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Original article

The importance of the vehicle driver's cognitive processes in shaping road safety

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ABSTRACT

The article addresses road traffic safety. The issue constitutes a contemporary and fundamental social problem. That is because over 1.3 million people die on roads annually globally, while in Poland alone about 3,000 people.

The article aims to discuss the factors influencing road safety, emphasizing the human factor and its complexity. A hypothesis was made that the efficiency and nature of cognitive processes affect human activity during road traffic. The method of analyzing the subject literature and the available statistical data and the method of synthesis were used to verify the formulated hypothesis.

The text presents the characteristics of the most important cognitive processes and attempts to analyze their significance for the proper functioning of the person driving the vehicle. It is an issue that requires particular emphasis in the process of building road safety. Scientific research and social practice indicate that a significant proportion of road accidents result from inappropriate reception of stimuli from the environment and storage, transformation, and use of information, i.e., broadly understood disorders of cognitive processes.

KEYWORDS

safety, driver, cognitive process, road traffic

Introduction

Road safety is a current and crucial social problem. In particular, the term refers to ensuring the safety of all road users (protected and unprotected[1]) on roads, in residential areas, and in traffic zones. There is no legal definition of this concept, but its semantic content is primarily shaped by practice, especially in the context of challenges in the indicated area of security.

[1] Protected road users are people using passenger cars, trucks, tractors, buses, trams and trolleybuses, while unprotected road users include pedestrians, cyclists, moped riders, motorcyclists, as well as people using quadricycles and other devices intended for recreation and practicing extreme sports, e.g., scooters, roller skates. Cf. Krajowa Rada Bezpieczeństwa Ruchu Drogowego. *Narodowy Program Bezpieczeństwa Ruchu Drogowego 2013-2020*. Warszawa: Ministerstwo Transportu, Budownictwa i Gospodarki Morskiej; 2013, p. 6.

Despite the actions of various entities responsible for the state of public safety and public order, participation in road traffic is associated with many challenges, usually in the form of threats, often ending in death or severe injury to people involved in road incidents. The scale of the problem is illustrated by, among others, data from the World Health Organization, which shows that 1,354,840 road users died in 2019 alone. From the beginning of this year to mid-March alone, nearly 300,000 fatal incidents were recorded, and car drivers constituted about a third of all injured [1]. They are the largest group of victims among all road users and, at the same time, the largest group of road accident perpetrators.

Road safety depends on many factors. However, the most critical link is always human. Their proper functioning in the cognitive, personal, and executive areas is the basis for proper functioning in road traffic situations.

Nowadays, while shaping road traffic safety, great importance is attached to the development of infrastructure and care for the efficiency of vehicles authorized to traffic. Meanwhile, a human – a driver with all his/her psychophysical attributes – should be the subject of even more excellent care than before. So far, while setting the general framework for shaping the desired level of road safety (primarily in the National Road Safety Program 2013-2020 [2]), but also formulating detailed guidelines, attention has been focused only on the manifestations of dangerous behaviors of pedestrians, cyclists and moped riders, motorcyclists, drivers, and their passengers, without simultaneously looking for the causes of such behaviors. The issues of efficiency and quality of functioning of these people's cognitive processes are largely ignored. Meanwhile, research [3; 4] and social practice have provided evidence for many years that human cognitive functioning is imperative for human behavior in road traffic.

Therefore, this article aims to indicate the role of selected cognitive processes in shaping the level of road safety in relation to people driving vehicles. For the research, the method of the subject literature review and the available statistical data and the method of synthesis were used.

Road traffic safety state in Poland

Since the beginning of the 1990s, the number of cars in Poland has been growing steadily – their increase was 228% over the last three decades (1990-2018). At the same time, during that period, a decrease in the number of road accidents by one third (37%) and fatalities by almost two-thirds (61%) [5, p. 6] was observed. Despite these positive trends, Poland's condition of road safety is still unsatisfactory, as evidenced by the annual Police statistics. Figure 1 displays data for the years 2009-2019.

In 2009-2019, there was a clear improvement in both the number of road accidents (–31%), of the injured (–37%) and killed (–36%) [6, p. 6-8]. In the last analyzed year, compared to the previous year, the number of accidents and injured people decreased, but there was a slight increase in the number of people killed (indicators per 100 thousand inhabitants were as follows: accidents – 78.9 in 2019 and 82.5 in 2018, the number of the injured – 92.4 in 2019 and 97.3 in 2018, the number of fatalities – 7.6 in 2019 and 7.5 in 2018) [6, p. 12].

The voivodships significantly differed in terms of the road safetylevel. The highest accident rates (the value of the ratio per 100 thousand residents) were recorded in the following voivodships: Łódzkie (136.2 accidents), Wielkopolskie (111.4 accidents), and Pomorskie (98.3 accidents). At the same time, the greatest number of people that suffered accidents were in these voivodships (Łódzkie – 164.5 injured, Wielkopolskie – 130.6 injured, Pomorskie – 133.1 injured). The rate of more than 100 injured people per 100 thousand inhabitants were

