JOURNAL OF MODERN SCIENCE
TOM 2/51/2023
www.jomswsge.com

DOI: https://doi.org/10.13166/jms/166250

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IS IT SAFE TO DRIVE A VEHICLE WITH A STEERING EQUIPMENT POSITIONED ON THE SAME SIDE AS THE DIRECTION OF THE TRAFFIC – DRIVING SIMULATION EXPERIMENTS

Abstract

Polish road traffic law was amended to reflect the EU legislation concerning the LHT vehicle registration in the RHT member states without repositioning the steering equipment, following complaints by Polish citizens to the EC and the subsequent ECJ judgment. This research was conducted to analyze the implications on the road safety when driving LHT and RHT vehicles in RHT. For the purposes of the study, the main research question was defined: Does driving an LHT vehicle adapted to RHT reduce the level of safety of the driver and other road users. Method: The experiment used a vehicle driving simulator. Research sample was selected by means of a survey on socio-demographic factors. During experiment participants were driving at first run RHT vehicles in RHT traffic and in second run a vehicle adapted to left-hand traffic in right-hand traffic. They had to drive a specific route on the simulator during both runs, with a defined traffic load. During individual journeys, the key information to assess the level of safety was collected by researchers. Results: The results of the conducted research clearly show that the risk of road accidents when using LHT vehicles in RHT road traffic is significantly higher. The results show a significant increase in the number of accidents and collisions when participants used an LHT vehicle in an RHT. The number of traffic incidents (accidents and collisions) was approx. 50% higher when driving RHD vehicles. At the same time, the validity of the use of simulation methods in the assessment of potential organizational changes in road traffic was proved. Practical Applications: Attention should be paid to the social costs of driving LHT vehicles in RHT and the growing number of road accidents. This type of research makes it possible to assess the risks of planned changes and can be used in the development of regulations related to the use of RHD vehicles in RHT traffic. The studies did not include traffic statistics for the years 2020 and 2021, as the European Commission estimated that lower traffic volumes related to the COVID-19 pandemic could have contributed to fewer road accidents and fatalities.

Keywords: *internal security, simulation, road safety, right-hand traffic, left-hand traffic, traffic simulator, accidents, collisions*

1. Introduction

1.1. Vehicle registration against the legal background

The registration of a vehicle adapted to left-hand traffic (LHT) in the European Union member states where right-hand traffic (RHT) is in force does not currently require a change of steering position. This situation is relatively new, because in some European Union member states, including Poland, until August 2015 it has been required to change the position of the steering equipment, i.e., to apply a time-consuming and quite expensive procedure. A breakthrough in the interpretation of the EU legislation was made by the European Commission (EC) because of complaints lodged by Polish citizens. The EC received in 2008 several complaints from Polish persons who worked in the UK and Ireland, purchased right-hand drive cars there and wanted to register them upon their return to Poland. However, based on the Polish national law, the registration of such vehicles was contingent upon repositioning the steering equipment on the left side to adapt them to the RHT, being at the same time a costly procedure.

At the pre-litigation stage, on 9 October 2009 the EC invited Poland to remove the barriers connected with the prohibition on registering cars with the steering-wheel on the right even if a vehicle satisfies the technical requirements defined in the separate directives referred to in Annex IV to Directive 2007/46, invoking an infringement of Article 4(3) of Directive 2007/46 and of Article 2a of Directive 70/311 in the case of new vehicles and an infringement of Article 34 TFEU in the case of vehicles registered in another member state.

Poland rejected the EC complaints stating that the relevant points of directives allow for registration only if that vehicle is adapted for use on the side of the road in force in a given state, hence the refusal to register vehicles which do not meet that criterion does not constitute an unlawful restriction on the free movement of goods, since such a condition is applicable on the grounds of public interest to ensure road safety taking into consideration the health and lives of people.

As the response did not dispel the doubts, the EC directed to the Polish Government a reasoned opinion on 1 October 2010 on this matter. Since the further reply of the Polish Government did not satisfy the EC, finally the EC decided to sue Poland in the European Court of Justice (ECJ) claiming i.e. that the provisions in force in Poland are prejudicial to the EU directives on the free movement of goods and services in the European Single Market. In particular, the EC referred to the ECJ for a declaration whether the Republic of Poland by making the registration of passenger vehicles with their steering equipment on the right, in the case of new vehicles or vehicles previously registered in other member states, contingent upon moving the steering wheel to the left-hand side, has failed to fulfil its obligations under Article 2a of Council Directive 70/311/EEC of 8 June 1970 on the approximation of the laws of the Member States relating to the steering equipment for motor vehicles and their trailers (OJ English Special Edition 1970(II), p. 375), Article 4(3) of Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (Framework Directive) (OJ 2007 L 263, p. 1), and under Article 34 TFEU (Case C 639/11, action for failure to fulfil obligations under Article 258 TFEU, brought on 13 December 2011).

It is worth noting that the EC distinguished in their application to the ECJ between new passenger vehicles, in the case of which the national measure under discussion should be assessed based on Directives 2007/46 and 70/311, and vehicles previously registered in another member state, in the event of which the assessment should be made based on Article 34 TFEU. The ECJ adopted such a di eventuation in the assessment.

With regard to the application of Directives 2007/46 and 70/311 to new passenger vehicles, the ECJ concluded that the place of the driver's seat, an inseparable element of the steering equipment of a vehicle is considered within the harmonization established by Directives 2007/46 and 70/311 and the member states may not demand, quoting the reasons of safety, with a view to the registration of a new vehicle in their territory, the driver's seat of that vehicle to be repositioned.

Regarding the application of Article 34 TFEU to passenger vehicles previously registered in another Member State, the ECJ stated that, taking into account all considerations, the disputable measure may not be deemed necessary to accomplish the intended purpose and it is not compatible with the principle of proportionality.

