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YOUNG ADULT DRIVERS: SIMULATED BEHAVIOUR IN A CAR-FOLLOWING SITUATION

ABSTRACT

This paper provides a description of driver testing in a simulator. As young drivers are more susceptible to collisions, this was done to determine how young drivers behaved in simulated road situations on a motorway. One of the traffic safety concerns is the failure to keep a proper distance from the vehicle in front, which may result in a rear-end collision. The tests simulated car-following situations in which the preceding vehicle performed emergency braking. The experiments were conducted for two scenario variants using different distances from the vehicle in front. The drivers could perform the following emergency manoeuvres: braking with steering away or only braking. The driver response times were compared and analysed statistically. The results were used to determine the emergency manoeuvres performed by the drivers in the simulated road situations. The study reveals that the vehicle surroundings may have a considerable influence on the type of emergency manoeuvres and the driver response time.

KEY WORDS

simulator; young driver; response time; two-lane motorway; car-following situation;

1. INTRODUCTION

The driver behaviour is dependent on a number of factors, with some being more important than others. In a car-following situation, for instance, when vehicles need to maintain a suitable distance to ensure traffic safety, these factors are responsible for the driver response time or the choice and performance of emergency manoeuvres.

For many years researchers have been trying to determine how various factors affect the driver behaviour in various traffic situations. Investigations have been carried out in different roadway environments, i.e. on a test track, in a simulator or using special test devices, with test participants including healthy drivers as well as drivers with permanent or temporary disabilities.

Tests conducted on drivers after accidents aim to assess the progress of treatment and their physical and mental fitness to drive a vehicle and properly respond to different road situations (simulated real traffic and environment). Many investigations have been performed on drivers after complex orthopaedic surgeries, which adversely affected their physical fitness. For instance, Spalding et al. focused on drivers after a total knee replacement and their ability to perform emergency braking [1].

Other researchers have tried to determine how much time is required for patients after a total hip arthroplasty to be able to drive again [2]. Driver tests are also carried out to assess the performance of drivers with chronic diseases, e.g. Parkinson's disease [3]. Much of the research into the effect of different factors on the driver behaviour concerned such factors as fatigue due to prolonged driving on a motorway, sleep deficit [4], sleepiness [5], alcohol impairment [5, 6] and drug impairment [7].

A number of studies also deal with the relationship between the driver response and the roadway environment [8, 9]. Recently, because of technological progress, research has been undertaken to determine the effect of gadgets, including car multimedia systems and cellular phones [10, 11, 12, 13]. Investigations into the use of mobile phone during motorway driving in a car-following situation have been carried out on younger (aged 18–25) and older (aged 65–74) drivers [14].

In the case of professional drivers, the aim of testing may be to determine their performance when affected, for instance, by sleepiness. The behaviour of lorry drivers in unexpected critical situations has also been investigated [15]. Simulator-based tests

[16] have been used to study how warning messages and variable speed limits (VSLs) influence the driving speed.

Muttart [17] analyses the driver steering behaviour with regard to the driver age, the driver fatigue, distraction, natural lighting and the buffer space available. Driver performance has been studied for many years and the tests have been conducted under real road conditions, on test tracks [18, 19, 20, 21] as well as in driving simulators [22, 23]. The investigations carried out under different circumstances and in different test environments have some advantages and disadvantages. The main strength of simulator-based investigations is that participants are tested under the same conditions.

Many studies on the subject focus on determining the driver behaviour in a car-following situation and modelling the movements of the vehicles involved. For example, the driver performance model proposed in [24] is based on the optical control of quantum flow. This dynamic and stochastic approach to the driver behaviour during a car-following situation indicates that the driver response time is largely dependent on their subjective perception of speed. Kesting and Triber [25] use the Intelligent Driver Model (IDM) to analyse the effect of different parameters, including the driver response time, on the stability of traffic flow.

The study presented in [26] involved applying a driver model to predict dangerous car-following situations for different styles of driving.

Autonomous systems capable of fully or partially controlling the vehicle, described, for instance, in [27] have been analysed under various driving conditions to assess their reliability and, if necessary, propose further improvements.

The existing methods used to describe the driver behaviour in emergency situations have been analysed to create a cognitive model able to predict the driver response time so that future assistance systems are better equipped to assess and adjust to changes in the road situation [28].

Many studies involve using computer simulations or simulator-based tests.

A vital argument for conducting investigations in a virtual environment is to perform identical, pre-programmed situations and tests with the same parameters [29]. Some virtually created road situations can be impossible or dangerous to perform under real conditions on test tracks as they may involve risk to the participants and damage to the measurement devices [23]. Another important argument for simulator testing is also that we can check the driver performance under specific driving conditions: strong fatigue, alcohol impairment, etc.