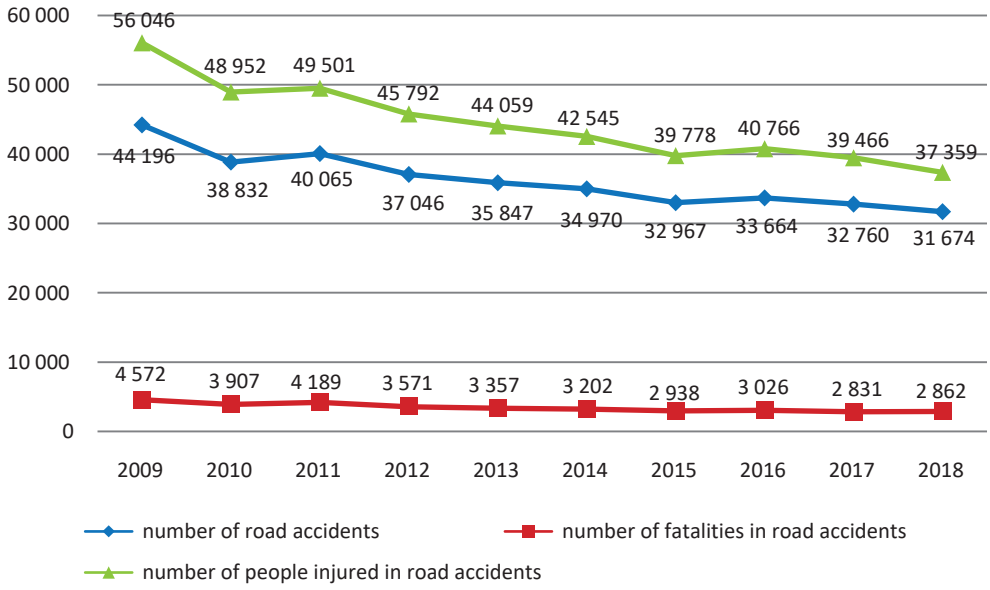

Fig. 1. Trends in the occurrence of road accidents and the injured and fatalities in these accidents in 2009-2018
Source: Own study based on: [6, p. 6-8].

registered in the following voivodships: Mazowieckie (without the KSP – 114.4), Małopolskie (109.1), Warmińsko-Mazurskie (104.2) and Świętokrzyskie (100.3). In turn, Kujawsko-Pomorskie, Podlaskie, and Lubelskie are the voivodships where the largest number of people per 100,000 inhabitants died in road accidents (respectively: 22.4, 18.1, and 14.9). At the same time, these voivodships were the safest last year as for the number of road accidents and injured persons (respectively: 46.6 accidents and 103.6 injured, 56.8 accidents and 106.0 injured, 57.3 accidents and 108,3 injured). The lowest number of fatalities was recorded in the following voivodships: Małopolskie (5.6), Śląskie (6.7), Pomorskie (7.0), Łódzkie (7.1) and Wielkopolskie (7.2) [6, p. 12].

In turn, in the case of road collisions, an upward trend has been recorded in recent years, as shown in Figure 2.

In 2010-2012 and 2013-2014, this trend was reversed, but since 2014 there has been a significant increase in the number of road collisions. In 2019, there were 455,454 collisions – there was an increase of almost 4.5% of this type of road incidents compared to the previous year. The year 2018 brought a slight decrease compared to 2017 – the number decreased by 55 collisions (–0.01%), but compared to 2016 – there was an increase by almost 30 thousand of this type of communication events (+7.3%).

In 2019, accidents were most often caused by the fault of persons driving vehicles (cars, bicycles, motorbikes, moped drivers – 87.6% of all accidents). Every fourth accident was caused by the failure to give way to the vehicle (27.3%). Slightly fewer accidents occurred because of mismatching speed to existing traffic conditions (23.6%), and every tenth accident was the result of failure to give way to pedestrians at a pedestrian crossing (11%) [6, p. 24].

Pedestrians also contributed to road accidents (6.2% of all accidents). In half of the cases, the traffic incidents they caused resulted from crossing the road directly in front of the moving

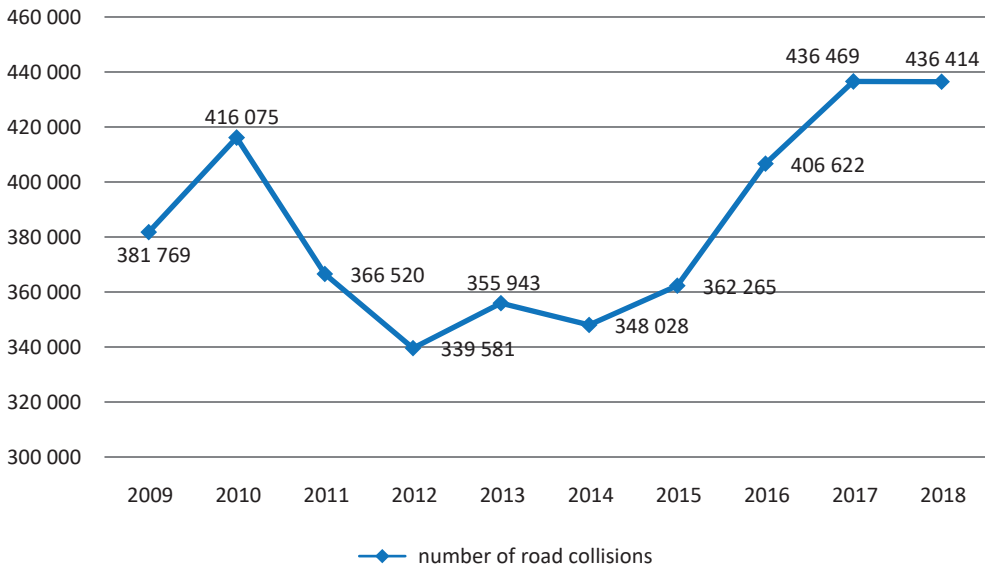

Fig. 2. Trends in the occurrence of road collisions in 2009-2018
Source: Own study based on: [6, p. 6].

vehicle (50.1% of accidents caused by pedestrians). Every eighth pedestrian accident perpetrator entered the road in a prohibited place (11.6%), every ninth – entered it from behind a vehicle/obstacle (10.7%), and every twelfth – was crossing it at a red light (8.2%) [6, p. 30].

In the case of 0.9% of accidents, the blame for causing them was borne by both parties involved. The least frequent accidents were the fault of passengers (0.4%). There were also other causes of accidents (4.4%) [6, p. 24], such as objects/animals on the road (23.1%), poor road condition (3.4%), the driver's loss of consciousness/death directly before the accident (5.3%), technical malfunction of the vehicle (2.6%), or being blinded by another vehicle/sun (1.7%) [6, p. 33-34].