According to the ECJ ruling, the Republic of Poland, by making the registration of passenger vehicle with steering equipment on the right, in the case of new vehicles or vehicles previously registered in other member states, contingent upon moving the steering equipment to the left-hand side, has failed to fulfil its obligations under Article 2a of Council Directive 70/311/EEC of 8 June 1970 on the approximation of the laws of the member states relating to the steering equipment for motor vehicles and their trailers, Article 4(3) of Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (Framework Directive), and under Article 34 TFEU.

One of the arguments raised by the EC maintained that the road safety level is not related to the side of the car where the steering equipment is located, but it is rather connected with the driver's behavior and experience while a significant role is also played by the quality of the roads and vehicles. The Polish Government did not provide the necessary evidence that registration of vehicles with the steering equipment on the right increases the number of traffic incidents and adversely affects the safety on Polish roads. The disputable measure was also considered dis-proportionate by the EC claiming that less stringent requirements, e.g., fixing additional external rear-view mirrors and the adaptation of lighting and windscreen wiping devices, would be sufficient to rectify the situation (The European Court of Justice (20 March 2014). Case C-639/11. The European Commission v. The Republic of Poland, http://curia.europa.eu/).

Right-hand drive cars can be registered in Poland today without any obstacles. The registration procedure itself is the same as for cars with left-hand drive. However, there are additional requirements related to the need to adapt the car to right-hand traffic and technical inspection. The share of such cars increased in the total number of used cars imported to Poland.

There was a lack of scientific studies that would relate to the safety of drivers of RHD (Right Hand Drive) vehicles and other right-hand traffic participants. Many entities operating in the field of road safety and the automotive sector pointed to the threat to road safety (Regulation of the Minister of Infrastructure and Development as of July 2, 2015). Article 36 of the Treaty on the Functioning of the European Union allows for implementing transport bans or re-strictions justified by reasons such as public security, provided that they are not a measure of arbitrary discrimination or hidden restrictions imposed on commerce between the EU members (Treaty on the Functioning of the European Union).

Considering the aspects of traffic safety or security from the historical perspective, moving on the left side seemed to be predominant in early societies, in the Roman Empire and in medieval times, the reason being the fact that majority of people in population are right-handed and right-eye dominant, and the practice helped them to counteract physically, e.g. by holding a weapon such as a spear, a pike or a sword in their right hand, a potential threat from adversaries coming from the opposite direction. With time, the tendency ceased within and across continents and states, along with the inventions such as the Conestoga wagon during colonial times of North America or later intro-duction of automobile models such as the 1908 Ford Model T in the USA which was the first of Ford's vehicles with a left-side driving position, or the decisions following the Napoleon's conquests in Europe which supported and sanctioned right-hand traffic, following the new custom of the aristocracy mingling after the French Revolution with lower social strata on the right side of the roads. England, not dominated by Napoleon, statutorily introduced left-hand traffic in 1835 which was also made official in the colonies of the whole British Empire. Nowadays, the division into right-hand traffic (RHT) countries and left-hand-traffic countries (LHT) shows that the former legal regime prevails globally with the rate covering 65% of total population whereas the latter is retained mostly in the UK and the former British colonies, overseas and dependent territories reaching 35% of the total population (Lay, 1992; Leeming, 2007). In Europe, the increase in the trading activity between nations following the economic renaissance enjoyed after the World War II resulted in the creation of communities such as the European Coal and Steel Community consisting at the beginning of six countries operating in the common market, followed structurally by the European Economic Community and, ultimately, the European Union encompassing nowadays as many as 28 member states sharing the internal market concept ensuring that four freedoms are granted to all citizens of the member states. In terms of the rule of the road, out of the total 28 member states, the EU area distinguishes 4 countries where LHT is in force according to their national laws: the United Kingdom and Ireland (which joined the former structure of the EEC in 1973), Cyprus and Malta (which joined the EU in 2004). Taking into account the position of the UK leaving the EU (the UK will not be a part of the EU Single Market or the EU Customs Union and the transitional period will end on 20th December 2020), the BREXIT considerations and the Withdrawal Agreement do not allow at this stage for giving decisive answers how the new relation might a etc. the future numbers of RHD vehicles in RHT, however, it can be assumed that, with time, the general share of RHD vehicles in RHT may be smaller in the territory of the EU. Regardless of whether and when the BREXIT effects may be reflected in the economic scenarios, the current legislative and economic environment faced by drivers and participants of the road traffic in the EU, and, more specifically, in the Republic of Poland, might require a more detailed analysis of the impact of RHD vehicles in RHT on the road safety. For this purpose, the paper focuses on the research made with the use of driving simulators.

1.2. Vehicle registration against the legal background

It is worth noting that research concerning both driving simulators and simulations of driving a vehicle in road traffic has been conducted for many years all over the world. Wide-ranging and comprehensive research aims at verifying driver behavior, increasing both driver safety and safety of other road traffic participants, including but not limited to offering and running specialist courses and training with the use of simulators of emergency vehicles. Recently, numerous studies involving the use of simulators have been undertaken with a view to building and improving the existing prototypes of autonomous vehicles, and the co-existing software that controls, navigates, and drives a vehicle.

Currently, many different methods of road safety assessment are used. Some of them are studies that analyze the condition before and after the introduction of specific changes on a relatively small scale [1]. Some rely on the analysis of the so-called black points [2]. The most frequently used research is the analysis of statistical data in the context of variables relevant to the researcher [3]. Monographic methods consisting in a detailed analysis of specific road events of high importance are also often used [4]. Standard statistical methods are often extended to include large amounts of data analysis [3] or multi-criteria analysis [5]. Scenario analysis methods are also frequently used [6]. These methods have many advantages, but their application is subject to requirements that may not always be met. The first element is access to valuable statistical data enabling their use. Which is a big problem in developing countries [7] or in areas related to the functioning of commercial entities that are reluctant to share information about their own problems. An important element is also the detail of the collected data, which often does not allow for precise analyzes of key risk factors. The second problem is that these methods can only be used some time after the potential changes have been made and the appropriate amount of data has been collected over time. There are many methods to overcome the identified problems, but they are often burdened with requirements that are impossible to meet. An example can be the traffic conflict technique [8]. They allow for generating scientifically justified conclusions in a shorter time in the scope of events concerning the areas selected by the researcher, not necessarily included in standard statistics kept by the services responsible for road safety [9]. However, significant disadvantages of this type of methods are time-consuming, limited scale and costs. Additionally, in the case of risks, the probability of which is low, they may be completely ineffective. Also, these methods cannot be applied when the changes to be assessed are only at the design stage. Often the only methods that can be applied are simulation methods [10]. Many applications allow for standard multi-agent simulation [11] or microsimulation [12]. In cases where the characteristics and behavior of human traffic participants – drivers, resulting from, inter alia, in terms of training, social and economic aspects, there are often dilemmas whether to use an engineering or behavioral approach [13]. A method that allows for combining these approaches is the use of driving simulators [14]. The quality of the results is of course influenced by the quality of the simulator and the level of realism of all aspects of its construction and operation [15].