Driving simulators can also be used to improve the safety of pedestrians. For example, Petzold studied pedestrian crossing situations, focusing on the safe gap between passing cars based on the time to arrival (TTA) judgements [30].

Driving simulators can be used to simulate different road situations, for instance, a car-following situation [31, 32]. Under real-world conditions, tests involving vehicles following one another at high speeds on motorways could be difficult and hazardous to perform. Many publications recommend that in a car-following situation an appropriate distance should be maintained to ensure an appropriate level of safety. Brakstone et al. [33] studied the distance between vehicles moving on motorways using a specially equipped vehicle. Different factors were taken into consideration to analyse traffic safety in such situations [34]. Problems related to car-following situations have been dealt with by numerous researchers [35, 36].

This paper discusses the behaviour of young adult drivers in a car-following situation on a two-lane motorway. The tests involved measuring and analysing the times of response to rapid braking by the lead vehicle in order to determine the safe distance between vehicles in two different situations. The paper focuses on emergency manoeuvres undertaken by drivers in a car-following situation. Section 2 will discuss briefly the methodology of the simulator-based tests, while Section 3 will present and analyse the test results for both scenarios of road situations.

2. METHODOLOGY

2.1 Characteristics of the driving simulator

The testing was conducted at the Automotive Engineering Laboratory using an Oktal® dynamic driving simulator. The simulator consists of a fragment of a car compartment and three 1920x1080 42 inch monitors, placed on a mobile hybrid platform. The 6 DOF platform enables the following motions of the compartment: an angular rotation of ±10˚ about the X, Y and Z axes with an angular acceleration of ±150˚/s2 and a linear displacement platform of ±50 mm with an acceleration of up to 3m/s2. In the simulator cabin, there is an adjustable driver seat equipped with an inertia-reel seat belt.

Drivers sitting in the simulator have a real vehicle dashboard in front of them and all the typical driving elements used in vehicles. There is also a 10-inch LCD digital instrument panel with configurable display elements specific for the make and model selected. While driving on rough surface, the driver feels vibration on the steering wheel. Similarly, while turning the steering wheel during an emergency steering manoeuvre, the driver feels some resistance on the steering wheel. The driver's compartment also comprises 5.1 speakers that can reproduce sounds related to the vehicle movement through traffic, i.e. noise of the engine, noise produced by wheels in contact with the road surface, and any other noise from the surroundings. The system uses two computers for visualising the created traffic situation and controlling the platform motion. The simulator comprises Scaner Studio® software which allows drivers to create their own type of vehicle (e.g. by modifying the parameters of the existing models), generate a new road profile and the road environment and design a test scenario.

Road modification may involve changes to the road surface properties, e.g. a change in the pavement type, coefficient of grip and road roughness, which are used by the model of the vehicle dynamics. The simulator software contains an advanced simulation model of a vehicle (Callas® model), which, depending on the options used, can have from 15 to 43 DOF [8, 37].

2.2 Description of the test procedure

In the simulation-based tests performed in 2016, sixty young adult drivers were included. They were male students with little driving experience, aged 21–25, with the age average being 22.54 (standard deviation 0.91 years). Young drivers were selected to take part in the simulations because in Poland drivers aged 20–24 are reported to be at the highest risk of being killed in a car crash (per 1 million people) [38]. The subjects were driving in the right lane of the road, as shown in *Figure 1*. The measurements began at a speed of about 100 km/h and a pre-determined constant distance of 10–50 m from the preceding vehicle. The road situation can be simulated on a motorway, a dual carriageway or other types of roads divided into lanes. The road along which the subject vehicle was moving was flat and had two traffic lanes and an emergency lane. Each lane was about 4 m in width. In version 1 of the scenario, there were no other vehicles moving next to the subject vehicle. At a randomly selected moment, the lead vehicle decelerated by 9 m/s^2. This value of the maximum braking is a typical physical limit on dry surface roads [34].

Figure 1 – View from the driver seat of an Oktal™ simulator and a diagram of version 1 of the scenario

The drivers of the following vehicle, i.e. the drivers tested, were free to choose between the emergency manoeuvres: braking, steering around the lead vehicle or combined braking and steering. The data registered during the tests were used to assess the driver behaviour and the driver response time. The parameters measured included:

- the steering angle characteristics (to determine the steering response time),
- the displacements of the braking and accelerator pedals (to determine the braking pedal response time and the accelerator pedal response time, respectively),
- the speed and driving paths of the vehicles,
- the vehicle deceleration.