In every eleventh case (9.0%), the involved road users were under the influence of alcohol, and more often than in every fourteenth (6.9%), these people were the perpetrators of the incident. The most significant risk to safety was posed by vehicle drivers (79.7% of all accidents caused by people under the influence of alcohol), especially of passenger cars (66.0%) and bicycles (14.7%) [6, p. 59-64].

About 40% of all road accident victims in Poland in 2019 were unprotected road users. Accidents involving them most often took place in built-up areas. At the same time, higher mortality was recorded in accidents in undeveloped areas (there was a fatality more often than in every second accident in an undeveloped area involving pedestrians and in every fifth incident involving cyclists, while in built-up areas – in every twelfth with the participation of pedestrians and almost in every twenty-ninth with the participation of cyclists) [6, p. 44, 49]. Particularly many accidents (over 50% of all accidents involving pedestrians) were recorded in places made available for pedestrian traffic, especially at pedestrian crossings [6, p. 48], which should be an area where these road users safely cross the road.

The increase in the number of fatalities in the last analyzed year is tantamount to departing from implementing the priority objective of actions aimed at increasing the road safety

level through the complete elimination of killed people. That assumption was made in the National Road Safety Program 2013-2020 [2]. Moreover, the process of reducing the number of seriously injured victims is not proceeding at the pace assumed in the Program – based on the currently available data: a 40% reduction in this value compared to the 2010 data seems unattainable. The level of implementation of the National Road Safety Program assumptions is also reflected in Poland's position compared to the European Union countries in terms of the road safety level indicator. Still, the ratio of road fatalities in our country in relation to its general population is relatively high compared to the Community average. According to data from the European Commission, in 2018, approximately 25,100 people lost their lives on the European Union roads; it decreased by 21% compared to 2010, but only by 1% compared to 2017. The average fatality rate in 28 EU Member States amounted to 49 deaths per 1 million inhabitants. The Polish indicator with the value of 75 victims per 1 million inhabitants was one of the highest among the EU countries. That value was over 2.5 times higher than the value of the Great Britain index (28 deaths per 1 million inhabitants) and 1.5 times higher than the EU average (49 deaths per 1 million inhabitants) [7].

Factors influencing the road safety state

The difficulty in ensuring the desired level of road safety stems, among others, from the fact that many factors condition it. Therefore, when building short- and long-term strategies for its improvement, the multiplicity and complexity of the causes and circumstances of road accidents should be considered. Classically, the role of only three factors was indicated: a human, a road, and a vehicle, within which more detailed determinants were mentioned.

In relation to humans, road users' knowledge and skills (pedestrians, cyclists, motorists) comply with road traffic regulations, mainly speed limits, right-of-way, adaptation of driving to weather conditions, and staying sober were raised.

As for roads, the importance of proper hierarchization of the road network, correct traffic organization (horizontal and vertical marking, traffic control), cross-section (width of traffic lanes, roadsides, and dividing lanes, the number of lanes and traffic directions, distance from side obstacles), longitudinal profile (radii of vertical curves, falling and rising gradients) and road layout (curvature, radii of horizontal curves, construction of transition curves), intersections and junctions (the type of intersection, the number of collision points), the technical condition of roadways, sidewalks and roadsides, rational shaping of road surroundings, securing the traffic of unprotected users, or the possibility of building express roads and ring roads were specified.

Regarding vehicles, the role of active and passive safety devices and systems[2], maintaining the technical efficiency of the car, regular vehicle diagnostics, and proper tires were emphasized.

Today, it is already known that, in addition to the factors listed in the traditional safety triangle, many more variables affect the road safety level. The extended catalog is presented graphically in Figure 3.

[2] The vehicle active safety is a set of factors that reduce the likelihood of a road accident. It includes, among others, the vehicle structure (ensuring visibility of the vehicle and visibility from the vehicle), ergonomics of the vehicle interior, electronic systems integrated with the braking system, steering system, suspension, and tires. The vehicle passive safety is a set of vehicle features aimed at reducing the effects of a road incident from the point of view of all its participants. It includes, among others body structure, seat belts, airbags, car seats for children, and glued windows.

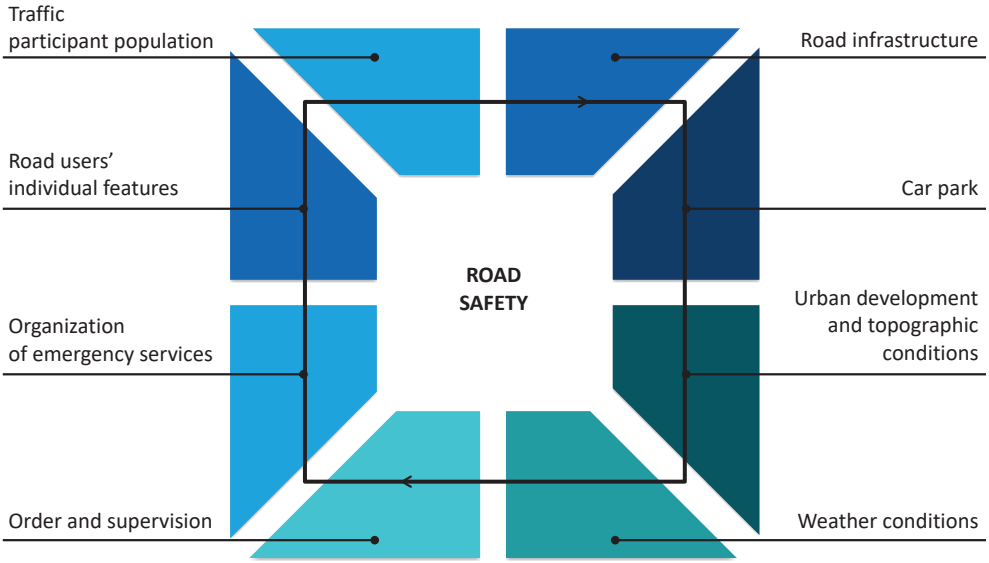

Fig. 3. Groups of factors influencing road safety
Source: Own study based on: [8, p. 51].