Many advantages were shown while driving simulations, e.g., features that can be programmed to emulate authentic driving on the road with ease. In Taheri, Matsushita, & Sasaki, 2017 a study was initiated to scrutinize driver adaptation patterns to a three-dimensional driving simulation by analyzing driver behavioral reactions in the simulator [34]. Similarly, advantages and disadvantages of driving simulators were discussed by Winter & Happee, 2012 [38]. Recently, Schoner,¨ 2018 showed that simulation supports testing the behavior of autonomous vehicles in a variety of scenarios, environments, system set-ups and driver profiles and, simultaneously, constitutes a vital part of the development and testing of autonomous driving software [32]. Chaczko et al., 2020 presented in their article research on a system assisting a driver in an autonomous vehicle [24]. The task of the system is to prevent situations and scenarios which are unpredictable at the stage of building the embedded AI system from appearing, and to inform the driver about such events (explain such situations) so that the driver could initiate relevant actions to avoid a collision or an accident [23].

Brookhuis & Waard, 2010 presented several examples illustrating the capacities of modern high-standard driving simulator environments with regard to testing drivers' neurophysiologic, perceptual, and cognitive burdens in the process of performing their tasks [6]. Due to a small number of investigations focusing on the validity of the simulators Blaauw, 1982 evaluated absolute and relative validities taking into consideration system performance and driver be-havior in the case of inexperienced and experienced drivers during straight-road driving [20]. Drivers were supposed to demonstrate lateral and longitudinal vehicle control both in the simulator and in an instrumented car in a real road traffic situation. Bedard, ´ Parkkari, Weaver, Riendeau, & Dahlquist, 2010 examined statistically the validity and repro-ducibility of the assessment of the driving process in the simulator and, consequently, suggested that simulators could be introduced to support the assessment of fitness to drive [19]. Also, the research done by Auberlet et al., 2012 proved the utility of driving simulators in the road design procedure [18].

The work Crundall & Underwood, 1998 analyzes the behavior and variety of reactions of novice and experienced drivers about distribution of visual attention [25]. The research focused on eye movements, i.e., fixation durations and the spread of search in both the horizontal and vertical axes. Similarly, Underwood, Crundall, & Chapman, 2011 found enhanced scanning in the case of more experienced and particularly professional drivers, and previous eye fixations on hazardous objects in the case of experienced drivers [36]. Konstantopoulos, Chapman, & Crundall, 2010 proved that environmental factors such as night-time driving and driving in rain elevates the risk of a crash involvement [30]. According to the results, driving instructors were characterized by an increased sampling rate, shorter processing time and broader scanning of the road in comparison with learner drivers. The findings underline the effect of driving experience in adjusting eye movement strategies. They explained high levels of the accident risk while driving at night and driving in rain by the decrement in visual search strategies in poor weather conditions. They also claimed that the application of driving simulators can contribute to offering valuable insights into driving safety. The article by Winter et al., 2009 discusses relations between performance in the simulator and driving test results, and o ers fresh views on factors which are distinctive in young drivers' behavior [37]. The study encompasses a theoretical framework measuring at the same time driving skills in the light of speed of task execution, violations and mistakes.

Another publication by Godley, Triggs, & Fildes, 2002 compares speeding and reactions to the transverse rumble strips, deceleration, stop sign intersections, right curves, and left curves using an instrumented car and simulator in two independent experiments [27]. Similarly, Calvi, Benedetto, & Blasiis, 2012 describe the outcome of a driving simulator study that was concentrated on driving performance while approaching a divergence area and decelerating during the exiting maneuver [22]. The results of the paper by Antonson, Mårdh, Wiklund, & Blomqvist, 2009 indicated that the driver is influenced by various landscape types (open, forested, or varied) [16]. In the open landscape, subjects were driving faster, did not drive closely to the center of the road, and grasped the steering wheel more frequently while simultaneously feeling less stress. The authors also demonstrated that landscape tends to be significant to traffic safety, which translates into the manner of selecting new routes when designing new roads and into the maintenance of existing roads. The authors Hatfield & Chamberlain, 2008 proved that drivers had been exposed to audiovisual entertainment displays in other vehicles and this may have impaired driving [28].

The authors Davenne et al., 2012 compared the influence of extended wakefulness and prolonged driving at the wheel in simulated and authentic driving environments [26]. They showed that the authentic and simulated driving conditions exerted the same influence on fatigue and sleepiness during extended periods of nighttime driving. Relatively different research performed by Abu Dabrh et al., 2014 reported that several medical conditions such sleep disorders, diabetes, hypertension, and obesity are common in the case of commercial drivers and can be linked with an elevated risk of crashes, hence providing a reason for health examination with regard to this type of drivers [16]. The paper by Campos et al., 2017 describes the consensus achieved by the driving assessment group that was supposed to describe the role of driving simulators in assessing driving performance across a variety of applications and populations including persons suffering from sensory, motor, or cognitive impairments, psychiatric and neurological disorders [23]. In particular, a study concerning conditions that diminish simulation sickness in VR driving simulation was carried out by Ihemedu-Steinke et al., 2017 [29].

For the purposes of the conducted research, the following research problems were defined: How does the movement of RHD vehicles in RHT traffic affect the safety of road users?