In version 2 of the scenario, two other vehicles, i.e. a bus and a lorry present in the left lane, were added to the simulated road situation (see *Figure 2*). As the subject vehicle was moving at a speed of about 100 km/h, the driver could perform only one emergency manoeuvre - rapid braking. The aim of the simulator-based investigations was to determine the behaviour of drivers faced with sudden braking by the preceding vehicle. The main parameter determined during the tests was the driver response time.

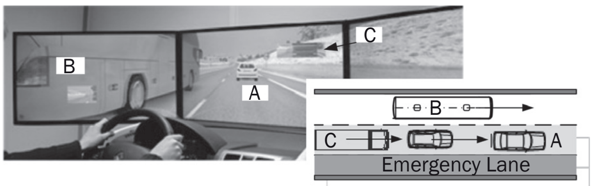

Figure 2 – View from the driver seat of an Oktal™ simulator and a diagram of version 2 of the scenario

Before the tests, the participants were trained to use the driving simulator and drove a similar route several times. Each subject took ten tests but the version of the scenario and the test parameters were selected at random to ensure as much realism as possible. The total experiment time was about 45 minutes per person. Our future projects will involve testing older drivers with more driving experience to compare their behaviour depending on the experience. We also intend to perform tests based on identical scenarios but under night driving conditions when the low-beam visibility of the vehicle in front is limited.

The main purpose of the study was to analyse how a road situation could affect the driver response time. It was important to question whether the driver response times obtained in the simulations of the car-following situations would differ for different distances between vehicles. Another objective was to determine whether a change in the stimulus that the drivers were exposed to (from a warning message displayed on the screen to an emergency situation with a preceding vehicle braking suddenly viewed on the screen) would affect the response times.

The scenario considered in the earlier research project [8] was simpler; the average braking response time was about 0.9. However, there was a large scatter of results; they ranged from 0.3 s to 1.8 s, depending on the driving conditions. As described in other publications, the driver response time used in various analyses (especially those required for the reconstruction of accidents) should be assumed on the basis of investigations conducted under very similar conditions and in similar scenarios. The assumed value of the braking response time was either shorter or longer than the one obtained on the test track or in the simulator [23]. Of importance is the fact that the values of the driver response time for identical situations determined during tests on the track and tests in the simulator are different but correlated [20]. The diagram of a hypothetical road situation is presented in *Figure 3*.

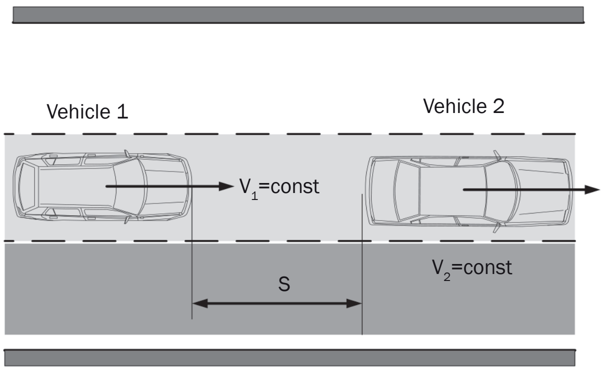

Figure 3 – Diagram of a car-following situation

Two vehicles, i.e. vehicle 1 and vehicle 2, move at identical speeds of about 100 km/h at a certain distance from each other, e.g. 30 m. Suddenly, the driver of vehicle 2 – the preceding vehicle – starts to brake. From the moment that the brake lights come on the preceding vehicle (vehicle 2) to the moment when braking is initiated with a predetermined deceleration, a certain time passes (here, we assume it to be about 0.5 s). The time is a sum of the brake system activation delay time and the pressure build-up time. The driver of vehicle 1 begins to respond after the assumed response time [37]. Vehicle 1 approaches the preceding vehicle 2.

The distance between the subject vehicle and the lead vehicle is maintained constant by properly setting the simulator.

If, however, the deceleration of vehicle 1 is smaller than the deceleration of vehicle 2, there is a dangerous decrease in the distance between the vehicles. This situation may occur when the vehicles taking part in the event are not equipped with modern safety systems, e.g. brake assist system (BAS). It is crucial to find out what would happen if the driver response time was different – shorter or longer – than the predetermined, e.g. 0.9 s, and how a change in the driver response time would affect the minimum relatively safe distance between the vehicles in a car-following situation.

Numerous investigations concerning the driver response time show that there are other factors affecting the driver performance, e.g. fatigue and sleepiness, which may increase the response time [4].