Contemporary considerations on shaping road users' safety also emphasize the participation of such elements as traffic supervision, rescue, topography, organization of the road environment, legal regulations, or weather conditions. These factors are closely related and strongly interact.

Regardless of the adopted perspective – classic or modern – still people determine the road safety state to the greatest extent. Their psychophysical predispositions, knowledge, skills, experience, and – more often noticed and exposed – driving culture as an element of road safety culture translate into behavior in road traffic. For this reason, it is the weakest link among all the factors, as mentioned above.

That is, since driving a vehicle is a complex activity involving many psychophysical processes and properties, the efficiency and nature of which determine the quality of this activity. In road traffic, high human efficiency is desirable in many areas, mainly concerning (1) receiving information through various senses, the most important of which are sight, hearing, and kinesthetic. Medical and psychological tests allow identifying the state of perceptual abilities and psychological efficiency of the receptors. It happens that the driver experiences a sensory perception, but the understanding, identification, interpretation, and preparation to respond to the stimulus do not occur. In other words, although the driver passively registers what is happening while driving, his/her brain does not process the information sufficiently, (2) it does not process information in the context of taking specific behaviors and actions. Driving a vehicle is not only reflex processes but also proper analysis and assessment of the current road situation, which is the basis for decision-making processes. The parallelism of both types of processes requires the driver to have a sufficiently high intelligence quotient. He must see and understand what is happening on the road, (3) execute the decision, i.e., drive efficiently – at this stage, not only manual dexterity is necessary, but most of all, specific eye-hand coordination [4].

In the subject literature, there are many models explaining the impact of various factors on the road safety level. The role of the human factor in various dimensions and contexts is considered, among others, by the following theories:

1. The subjective and objective risk model by Dieter von Klebelsberg. This author distinguished between subjective and objective road safety (risk) (between RS and RO). He associated the former with the situational determinants of the sense of security, including primarily the perception and experience. In turn, the other was associated with external factors, including physical safety determinants, road infrastructure, vehicle technical parameters, weather conditions, etc. According to von Klebelsberg, both safety components interact, and a change within one leads to changes in the other. From the social point of view, the desired state is a situation in which the objective security level is equal to or greater than the level of subjective security. The compensation mechanism that allows maintaining a relative balance between the two components is cognitive regulation, which indicates the driver's active role in pursuing various goals in a risk situation. The risky behavior strategy used by this driver is also essential. The two most common strategies are imposing and adaptive. The former's features are stiffness and ossification, while the latter – flexibility, the ability to adapt to the current road conditions [4; 9].

   In his considerations, von Klebelsberg did not consider the issue of how to build a cognitive representation of the relationship between subjective and objective risk, pointing only to the active role of the vehicle driver. The author also did not sufficiently explain the dynamics of the cognitive representation schemas characteristic for specific systems of relations between subjective and objective safety (RS = RO, RS > RO, RS < RO), and, as a result, also for building a given risk-taking strategy as the dominant one. Von Klebelsberg only partially discussed the importance of accumulating new experiences by the driver to perceive the relationship between these necessary safety components (subjective and objective risk/safety) – the researcher referred only to the motives manifested in the primary conflict in road traffic [4].

2. Gerald Wilde's homeostatic risk theory. This researcher assumed that participating in road traffic is tantamount to taking risks. In his considerations, he emphasized that each person participating in road traffic is characterized by an individual, presumably constant in each unit of time and at a specific point of the traveled route, level of risk. The observed risk level is compared with the accepted risk level. In a situation where the perceived risk level significantly differs (is lower or higher) from the accepted risk value, which determines the limits of human psychological comfort, interventions are undertaken to remove this discrepancy. The behavioral correction enables a rational, objective assessment of the likelihood of an accident. Taking account of the sum of all corrective actions of a specific road user in a specific period make up his account of accidents, i.e., accident statistics. According to Wilde, not all interventions aimed at increasing safety are useful, but only those that affect the risk acceptance level [9]. Accident statistics, according to this author, depends on the driving style. It, in turn, is determined by three types of parameters: "constant" (age, sex, driving license category, experience, abilities – in terms of observation, decision-making, vehicle control, etc.), related to the journey (destination, fatigue, etc.), and "temporary" (traffic congestion, other drivers' behavior, etc.) [4].

   The homeostatic risk theory gained international recognition and many adherents. It is relatively well elaborated, explained, and justified theoretically; nevertheless, it

should be emphasized that Wilde did not sufficiently precisely discuss the meaning of the three terms, which are essential for the interaction between an individual accident balance and road traffic behavior. It is about the concept of risk perception, risk acceptance, and the desired adjustment related to simple (in the case of the first term) and complex (in the case of the other two) cognitive processes. This definition inaccuracy may lead to misinterpretation of the concept's assumptions. The theory is also accused of extreme personification and the inability to translate its theses into a practical aspect in the form of increased road safety [4].

3. The concept of defensive behavior in road traffic by Thomas Ranney. In his works, this researcher leaned towards interactive analyzes, considering the interdependence of the influence of many variables on the drivers' behavior. He considered motivational factors as a criterion category in the study of road users' behavior while pointing out that other variables, such as traffic intensity, other drivers' behaviors, and situational conditions, referred to as compensatory conditions, also have an impact. The interactivity and interdependence of many factors were discussed on the example of drivers' defensive behavior described as a tendency to shorten the distance between one's means of transport to the vehicle in front of (the so-called *car-following behavior*) [9]. The approach, however, is not without inaccuracies and errors, for example, categorization ones, i.e., distinguishing qualitatively different areas strongly related, on the one hand, to the control of behavior aimed at achieving the driving purpose, and on the other – the freedom to choose other available options. There is also a question about the number of separated distance spheres between vehicles – it is wondering what the premises were for the separation of precisely three (with low, medium, and high traffic intensity), and not a different number of spheres.
4. Road users' behavior from the perspective of the learning theory by Ray Fuller. According to the researcher's position, drivers experience emotionally and rationally estimate the dangers of participating in road traffic. They learn to perform or refrain from a specific reaction due to the possibility of negative consequences. It is true that most of the time, drivers are influenced by non-aversive stimuli[3], but they may take the form of threatening, aversive stimuli at any moment. Hence, their activity mostly boils down to avoiding threats – whether in the form of any aversive stimulation (avoiding traffic jams or dangerous sections of the road, losing control of the vehicle, avoiding a state of intense emotional arousal, etc.) or possible aversive stimuli (driving along well-known routes, slow car speed, etc.) [9].