The main research problem was also decomposed into detailed problems with the following content:

1. What are the rules governing the ability to drive RHD vehicles in RHT traffic in Europe?
2. Are there any statistical data allowing for the assessment of the effects of the introduced regulations?
3. How to make an objective ex ante evaluation of the potential safety effects of the legal regulations introduced in the field of RHD vehicle admission to traffic?
4. How to use a driving simulator in the research?
5. What subjective feelings in terms of road safety do people who use RHD vehicles in RHT traffic?

1.3. Safety implications put forward in the paper

Currently, no results of studies on the use of RHD vehicles in RHT traffic have been presented in the literature. The available statistical data has many disadvantages resulting from the way it is collected and its scope. Data for Poland concern the number of registered vehicles and events in which they participated in the analyzed periods. However, there is no information on how often they are used and how many kilometers they travel in practice. A common practice is to buy a vehicle, bring it to Poland and leave it in the garage until it is modified, or it is used only temporarily. To summarize, statistical data that would allow a scientifically justified assessment of the risks associated with the use of RHD vehicles in RHT traffic are not available. There are also no simulation studies available in this area. Thus, the research results presented in the article are the only data currently available that allow for a real risk assessment of allowing RHD vehicles to move in RHT traffic without modification. Their complementarity allows for attempts to extrapolate to any populations in countries with similar road traffic characteristics and culture. As indicated above, the scientific literature lacks credible research results that would allow to unambiguously dispel doubts connected with road safety in the case of driving RHD vehicles. The argument forced the conduct of scientific research aimed at assessing changes in the level of safety of drivers when driving vehicles adapted to left and right-hand traffic in right-hand traffic. The research team stated the hypothesis that driving a vehicle adapted for left-hand traffic in right-hand traffic reduces safety levels of both the driver and other road users.

2. MATERIALS AND METHODS

2.1. Simulator setup and driver maneuvers

For the purposes of the study, the "Emergency vehicles driving simulator during typical and extreme operations" was used. The research used the Kia Ceed 2.0 CRDi (140HP/103kW) vehicle model with station wagon body adapted for left-hand traffic (with the steering wheel on the right). Test stands included a vision system consisting of three high-resolution monitors, steering wheel, gear lever, pedal system (clutch, gas, brake) and an adjustable chair.

The tests were carried out at three test stands simultaneously. Study participants did not see each other and they did not see the instructor.

Drivers operated in a virtual environment along a preselected route. The terrain database, artificial intelligence of other road users and system logic were typical for right-hand traffic. The system provided information to participants in which direction they should move by marking the road lane. Driving took place under generated conditions: no cloud, no rain, during daytime between 12 p.m. and 4 p.m., with excellent visibility, the road was dry and without damage. According to statistical data on road traffic in Poland, the most accidents occurred in good weather conditions, between 10 a.m. and 6 p.m., in summer, between July and August. Driving (testing) took place on a two-lane two-way road. The prepared route driven by participants of the experiment was 50 km long, which was sufficient for the intended time. The start and end of driving were selected so that the study participant did not move in the same location of the terrain at the same time of the experiment. The driving was carried out in mountainous terrain and included the following elements:

1. Three horizontal curves with limited visibility.
2. One section with a longitudinal slope of the road exceeding 10% with a length of 6.3 km marked with the road sign A-22.
3. One steep uphill slope above 8% marked with A-23 sign with a length of 9.5 km.
4. Two viaducts.
5. Two intersections without traffic lights, on which drivers entered from the subordinate road.
6. Two tunnels with a length of 0.7 km and 1 km respectively.

Driving took place in heavy traffic, outside built-up areas, with a speed limit of 90 km/h. The route and its traffic load were identical for all tests. The simulation system generated 12 vehicles in equal proportions of time moving in a compatible direction and opposite to the direction of driving of the study participants, over a distance of 900 meters. The vehicle generation area was moving dynamically with the test vehicle in its center. The number of overtaking maneuvers depended on the driving style. The vehicles generated by the system were driven in accordance with applicable traffic regulations and rules. There was also one point on the planned route where the obstacle avoidance maneuver was forced (branch blocking one lane). This place was on a two-lane road, one lane in each direction. There were five vehicles between the study participants and the bough, which in turn drove up to the obstacle and, after stopping for 1 second, performed the maneuver of bypassing it.

Drivers moved in right-hand traffic for 10 minutes in a left-hand traffic vehicle (steering wheel on the right-hand side), then in the second round for 10 minutes in a right-hand traffic vehicle (steering wheel on the left-hand side). The interval between changes was 5 minutes. While driving, the study participants were observed by the research team directly involving the observation of the vision system of each driver. In addition, the observation was conducted using simulator supervision tools offering a third-person perspective view. The third person perspective view (TPP) has very similar features to the isometric view, but the di erence lies in the fact that it uses the full perspective. During the study, the observer's camera was located 7 meters behind the vehicle in a virtual environment at the height of 4 meters. This allowed the observation of the vehicles of the study participants from all sides and the observation of all events with their participation while maintaining an eye-view close to the vehicle's driver.

2.2. Research questions and sample

For the purposes of the study, a research sample consisting of 93 people was established, including 39 women and 54 men. The sex structure of the study participants was 41.94% women and 58.06% men, respectively. The structure of the research sample was selected in such a way that it corresponds to the structure of drivers with driving license Category B in Poland and it is congruent with many states worldwide. For example, in the subsequent years 2016, 2017 and 2018 the driving license Category B was held by, respectively, 20.4 million, 20.8 million and 21.2 million people in Poland, out of which there were approximately 40-41% women and 59-60% men (the exact figures read 40.19% / 59.81%; 40.46% / 59.54%; 40.72% / 59.28%). For a general population size, it was assumed that 21.2 million drivers have a category B driving license. The research sample was determined according to the formula:

$$n = \frac{P\cdot(1-P)}{\frac{e^2}{Z^2}+\frac{P\cdot(1-P)}{N}} \tag{1}$$

where: n – size of the research sample, N – size of the population, P – estimated proportion in the population (structure), e – permissible statistical error, – confidence level, Z – the value resulting from the assumed confidence level, to include at least 93 people (μ = 95%, Z = 1:96, e = 10%).

