.62	2.27	6.89
	Amplitude, mV	7.25	12.49	8.05	16.88	6.87

The EEG rhythms (Table 3) increased by 15–20 % when the tests were conducted for simple and difficult situations, compared to the drivers' being at rest. It is noteworthy that an increased information load changed the values of the beta, gamma and delta rhythms. These values increased to reflect the drivers' mental stress, focused attention, and prolonged mental work. The indices of alpha and theta rhythms fell as the problem became complicated.

The influence of the functional state of the different groups of drivers was researched using the stress index and the activity index of the regulatory systems with regard to reactions under different conditions. For clarity, the research results on the reaction time dependence on the information load and the RSAI are shown only for the real conditions (Fig. 8, 9).

It should be noted that when in the real conditions the information load and the RSAI increased or decreased 2 times, the drivers' reaction time increased, on average, by 0.20–0.30 sec.

While analyzing the results of the tests for the drivers in the laboratory conditions, it was found that if the drivers' fatigue increased by 25 %, the average response time increased by 20 %.

Table 4 presents the summary of the research results on changes in the reaction time of the drivers of different age groups depending on their functional states.

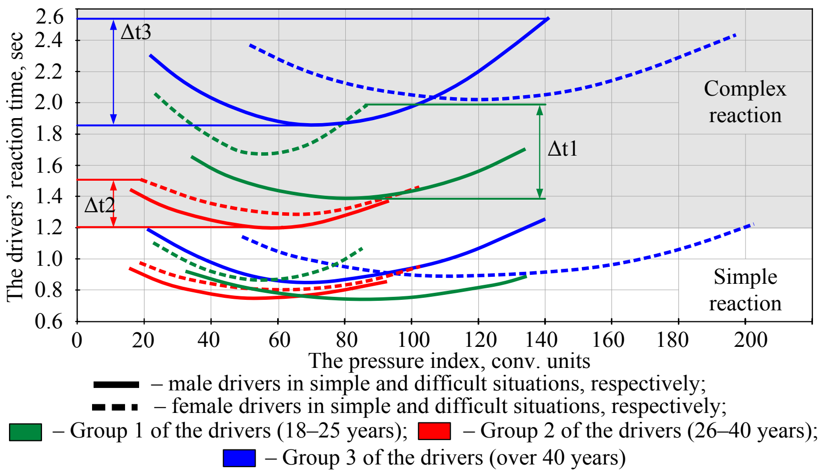


Fig. 8. The dependence of the drivers' reaction time on the pressure index in the real conditions: Δt is the difference between the maximum value and the minimum value of the drivers' reaction time in each group

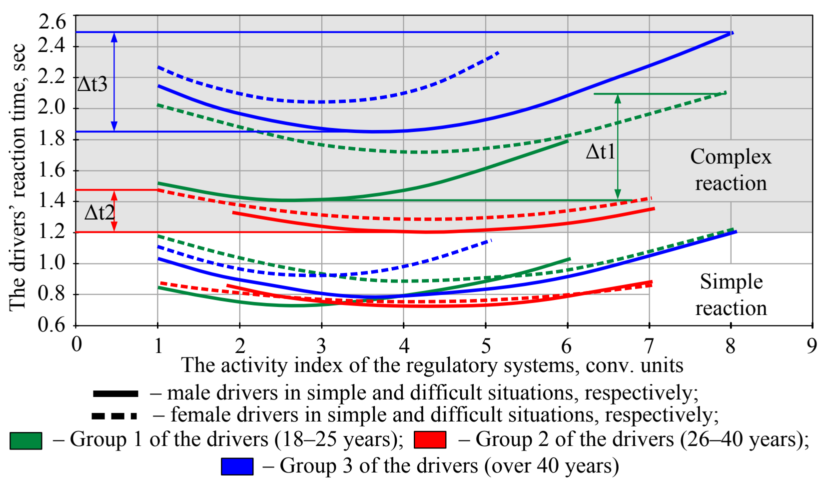


Fig. 9. The dependence of the drivers' reaction time on the activity index of the regulatory systems in the real conditions: Δt is the difference between the maximum value and the minimum value of the drivers' reaction time in each group

Table 4

Summary of the reaction time of the drivers of different ages depending on their sex under different conditions

The driver's reaction type	The driver's sex	The reaction time in each age group, sec					
		Laboratory conditions			Real conditions		
		Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Simple	Male	0.23–0.31	0.27–0.38	0.30–0.41	0.75–0.90	0.70–0.85	0.80–1.10
	Female	0.29–0.38	0.28–0.39	0.31–0.42	0.90–1.10	0.80–0.90	0.90–1.20
Complex	Male	0.55–0.63	0.71–0.89	0.85–1.05	1.45–1.70	1.25–1.38	1.90–2.20
	Female	0.71–0.85	0.75–0.95	0.90–1.10	1.70–2.00	1.35–1.50	2.10–2.43

The reaction time of the drivers in different age groups varied quite extensively. First of all, it depended on their functional state, age, and driving experience. The correlation of the experimental dependencies was evaluated by the R-squared criterion and the adjusted R-squared criterion being close to 1 [4].

It was found that each driver in some specific traffic situation behaved differently. Above all, such a behavior difference was displayed by the functional state of the driver that affected the reaction time. Thus, at a speed of 50 km/h, the reaction time increased by 0.2 sec, which resulted in increasing the vehicle stopping distance by more than 3 meters.

According to the research findings on the drivers' reaction time on the basis of their functional state, the safe speed of the vehicle for calculations in projects of automated control systems should be taken as 8 km/h lower than the previously recommended values.

The resulting patterns of the driver's reaction time with regard to distance visibility and safe vehicle speed are essential for the information base to determine safe speed modes and to justify speed limits.