The Fuller concept is continuously being modified and supplemented. Its apparent theoretical coherence may be a source of numerous pitfalls because of too far-reaching simplifications, over-generalization, or detail [4].

A human plays a twofold role in the road safety system – as the creator, organizer of this system, and road user. Fulfilling both roles depends on many variables, among which human psychological properties deserve special attention. The theories cited above pay more or less attention to their role. There is no doubt that driving a vehicle is to a large extent a mental process involving many cognitive functions. It is assumed that their efficiency and quality influences human behavior in road traffic.

[3] A stimulus or situation that causes no pain or other unpleasant physical or mental sensation.

Driver's cognitive processes in road traffic

While driving, there are many cognitive processes in which the driver participates, although not always fully consciously. The word "cognitive" refers to a person's ability to learn about reality, while the word "processual" indicates their dynamic character. Thus, cognitive processes determine the entirety of the processes creating and modifying cognitive structures in the human mind, serving to learn about the environment. These are also information processing processes in the nervous system, consisting in receiving information from the environment, storing, modifying, and using it to manage one's own and other people's behavior [10; 11].

Cognitive processes can be classified in many ways. Psychologists most often divide them into elementary and complex cognitive processes [10]. The first group relates primarily to receiving, interpreting, and storing information. They comprise perception (impressions and insights), attention, and memory. Some researchers suggest that cognitive control and executive functions should also be included in this process category [10]. The others include images in the catalog of elementary cognitive processes [11; 12]. The issue of the interpretation and location of images in a conceptual grid still arouses lively discussions among scientists (A cognitive process or a cognitive structure? A simple or complex cognitive process?). On the other hand, complex cognitive processes include thinking and language [10-12]. There are also more narrow categories of this kind of process that can be treated as detailed forms of thinking. These include, among others, abstraction, formulation of judgments, organizing and planning, making decisions, solving problems, creating concepts, and performing calculations and arithmetic operations [10]. Only drivers' selected cognitive processes and their importance for road safety will be described below.

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Basic cognitive processes

The sensation is one of the most primary and most basic mental processes that are launch while driving. They consist in reflecting the individual features of objects and phenomena that act on human sensory organs at a given moment. They arise from the direct impact of stimuli coming from the external environment or the body inside on the receptors, or nerve endings, causing a mental reaction [13]. For participation in road traffic, visual and auditory impressions are of primary importance. They arise when a stimulus (light/sound wave) acts on the sight/hearing sense organ (eye/ear). Its various features (wavelength, amplitude, frequency) result in the activation of various receptor systems that process this stimulus into nerve impulses transmitted to the brain. There, they are read, deciphered, and sent back to the appropriate executive organs; hence the process of becoming aware of the type and nature of the content takes place [13]. Impressions are mono sensor, which means that they reflect one feature of an object, process, or phenomenon. On the other hand, observations, the essence of which is subjective reflections of reality by distinguishing entire objects, the perception of a more significant number of features, are polysensory in nature [13]. Observations, however, are not a simple sum of impressions – they are a combination of impressions and ideas. The perception process takes place on two levels: sensorimotor and sensory-operational (semantic-functional). On the first level, the sensual image of an object, process, or phenomenon is reflected in the consciousness, resulting from which figural perceptions arise, while on the second level, perceptions are given meaning – objective perceptions appear [14].

The reception and analysis of stimuli allow for constant recording elements creating traffic situations and subjective factors related to the experience, knowledge, abilities, and skills, emotional relationship, and driver's motivation [15]. A person perceives traffic situations and individual elements of the road safety system organization differently if they have specific knowledge and emotional attitude related to the presence in that traffic than when they do not have such experience. Each form of practice facilitates the identification and analysis of driving situations.

It should be emphasized that the proper course of perceptual processes, as well as other cognitive processes, largely depends on the efficient functioning of sensory analyzers, including eyesight (visual acuity, binocular vision, twilight vision, speed of eyesight adaptation to light and darkness, visual resistance to glare), correct perception and recognition of colors, spatial vision, a field of vision, etc.), hearing (noticing differences in pitch and sound intensity, hearing sensitivity threshold, resistance to high sounds, etc.), and smell and polysensory perception (perception accuracy, tactile precision, perception and recognition of changes in the direction of movement, recognition of pressure force, position and balance of the body, assessment of the weight, volume and size of objects, etc.) [16].

Imaginations, which are very similar to perceptions, are also of great importance for the functioning as a driver. They contain almost all their features (ranging from color, through shape, to the arrangement of various elements that make up the cognitive representation of an object), but they are less accurate than them [17]. In the psychological literature, imaginations are divided into recreational and creative. A characteristic feature of the former is the fidelity to mapping the properties of real objects, processes, and phenomena. A human can recall them in mind at any time, regardless of the material presence of the pattern. The latter stems from deliberate human activity. Their formation is often motivated by limited memory possibilities. The imagination then constructs the missing parts of the image, giving the object a specific form. However, whole ideas are more often created, not only its components.

Because imaginations may constitute a starting point for creating visual-spatial representations [17], their role in shaping the level of road safety is difficult to overestimate. They make it possible to create a visual representation of objects, processes, and phenomena based on previous observations and information available in the driver's memory. Using imaginations helps to solve selected problems. These are particularly ones in which the availability of pictorial representation makes it easier to see relationships and dependencies between the components. Such a description includes problem situations resulting from different behaviors of road users. Imaginations enable not only the analysis of the existing situations (reproductive imaginations) but also allow predicting events and avoid situations posing a threat to road users or the road infrastructure (creative imaginations). One should also consider the unreliability of human imagination and the volatility of parameters of road situations.