2.3. *Participants demographic data and follow-up questionnaire*

After completing their driving, the study participants filled up a questionnaire consisting of 12 questions (9 open-ended and 3 closed ended). The closed-ended questions used the Likert scale of five responses arranged in order from the degree of total acceptance to the total rejection. As a part of the prepared questionnaire form, 5 questions regarded the sociodemographic characteristics of the participants of the experiment (age and gender of the subjects, as well as data relevant to the assessment of experience in driving motor vehicles, i.e. the time of having a driving license, the category of driving license, the number of kilometers driven after obtaining category B driving license and the number of kilometers driven in left-hand traffic). The remaining 7 questions concerned elements related to the study itself. The respondents were asked about the assessment of the level of safety of road users driving in left-hand traffic vehicles in right-hand traffic, the number of situations threatening safety, the number of accidents and road collisions in which the subjects participated during the test, and whether they would drive a vehicle adapted to left-hand traffic right sided as a permanent means of transport.

All surveys that were filled out appeared to be complete and fully usable when analyzing the results. All study participants were right-handed. None of the subjects complained about an illness. It was assumed that the research will involve young drivers only to minimize the elements of habituation and routine resulting from the years of experience in driving right-hand vehicles in right-hand traffic.

The mean age was 20 years and 7 months, the median 20 years, and the standard deviation 1.40. The largest group – 59.14% percent were people under 21. An additional element indicating little experience of drivers was the number of years of holding a driving license of any category, shown in Fig. 2 and the number of kilometers driven from obtaining the driving license of B Category, shown in Fig. 3.

The age structure of the study participants is presented in Fig. 1.

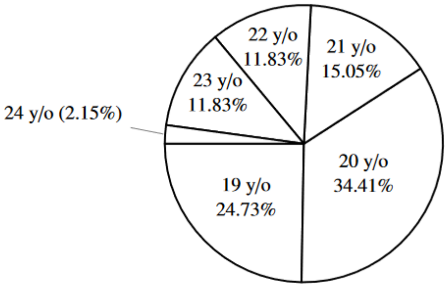

Fig. 1. *Age structure of the study participants. The research involved young drivers only, to minimize the elements of habituation and routine*

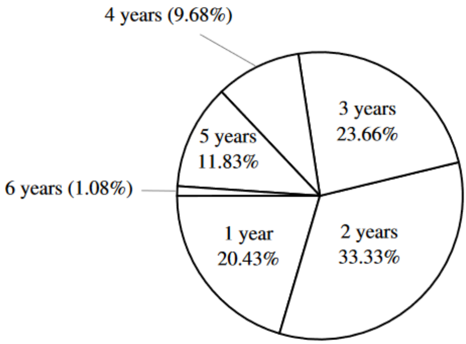

Fig. 2. *The number of years of holding a driving license of any category*

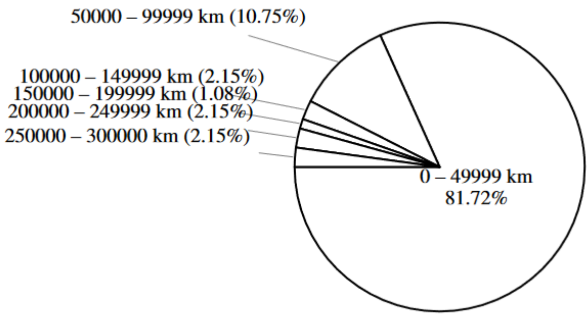

Fig. 3. *The number of kilometers driven since receiving the driving license of B Category*

The answers indicate that 77.42% of study participants have had a driving license for 3 years and less. None of the study participants can be considered a driver who, as a result of many years of having a driving license, may have restrictions resulting from routine and habits. On average, the participants of the experiment had a Category B driving license for 2 years and 7 months, for a median of 2 years, and the standard deviation was 1.30. A significant concentration of observations around the average age indicates a small diversification of the study group in this aspect. It is characteristic that these values were similar for both women and men (tab. 1).

Tab. 1. *Sample examined*

Sex		Men	Women
Age	average	20.67	20.46
	median	20.00	20.00
	std. dev.	1.44	1.35
Possession of driving license category B in years	average	2.72	2.49
	median	3.00	2.00
	std. dev.	1.35	1.23
Kilometers driven since obtaining category B	average	40884.91	15150.00
	median	20000.00	5000.00
	std. dev.	62280.68	33049.05
Kilometers driven in left-hand traffic	average	15.02	2.24
	median	0.00	0.00
	std. dev.	55.77	7.32

The number of kilometers driven since receiving the Category B driving license has not exceeded 50,000 in the case of 81.72% of participants of study. A thorough analysis indicates that about 1% of the data provided by the participants of the experiment in this regard seems unreliable. One participant reported that he had driven 300,000 km within 2 years from obtaining the driving license. Men declared significantly more kilometers driven than women, i.e. an average of 169.87% more (Table 1). In spite of the comments made, there is a high probability that a limited experience and a lack of routine did not allow the subjects to drive inconsiderately and thus prevented behavior that would lead to a greater number of situations threatening the safety of the driver. This applies especially when driving a left-hand traffic vehicle in right-hand traffic.

Additionally, an important element of the study could have been the number of kilometers driven in left-hand traffic. Eighty respondents (87.1%) from the research sample do not have such an experience at all. Only three persons have driven over 100 km in left-hand traffic.

3. RESULTS

3.1. Safety ratings by participants

The majority of study participants when asked for expressing their opinion after the simulator test, rated the safety of road users moving on left-hand traffic vehicles in right-hand traffic, as shown in Fig. 4. The study participants answered the question: "How do you assess the safety of road users driving left-hand traffic vehicles in right-hand traffic?"