While driving the car at short distances of visibility, the safe speed should be decreased by an average of 10 %, taking into account the reaction time of the driver.

6. Discussion of the results of researching the influence of the drivers' functional state on the reaction time duration

Fig. 7 shows that the duration of the latent period in the laboratory conditions varied from 0.13 sec to 0.79 sec at the values of the reaction time ranging from 0.54 sec to 1.92 sec. In more difficult situations, the duration of detecting, identifying and accepting the drivers' corrective action increased. In the real conditions, it was found by analyzing the cumulative curves of the interval distributions of the latent period and the reaction time that the minimum time of the drivers' reaction was 0.81 sec, whereas the maximum was 2.43 sec. It does not contradict the empirical data that are well known from [1, 5, 7.8, 10, 16, 19, 20], the authors of which also studied the reaction of drivers in various conditions. However, in contrast to the research results published in the previous studies, the findings of this study make it possible to understand in more detail the process of forming the reaction time of drivers.

When conducting the research on the components of the drivers' reaction time by using the NeuroCom package and the computer program (Table 2), it was found that the duration of the flow of information to the cerebral cortex in different situations was on average 0.034 sec. From the total length of the drivers' reaction, the detection and identification of the stimulus took an average of 0.22 sec (15 %), the right decision was taken within 0.40 sec (27 %), and the appropriate action required 0.93 sec (58 %).

The description of the grouped and tested drivers (Fig. 8, 9) in the real conditions revealed that the least effect of the functional state on the reaction time was produced in the second age group, whereas the most affected drivers were in Group 3. The fastest response time in the real conditions was produced by the drivers of the second age group (1.37 sec). The drivers' reaction time was 25 % longer (1.71 sec) in the first group and 60 % longer (2.43 sec) in the third group.

This is due to the fact that the reaction time in real-life conditions is affected by the driving experience. The limited driving skills of the drivers of the first group thus required more reaction time. The third group results depended on the psychophysiological factors: the drivers faster got tired of driving.

The smallest impact on the functional state of the drivers' reaction in the laboratory conditions was produced on the drivers of the second age group, whereas the biggest impact was produced on the drivers of the third group.

It is especially noteworthy that in all of the age groups the male drivers' reaction time was by 15 % shorter than the reaction time of the female drivers. Obviously, this process of the drivers' functional state on their reaction time is an important factor in determining the braking distance of the car and the safe visibility distance in difficult driving conditions. For safety reasons, it is particularly important to interpret the research results about the drivers' reaction time in terms of setting safe modes and justifying speed limits. When creating an automated traffic control system, the response time is a crucial factor.

7. Conclusion

Regularities in changes in drivers' reaction time were determined in both laboratory and field conditions. The results obtained in the real conditions show that the reaction time of drivers on average is twice as long as in the laboratory conditions. However, the advantage of the laboratory conditions is the ability to eliminate the influence of extraneous factors on the driver's reaction time.

The obtained results were analyzed to reveal changes in the drivers' reaction time in different age groups. It was determined that in the laboratory conditions the difference between the maximum and minimum values of the drivers' reaction time (Δt) in the first age group was 0.30 sec, in the second group it was 0.24 sec, and in the third group it was 0.25 sec. In the real-life conditions, the difference for the first group was 0.55 sec; for the second group it was 0.25 sec, and for the third group it was 0.53 sec. These results show the impact of the functional state on the drivers' reaction time in both simple and difficult situations. Each driver has an individual optimum functional state for the best response to a stimulus. If there was a '+' or '–' deviation in the values of the information load and the regulatory system activity index, the functional state of a driver worsened and extended the reaction time.

The values of the main components of the drivers' reaction time were obtained by using a computer program and the software packages NeuroCom and Cardio Sens. It was determined that the proportion of latency relative to the total duration of the drivers' reaction time varied on average from 30 % to 45 %.

The research results are used in determining the visibility distance and the safe vehicle speed under different conditions. These indicators should be taken into account for determining safe speed modes and justifying speed limits in automated traffic control systems.

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ESTIMATION OF TRANSPORT ACCESSIBILITY OF THE CAPITAL ECONOMIC REGION

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Визначено методику для обчислення транспортної доступності регіону. Обгрунтовано вибір Столичного економічного району як регіону для визначення транспортної доступності. Адаптовано іноземний підхід до обчислення транспортної доступності Столичного економічного району України. Формалізовано вираз для обчислення потенційної транспортної доступності. Розроблено шкалу рівнів доступності. Проведено кількісну оцінку значень транспортної доступності міст регіону відносно столиці

Ключові слова: транспортна доступність, транспортне планування,транспортна мережа, автомобільний транспорт

Определена методика измерения транспортной доступности региона. Обоснован выбор Столичного экономического района как региона для определения транспортной доступности. Был адаптирован иностранный подход к измерению транспортной доступности Столичного экономического района Украины. Формализовано выражение для измерения потенциальной транспортной доступности. Разработана шкала уровней доступности. Проведена количественная оценка значений транспортной доступности городов региона относительно столицы

Ключевые слова: транспортная доступность, транспортное планирование, транспортная сеть, автомобильный транспорт

1. Introduction

Modern researchers utilize various approaches and indicators for analyzing the state of transport systems development. Among other indicators that combine technical and economic influence, the indicator of transport accessibility should be highlighted.

Transport accessibility (TA) as the indicator of efficient functioning of transport systems is used to define the attractiveness of the region for passengers with regard to location of main transport nodes. The given indicator reveals the efficiency of capital investment into transport infrastructure projects. TA is an essential element of planning and development of the national transport system (TS).