Another necessary cognitive process in the driver's mind is attention. It consists in maintaining the organism in a state of readiness to act, perceive, etc., directing the awareness to essential elements of the perceptual field while omitting non-essential elements, engaging in the analysis of a given stimulus, and shifting concentration from one stimulus to another [10-12]. Thanks to attention, a person perceives only some of the stimuli reaching his/her sensory organs, remembers only a part of the information encoded in memory, activates only one of many possible activities, etc. It prevents the same adverse effects of information overload.

Attention is divided into involuntary and arbitrary [11]. A sudden change of environment triggers the first. A visual or auditory stimulus, processed by the human brain, automatically directs attention towards it. The attention inhibits the currently performed activities, shifts the interest to a new object – an object that stands out. In the context of participation in road traffic, the role of involuntary attention is difficult to overestimate, especially in a situation when the driver receives sound signals from an emergency vehicle. In turn, arbitrary attention is triggered by the organism and consists in intentional, volitional focus on a specific object. This type of attention requires effort, and often overcoming internal fears and resistances. Directing awareness on other road users and objects in its vicinity, on the processes and phenomena occurring during road traffic, allows for selecting information important for solving problematic issues arising while driving.

Deliberate directing of attention takes place in the course of using one of its functions: selectivity, prolonged concentration, divisibility, shifting, and searching [10]. Attention selectivity refers to the selective perception of information available in the driver's environment, the ability to direct (focus) the attention channel to retrieve specific information relevant to safe movement to a destination point. Prolonged concentration is associated with the ability to maintain attention for a long time, waiting for the stimuli desired by the driver. The attention divisibility and shifting are particularly crucial for road safety. The first phenomenon relates to the ability to focus attention on more than two objects or aspects of the environment simultaneously, while the second relates to the ability to switch attention between them. No less important is the search, the content of which is active, targeted selection of specific data from the environment, which is essential for successful functioning as a road participant.

Vehicle drivers must suppress distracting thoughts, associations, and memories. Through attention, he/she must direct own cognitive processes towards issues important for safe road navigation, ignoring less important signals [16]. At the same time, he/she cannot limit himself/herself only to the resources of stimuli that reach it directly, but always search the data field available to it, capturing data relevant to a specific decision-making situation in road traffic.

Depending on the nature of the problematic situation, a person uses different amounts of resources. In the case of difficult, important, or new tasks, energy expenditure is significant and is based on a different pool of cognitive resources than in the case of simple, insignificant, or known tasks [12]. That means that the functioning of the driver's cognitive processes during high traffic intensity involves significant amounts of his/her energy. While driving, the driver must divide his/her cognitive effort between different activities simultaneously. In the case of complex tasks, the quality of performance is improved during exercises [16]. Trained activities require smaller resource pools of attention and cognitive energy. A driver with extensive experience feels comfortable behind the wheel, maneuvers automatically, and directs attention and cognitive energy to assess the current road situation.

The next mental process that, apart from perception, has the most significant impact on other cognitive processes is memory. The mind can code, store, and extract information in the form of representations of thoughts, objects, processes, phenomena, and actions [17]. Coding road safety-relevant information relates to the driver's process of adopting new content and incorporating it into the experience and knowledge gained previously. New information assimilated into memory may take the form of impulses, signs, models, diagrams, procedures, and mental maps.

For the process of storing newly acquired information to be permanent, it must take place in certain conditions. The most important are: (1) new information is adapted to the existing knowledge structures, (2) information has a structure resulting from the correlation of traffic knowledge elements, (3) essential knowledge elements are consolidated through regular repetition, (4) newly acquired information is linked by logical cause-effect relationships, (5) new information is emotionally colored, (6) objects, processes, and phenomena in road traffic affect the receptors, activating the sensory fields in the brain, (7) new information resulting from, e.g., from participation in previously unknown road situations is consolidated thanks to the dependence on the activity of the left cerebral hemisphere that allows for perceiving similarities and differences, content and meaning analysis, discovering and applying the rule, (8) neurotransmitter synthesis (the so-called memory trace consolidation) takes place, i.e., long-term neurophysiological changes resulting in the transition from dynamic form to structural permanent memory [15].

Extracting information from memory is about reproducing and recognizing it. In this context, three types of memory play a significant role: sensory, short-term, and long-term. Sensory memory is related to the registration of a specific modality stimulus [10]. It is the first type of memory that incoming information passes through – it stores a small amount of information in a short time. Stimuli received during road traffic participation are stored as unprocessed, then forgotten – displaced by other stimuli or transferred to short-term (operational) memory if they were considered necessary. Sensory memory includes iconic and echoic memory, thanks to which the recognition of visual and auditory stimuli, respectively, is carried out, then transmitted to short-term memory. On the other hand, short-term memory stores information coming to it from sensory memory and information recalled from long-term memory. That memory is responsible for the conscious storage of information covered by processing attention [12]. Repeating information contributes to keeping it in short-term memory for the time of performing a given activity, e.g., gear changes. Long-term memory, in turn, refers to information that is consolidated and permanently stored. It stores the entirety of the individual experience, messages, emotions, skills, assessments, etc., that have been transferred from working memory [11]. That memory includes all the knowledge about oneself, other people, and the world, also in relation to traffic. Long-term memory consists of declarative

and non-declarative memory [10]. The first is conscious and responsible for storing facts, experiences, etc. It is divided into semantic memory – having the form of general knowledge, devoid of personal context, e.g., knowledge of road traffic regulations, and episodic memory – expressed in knowledge about events and cause-and-effect relationships between them, placing them in a specific space-time, embedded in an autobiographical context, e.g., knowledge about the date when the driver obtained his/her first driving license or improving his/her qualifications. Non-declarative memory accumulates experiences in the form of relationships between specific stimuli and reactions. Extracting information from it is automatic, usually without control of consciousness. The type of memory is procedural memory (next to conditioning[4], priming[5], and non-associative memory)[6] [10]. It refers to acquiring skills and habits and practicing in a specific activity (cognitive or motor). It includes, among others, automatic mastering of activities related to driving a vehicle (switching indicators or gears, operating pedals in a car, etc.). The more the basic activities are learned and automated, the less attention the driver can focus on new tasks and assessing the traffic situation.