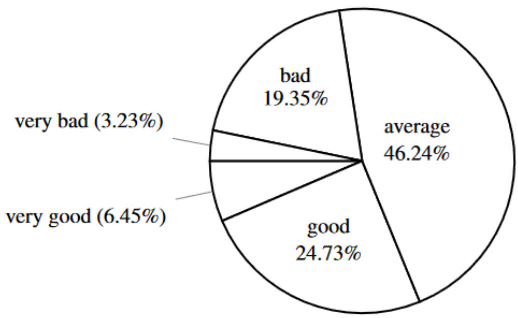

Fig. 4. *Safety assessment of road users driving in left-hand traffic vehicles in right-hand traffic*

As much as 77.42% of participants indicated the level of security as very good, good or average. Only 21% indicated that it was bad or very bad. This is contradicted by the results regarding the number of events that pose the threat to the driver when driving left-hand traffic vehicles.

To assess the reasons for such a good assessment of the examined the safety level of drivers of this type of vehicles, two questions were introduced as a part of the prepared research. Participants were to indicate the number of events generating an exposure to the driver's safety related to driving left-hand traffic vehicles in right-hand traffic and not related to driving left-hand traffic vehicles in right-hand traffic. They were asked although the number of traffic incidents (road collisions and accidents) for two types of vehicles was recorded by the investigators for each participant.

The results presented in Fig. 5 indicate that 16.13% did not have any events at all whiles driving a left-hand traffic vehicle and 23.66% had only one event. One can notice that about 4.30% of subjects could not handle driving such vehicles indicating a significant number of incidents threatening their safety, i.e., above 8. As much as 78.49% of the research participants indicated that the number of such situations ranged from 1 to 4.

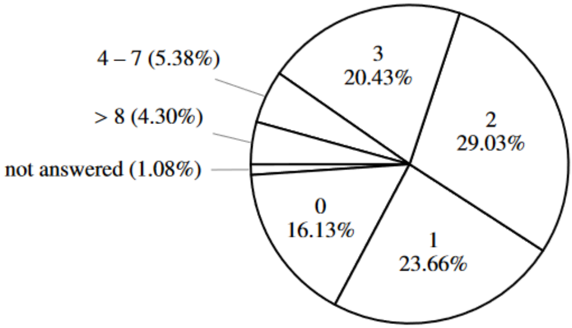

Fig. 5. *Number of incidents generating an exposure to the safety of the driver related to driving a left-hand traffic vehicle in right-hand traffic*

In this context, the results of the answers provided by the study participants to the question about the number of events threatening the safety of drivers not related to driving a left-hand traffic vehicle in right-hand traffic are extremely important and shown in Fig. 6. As shown, as much as 36.56% of study participants did not report this type of event. 12.90% of subjects participated in 3 or more such situations. For comparison, 3 or more situations related to driving a vehicle not adapted to right-hand traffic were indicated by as much as 30.11% of participants of the experiment (Fig. 5).

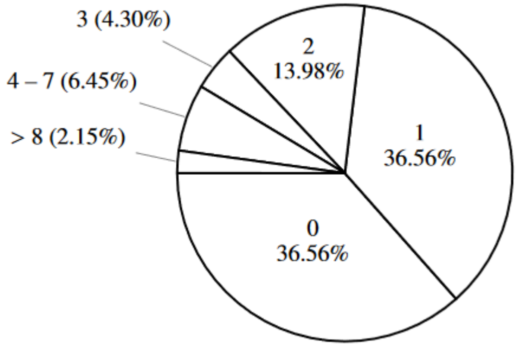

Fig. 6. *Number of incidents generating an exposure to the safety of the driver not related to the driving of a left-hand traffic vehicle in right-hand traffic*

It is clearly seen, contrary to the feeling of most drivers surveyed that safety when driving a left-hand traffic vehicle in right-hand traffic is average or good, that the number of hazardous events is significantly higher. The increase in the category above 3 hazardous situations is over 133.33%. In total, the subjects indicated that they participated in 377 hazardous situations while driving on constructed test stands, of which 69.23% concerned situations related to driving the vehicle with the right-hand drive, and 30.77% with other factors.

During the study, the participants were driving a similar number of kilometers using left – and right-hand traffic vehicles. The average speeds achieved by study participants were also very close. The results are presented in tab. 2.

Tab. 2. *Average speed and average number of kilometers driven by participants of the study*

Left-hand traffic vehicle	**average**	**median**	**std. dev.**
Distance [km]	9.96	10.00	2.15
Speed [km/h]	59.77	60.00	12.87
Right-hand traffic vehicle	**average**	**median**	**std. dev.**
Distance [km]	10.00	10.00	1.77
Speed [km/h]	60.02	60.00	10.63

The study also revealed that participants did not show much caution when moving a left-hand traffic vehicle. It cannot be argued that drivers using such vehicles will increase their level of safety by reducing the speed at which they were driving. The results indicated that women were driving on average about 4.30 km/h slower than men with right-hand traffic vehicles and as much as 12.04 km/h slower when driving a left-hand traffic vehicle. They showed significantly more caution than men in a non-standard vehicle.

3.2. Incident type breakdown

The investigators registered 107 traffic incidents in which the surveyed drivers took part. In order to specify the incidents in more detail, the study makes a distinction between accidents and road collisions. To assess whether the event was an accident or a road collision, the simulation system performed characteristics of the event, including the vehicle speed and the nature of their damage. Accidents were construed as such events in which the driver would most likely be injured or killed. The assessment was made by police traffic experts based on the system data and observation of the event. The results indicated that when driving left-hand traffic vehicles there were 71 incidents of the total of 107 events that is 63.55% (Fig. 7). This means that there were twice as many accidents and collisions than while driving right-hand traffic vehicles in right-hand traffic, in the case of which there was a significantly smaller number of 36 accidents and collisions. Among the total number of 107 events, the most serious incidents should be highlighted, i.e. the accidents. When driving a right-hand traffic vehicle there were 78.57% more accidents on the left-hand traffic than for a right-hand traffic vehicle.