Changes taking place in the human mind contribute to the reconstruction of information encoded in the memory. The processes of organizing encoded, stored, and reproduced information are interrelated. Organizational compatibility between them promotes greater efficiency of the recalled content [15]. Memory disorders, quantitative (the so-called dysmnesia: hypomnesia[7], hypermnesia[8], amnesia[9]) and qualitative (the so-called paramnesia: memory illusions[10], confabulations[11], cryptomnesia[12]), lead to distortions and pathologies of all cognitive processes. Viewing the traffic situation with disturbed memory is limited only to what is happening in a given place and at a given time [12; 16]. When analyzing the incident, the driver is unable to take into account his/her knowledge and individual experience. Meanwhile, it is necessary for him/her to use the acquired knowledge and perceive objects, processes, and phenomena, etc. in the light of the information he/she has gathered so far. What is more, the driver should successively expand and update his/her knowledge and raise broadly understood qualifications. It is difficult to imagine and accept a situation in which a person, not knowing the current legal regulations regarding road traffic, having "memory gaps", preventing him/her from relying on the possessed cognitive schemes[13] and scripts[14] as well as professional and life experience, sits behind the wheel. It does so at the risk of his/her health and other road users' lives.

[4] A form of learning that involves the emergence of new combinations of stimuli and responses as a result of repeated experiences.

[5] A phenomenon whose essence is to facilitate the occurrence of a reaction to a specific stimulus through repeated exposure of a stimulus belonging to the same category or a stimulus meaningfully or affectively associated with this category.

[6] A type of non-declarative memory referring to single stimuli unrelated to other stimuli, e.g. rewards or punishments.

[7] Disruption of the processes of remembering information.

[8] Increased memory.

[9] Complete or temporary memory loss.

[10] Distorting memories.

[11] Supplementing the missing memories with false information unknowingly.

[12] Unconscious memory, memory without identifying the remembered content as previously known.

[13] Internalized and system-forming patterns of behavior and views that influence human thinking, acting, and perception of the world.

[14] Cognitive scenario; a mental representation of a sequence of events and works, containing information about their typical course.

Complex cognitive processes

Thinking is a complex cognitive process relevant to road safety. In general terms, it consists in combining elements of the cognitive representation of the world (judgments, concepts, images, etc.), creating a model of reality in order to perform various operations or transformations in this model, not in the real world. Therefore, it replaces action in reality by making simulations in the mind. In a narrower sense, this term is an intellectual activity focused on processing data into information, generating new information logically connecting thought sequences, creating the structure of thought processes, and formulating conclusions [11; 12]. Thinking includes a number of thought operations such as abstracting, anticipating, analyzing, comparing, synthesizing, generalizing, and inferring, etc.

As a road traffic participant, the driver carries out many of these operations [15]. The most important ones include (1) analogy of thinking, establishing the similarity of certain features between different objects in road traffic, (2) analysis of road situations by fragmenting and then combining individual elements to optimally understand the relationships and relationships between them for the application of appropriate traffic rules (3) synthesis by connecting, merging, integrating various road traffic components in order to create and improve the conditions for safe functioning in public space, (4) abstracting by extracting a specific feature and ignoring another, (5) comparing different road situations by pointing to similarities and differences, (6) predictive thinking, (7) generalization by identifying features that connect certain classes of traffic objects.

From the point of view of road safety, an important type of thinking is realistic thinking (distinguished next to autistic thinking[15]). It serves a specific purpose in the real world. It is possible thanks to three specific types of thinking: reproductive, productive, and critical [11; 12]. Reproductive thinking involves recreating past experience (e.g., during a driving test, when navigating the road according to your knowledge of the rules of the road, etc.). The course and end result of the thought process do not bring new knowledge to the driver. Productive thinking, on the other hand, is related to the production of new intellectual content, thereby the course of the thought process or its effect constitutes new knowledge for the individual. This type of thinking is divided into reproductive thinking – when it is considered productive only by humans, not by society, and creative thinking – when the applied solutions are new not only for the individual, but are also something new from a social perspective of a given historical period. It applies in particular to new techniques and technologies used to increase the road safety level. The essence of critical thinking is the assessment of intellectual activity, the assessment of products of productive thinking in terms of the criterion of obtaining the expected result. This type of thinking seems essential when driving a vehicle. It enables an objective assessment of road situations, dealing with challenges and threats thanks to the analysis and drawing conclusions from one's own and other drivers' behavior, taking up activities characterized by diligence and precaution, and applying the principle of limited trust.

The division of thinking into convergent and divergent is also interesting for road safety [18]. Convergent thinking is used in problematic situations with one possible solution. In road traffic, these are events in which one can only decide to brake. Divergent thinking is referred to when in problem situations there are many solutions, e.g., braking, accelerating, overtaking, avoiding, etc.

[15] Not serving a specific purpose.

When dealing with traffic problems, the driver must make decision sequences. The decision is the choice of a solution from among the options available to the driver resulting from his/her broadly understood qualifications and the road situation, i.e., subjective (knowledge, skills, reaction time, driver's intelligence, etc.) and objective conditions (the type of road, driving speed, curve radius, etc.) [18]. Over a distance of one kilometer of the road, the driver makes several hundred decisions, such as where to turn, how deep the turn should be, reduce or increase the gear, brake lightly or hard, give way, or use the right of way, etc. A decision-making process precedes each action – decisions affect the time, manner, and scope of the reaction. That means that decisions and reactions are related to specific dependencies of a cause-and-effect nature.

The decision-making process in traffic situations includes the following phases:

1. The decision-initiating phase understood as a set of factors justifying the need to make a decision,
2. Noticing and justifying the decision,
3. Determining the set of elements influencing decisions,
4. Assessment of the possibility of the decision application in a specific situation,
5. Assessment of the road user's subjective determinants,
6. Predicting the effects of a decision,
7. And making an optimal decision [19].

The complete picture of the vehicle driver's activity includes orientation, decision, and execution. Only complete, correct orientation ensures optimal conditions for the processing of available data into information, which constitute the core of the right decisions and the correct task implementation in road traffic. The driver makes a lot of decisions in dynamic, often undefined situations where the intention is taken top-down, based on incomplete premises, gut feelings, ideas, and predictions [19]. In such situations, the effectiveness of the decisions made is not guaranteed; frequently, corrective decisions that are oriented at improving effectiveness and taking into account the variability of the circumstances affecting the problem situation are necessary.

For the proper conduct of the data processing process, the proper course of recording, storing, and transforming this data is required. Therefore, the process quality depends on the level of attention, its capacity, persistence, divisibility and shifting, as well as the readiness and fidelity of various types of memory, and vigilance in the face of unpredictable, rapidly occurring events. The correctly occurring processes of collecting, merging, reorganizing, and transforming the received data, the appropriate course of the analysis, synthesis, inference, facilitate safe driving in road traffic and other activities related to data processing. The condition for safe driving is also the ability to translate one's experience into new situations, especially difficult, unexpected, dangerous, requiring precise thinking, often unconventional, creative, going beyond the usual patterns, when there is a need to make decisions under time pressure [16].

Conclusions

Nowadays, many social and economic problems can be effectively counteracted and solved. Nonetheless, there are not tools useful enough to deal with the challenges in road traffic. Currently, road accidents are one of the most important causes of premature death of people. Each year, they contribute to the deaths of about 1.35 million people worldwide [1]. In

Poland, about 3,000 people die in accidents every year [6]. The state of affairs is influenced by many variables, both objectively and subjective, depending on the parameters and conditions of road traffic participants.

For many years we have been observing a systematic increase in mobility in the world. The trend is also visible in Poland. Motorized persons constitute an increasing number of road users. At the same time, it is they who cause most road incidents [6]. That is due to the fact that driving a vehicle is a complex system of activities in a specific task situation. The task implementation largely depends on the vehicle driver's psychophysical properties. Cognitive processes are of particular importance as they enable learning about the environment and communicating with it. Orientation in the world is a necessary condition for safe movement on the road, and the very functioning of cognitive processes depends on many factors, often independent of the driver. For example, in 2019 the most accidents were recorded in June (9.9% of all accidents). Slightly less in October (9.6%), September (9.5%), August (9.4%), and July (9.3%) [6, p. 14]. In the summer months, traffic increases due to holiday trips. In the autumn, the weather conditions deteriorate significantly, translating into the quality of reception of stimuli from the environment (rainfall, fog, etc.). In both cases, the circumstances of driving change significantly, various distractors appear, resulting in driving a vehicle requiring increased activation of cognitive processes and energy expenditure. Therefore, the open question is, why are some of these accidents perception errors, memory gaps, thought disorders, and disturbances in other cognitive processes.

All cognitive processes based on inaccurate or incorrect data result in wrong decisions and improper performance of tasks. In road traffic situations, each maneuver is an implementation of previously made decisions. Their rightness and accuracy affect the effects of the actions taken [16]. However, it seems that these issues are insufficiently informed not only by drivers themselves but also by decision-makers and executives in road safety. There is a need to highlight the content related to the efficiency and quality of road users' cognitive processes in the process of shaping this dimension of safety. Disturbances in cognitive processes are a fundamental cause of dangerous behavior on the road, often overlooked in diagnosis and preventive measures. Therefore, this issue should be reflected both in the documents setting out the general framework for road safety and the organizational documents and the content of social campaigns. Attention should be paid to the need to care for and improve cognitive functions for better, more efficient, and safer functioning in the world in many areas, including road traffic.

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The author declared no conflict of interests.

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The author contributed to the interpretation of results and writing of the paper. The author read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

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Biographical note

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Znaczenie procesów poznawczych osoby kierującej pojazdem w kształtowaniu bezpieczeństwa ruchu drogowego

STRESZCZENIE

Przedmiotem artykułu jest bezpieczeństwo ruchu drogowego. Problematyka ta stanowi współcześnie aktualny i niezwykle ważny problem społeczny. Wynika to z faktu, iż rocznie na świecie śmierć na drogach ponosi ponad 1,3 mln ludzi, zaś w samej Polsce ginie ok. 3 tys. osób.

Celem artykułu jest omówienie czynników kształtujących bezpieczeństwo ruchu drogowego, ze szczególnym uwzględnieniem czynnika ludzkiego i jego złożoności. Postawiono hipotezę zakładającą, że sprawność i charakter procesów poznawczych wpływa na aktywność człowieka podczas ruchu drogowego. Weryfikacji tak sformułowanej hipotezy posłużyły metoda analizy literatury przedmiotu i dostępnych danych statystycznych oraz metoda syntezy.

W tekście przedstawiono charakterystykę najważniejszych procesów poznawczych oraz podjęto próbę analizy ich znaczenia dla właściwego funkcjonowania osoby kierującej pojazdem. Jest to kwestia, która wymaga szczególnego wyeksponowania w procesie budowania bezpieczeństwa ruchu drogowego. Badania naukowe i społeczna praktyka wskazują bowiem, że znaczna część zdarzeń drogowych stanowi konsekwencję niewłaściwego odbioru bodźców z otoczenia, przechowywania, przekształcania i wykorzystywania informacji, czyli szeroko rozumianych zaburzeń procesów poznawczych.

SŁOWA KLUCZOWE bezpieczeństwo, kierowca, proces poznawczy, ruch drogowy

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