The data recorded by the investigators clearly indicates a considerable growth in the number of accidents and collisions in which the surveyed drivers participated in the case when they were using a left-hand traffic vehicle in right-hand traffic. The observed lower average speed of women driving right-hand drive vehicles did not significantly a ect the number of accidents and collisions caused by women. The results broken down by gender are presented in Tab. 3. Women caused on average the same number of collisions and by 23.08% more road accidents than men when driving left-hand traffic vehicles in the right-hand traffic. At the same time, they caused on average 86.92% less collisions and 20.37% less road accidents when driving right-hand traffic vehicles in right-hand traffic.

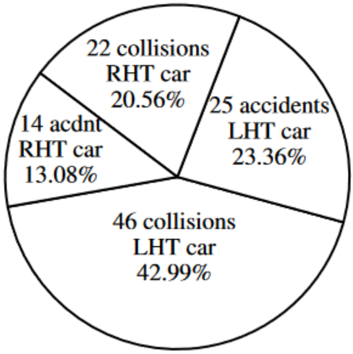

Fig. 7. *Number of collisions and accidents registered*

Tab. 3. *The average number of accidents and collisions by gender*

Left-hand traffic vehicle	**men**	**women**
Average number of collisions	1.61	1.62
Average number of accidents	1.30	1.60
Right-hand traffic vehicle	**men**	**women**
Average number of collisions	2.08	1.11
Average number of accidents	1.44	1.20

These results were confirmed by the respondents' answers to the question whether they would drive a left-hand traffic vehicle in right-hand traffic as a permanent means of transport. The data in fig. 8 indicate that 64.52% of people would not like to do this. Only 8.60% were convinced that the fact of adjusting the vehicle to the right-hand traffic was not relevant to the driver's safety.

Fig. 8. *Distribution of responses to the question whether the respondents would drive a left-hand traffic vehicle in right-hand traffic as a permanent means of transport*

69.89% of the study participants disagreed with the claim that driving a left-hand traffic vehicle in right-hand traffic does not affect the safety of its participants (Fig. 9). Further research indicated that 6.45% of subjects who strongly agreed that driving a left-hand traffic vehicle in right-hand traffic did not affect the safety of its participants determined the level of safety of road participants driving in left-hand traffic vehicles in right-hand traffic as good. Only 19.35% of respondents (18 people) considered the level of safety as bad or very bad and at the same time disagreed with the statement that there is no impact on the safety of the driver. This means that although a significant proportion of drivers are aware that there is an impact on driver safety, they underestimate the level of impact.

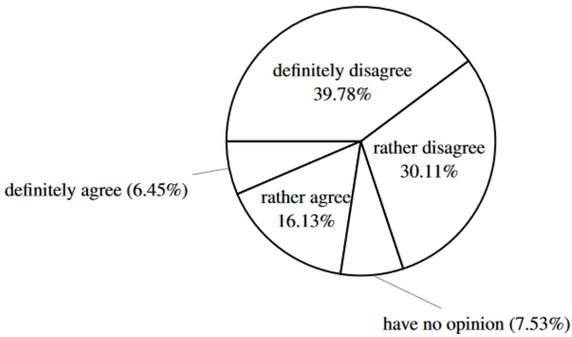

Fig. 9. *Distribution of responses to the question "Rate the statement: Driving a left-hand traffic vehicle in right-hand traffic does not affect the safety of its participants"*

For all variables regarding the number of collisions and accidents in both types of vehicles, average speeds achieved by drivers during the experiment and the number of kilometers driven in the history of holding a Cate-gory B driving license, two-tailed Pearson correlation coefficients were calculated. Correlations were calculated for data set of all 93 tested drivers. The results indicate that all observed strong correlations are not statistically significant. The results of the analysis are presented in tab. 4. As it can be seen, there is a negative correlation for the number of collisions when driving left-hand traffic vehicles and accidents when driving right-hand traffic vehicles and the number of kilometers driven from obtaining a category B driving license. Experienced drivers cause fewer accidents and collisions. Also, the average speed at which the participants were driving had an impact on the number of collisions, but only for right-hand drive vehicles.

3.3. Additional experiment with experienced drivers

In the same conditions, two very experienced drivers – Police traffic officers – were tested. Both were over 35 years old and with a history of around 500,000 kilometers driven since receiving the Category B driving license. The results obtained by them are presented in tab. 5. The results have shown that officers were driving much slower with left-hand traffic vehicles. Their speed was almost 25% lower. The examined young drivers were driving at similar speeds regardless of the type of vehicle. During the study, police officers did not report any accidents and collisions, however, they pointed to the occurrence of one situation posing a threat to their safety, associated with driving a left-hand traffic vehicle.

Tab. 4. *Correlation between the number of collisions and accidents in both types of vehicles and the average speed achieved by drivers during the test and the number of kilometers driven in the history of holding a Category B driving license*

		S-LH	A-RH	K
C-LH	Pearson correlation	0.163		-0.211
	Sig. (2-tailed)	0.279		0.165
	N	46		45
A-LH	Pearson correlation	0.132		-0.102
	Sig. (2-tailed)	0.53		0.635
	N	25		24
C-RH	Pearson correlation		-0.07	0.081
	Sig. (2-tailed)		0.756	0.728
	N		22	21
A-RH	Pearson correlation		0.133	-0.388
	Sig. (2-tailed)		0.649	0.171
	N		14	14
C-LH – collisions / left-hand traffic vehicle				
A-LH – accidents / left-hand traffic vehicle				
C-RH – collisions / right-hand traffic vehicle				
S-LH – average speed / left-hand traffic vehicle				
S-RH – average speed / right-hand traffic vehicle				
K – kilometers driven since obtaining Category B				
A-RH – accidents / right-hand traffic vehicle				

Tab. 5. *Average speed and average number of kilometers driven by officers of the Police traffic division*

average speed / left-hand traffic vehicle	51.69 km/h
number of kilometers driven / left-hand traffic vehicle	8.62 km
average speed / right-hand traffic vehicle	68.34 km/h
number of kilometers driven / right-hand traffic vehicle	11.39 km

4. DISCUSSION

The results of the conducted research clearly show that the use of left-hand traffic vehicles in right-hand traffic are not insignificant for the safety of drivers. Despite the feeling of the majority of drivers surveyed that safety when driving a left-hand traffic vehicle in right-hand traffic is average or good, the number of hazardous events is significantly higher. The obtained data allow for an unequivocal statement that most drivers are aware that there is an impact on driver safety, but they neglect the level of impact. We cannot rely on the increased caution demonstrated by drivers when driving RHD vehicles.

The average speed achieved by study participants was very similar. Some slight differences can be seen only in the case of women who were driving on average about 4.30 km/h slower than men with right-hand traffic vehicles and as much as 12.04 km/h slower when driving RHD vehicles. The number of traffic incidents (accidents and collisions) was approx. 50% higher when driving RHD vehicles.

For example, after reducing the speed limit in the built-up areas in Switzerland in 1984 from 60 km/h to 50 km/h, the number of accidents was reduced by 5%. Similarly, after the changes in Denmark that were introduced in 1985, the number of accidents on the road network was reduced by around 9%. In the context of all road incidents, the role of this restriction would be even smaller. Based on the Power Model developed by Nilsson, it is estimated that a 5% reduction in average vehicle speed results in a 10% reduction in the overall number of accidents. This means that the introduction of regulations allowing for the registration of RHD vehicles without modification (steering change) can be as important for road safety as reducing the speed by 10 km/h in built-up areas. The final effect will be influenced by, inter alia, the number of vehicles that will drive in right-hand traffic and the age groups of drivers who will use them. The average speed at which drivers covered the route did not have a decisive impact on the number of collisions when driving an RHD vehicle. Even extremely experienced drivers, police road traffic officers with extensive experience in driving a car did not avoid situations threatening their safety associated with moving a left-hand traffic vehicle. What is the current statistics of events involving vehicles adapted to left-hand traffic moving in Poland? In 2018, there were 23,429,000 passenger cars on Polish roads (for the Polish Automotive Industry Association, www.pzpm.org.pl), of which 218,453 passenger cars adapted to left-hand traffic. This year, there were 1,391,247 accidents and collisions involving passenger cars, of which 531 involving vehicles adapted to left-hand traffic (data from the SEWIK registration system). As you can see, only 0.24In order to correctly assess the ratio of the number of events to the number of registered vehicles, it would be necessary to know how many of them are in traffic in Poland. It is highly probable that registered vehicles are used occasionally in Poland, when the owner, permanently residing and working in Great Britain, returns to the country, e.g., on vacation.

Therefore, attention should be paid to other indicators such as the number of serious events in relation to total events. 3,271 people died in road accidents involving passenger cars in 2018, including 5 involving RHD vehicles. The incidents took place on straight sections of the road in a non-built-up area, on a hard surface in the area with a speed limit of 90 km / h. This means that as much as 0.94The death rate in accidents involving RHD vehicles was more than four times higher in 2018 than accidents involving left-hand traffic vehicles. This is confirmed by the data obtained from simulation studies, where serious events were a significant element. The interpretation of the presented data allows for the conclusion that the caution of drivers driving RHD vehicles in right-hand traffic causes that the number of minor collisions is significantly lower than in the case of LHD vehicles. However, when driving RHD vehicles in right-hand traffic, the risks associated with, for example, overtaking vehicles cannot be avoided, and the consequences of such events are usually very serious. The fatality rate in accidents involving RHD vehicles was more than four times higher in 2018 than accidents involving left-hand traffic vehicles. This is confirmed by data obtained from simulation studies in which serious events were an important element. The interpretation of the presented data allows for the conclusion that the caution of drivers driving RHD vehicles in right-hand traffic is high, the number of minor collisions – much lower than in the case of LHD vehicles, may result from the lower number of kilometers on average driven annually by vehicles of this type in Poland than those adapted to traffic right hand side. Unfortunately, there are no statistical data that would allow a clear interpretation. Therefore, it is worth taking into account the results of simulation tests, which are confirmed for example by the number of serious events involving RHD vehicles. Driving RHD vehicles in right-hand traffic cannot avoid the risks associated with, for example, overtaking vehicles, and the consequences of such events are usually very serious.

5. CONCLUSIONS

The European Union directives in the field of road traffic, including the issue of safety, directly affect domestic legal regulations of the individual Member States. They also have an impact on the safety of road users. Factors such as changing the provisions governing the registration of vehicles in right-hand traffic and allowing for the registration of vehicles adapted to left-hand traffic, with the steering wheel on the right without implementing modifications required so far, including steering gear ratio, may affect driver behavior. The driver's perception of the environment and reactions to the observed external stimuli may be slower. This means that the road safety area may be at risk. To answer the question whether driving right-hand drive vehicles in right-hand traffic affects the safety of road users, experimental research was carried out using modern simulation tools. For this purpose, a simulator was used to drive privileged vehicles during typical and extreme operations. The used setup is a training system designed to improve the skills of officers of various services in the field of privileged vehicles. In addition to improving driving techniques, the simulator primarily allows for driving training in simulated conditions of various hazards (e.g., pedestrian intrusion on the road, animals on the road, falling load, chase, and many others), as well as tactical learning to drive individual and team drivers. The study showed that factors such as reducing the speed in built-up areas to 50 km/h have a lower impact on the safety of drivers than driving a RHD (Right Hand Traffic) vehicle in right-hand traffic.

Overall, the results of the research allow the conclusion that driving RHD vehicles in right-hand traffic has a significant impact on road safety. Therefore, it seems that the subject-matter discussion should primarily concern road safety involving its social costs and should consider the increased number of road incidents.

The conducted research has shown that changes in road traffic organization can and should be preceded by advanced research on vehicle simulators. An ideal example is the implementation of changes in Polish law in the context of RHD vehicles in RTH traffic. In this case, before the changes, it was not possible to rely on reliable data considering significant aspects of the impact of driver training in Poland on their ability to drive such vehicles, as well as social and behavioral effects. Complementing standard statistical surveys with data from driving simulator experiments would allow a better understanding of the potential risks and impacts on road user safety. Policies for introducing changes with similar characteristics should consider research on simulators in the process of assessing the effects of potential changes in the future.

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