3. RESULTS

The tests involved registering the following data:

- the accelerator pedal response time, i.e. the time measured from the moment the brake lights come on the preceding vehicle to the moment when the driver of the subject vehicle responds by easing the pressure on the accelerator pedal;
- the braking response time, i.e. the time from the moment the brake lights come on the preceding vehicle to the moment when the driver of the subject vehicle begins to press the braking pedal;
- the steering response time, i.e. the time from the moment the brake lights come on the preceding vehicle to the moment when the driver of the subject vehicle begins to turn the steering wheel (analysed only for version 1 of the scenario).

The emergency manoeuvres were determined for each driving test. If a collision occurred, the fact was registered [37].

3.1 Version 1 of the scenario

In version 1 of the scenario, there were no limitations to the driver performance, because there were no other vehicles in the left adjacent lane. While analysing the data, we can see that there is a large discrepancy in the measured values of the response time. Although the data concerning the accelerator pedal response time are not taken into consideration, e.g. by experts in forensic investigations to reconstruct an accident, it is important to note that the accelerator pedal response is likely to initiate the braking pedal response.

As shown in *Figure 4*, the values of the accelerator pedal response time ta increase with increasing dis-

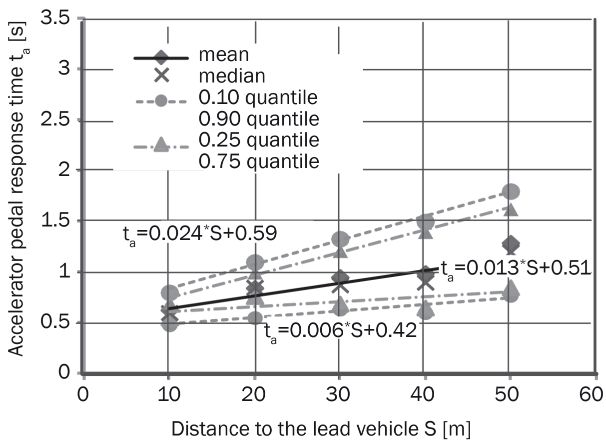

Figure 4 – Values of the accelerator pedal response time t_a

tance S from the preceding vehicle. *Figure 4* shows the regression lines for the median and the 0.1 and 0.9 quantiles of the accelerator pedal response time according to the distance to the lead vehicle.

If a constant value of the initial speed is assumed, the response time increases with the time to collision (TTC), which is a parameter used in numerous analyses [19, 20]. The difference in the median value is almost 0.5 s for the response time determined at distances of 10 m and 50 m. It should be borne in mind, however, that a vehicle moving at a speed of 100 km/h covers a distance of 27.8 m in 1 second so, in many cases, responses are initiated either at the moment the vehicle collides into or begins to steer away from the preceding vehicle. Analysing the response times from the range between 0.1 and 0.9 quantiles constituting 80% of all the response times obtained by the drivers, we can conclude that the differences in

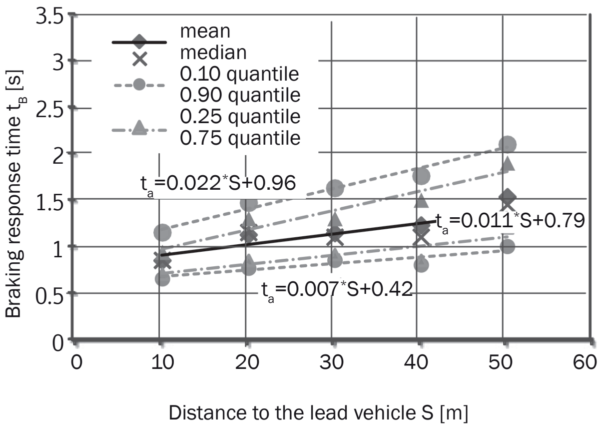

Figure 5 – Values of the braking pedal response time t_B

the driver response time increase with the increasing distance between the vehicles.

The values of the braking response time were assessed in the same manner. The statistical parameters of the braking response time are provided in *Table 1*.

The analysis of *Figure 5* indicates that there is a relationship between the braking response time and the initial test distance between the vehicles in an emergency situation. For the initial car-following distances, the braking response time increases but less rapidly than the accelerator pedal response time. For distances of 20–40 m, the median value of the braking response time is in the range of 1.1–1.15 s. From the results it is evident that an increase in the distance between the vehicles leads to an increase in the difference in response time, which is particularly visible for the 0.1 and 0.9 quantiles. *Figure 5* shows the regression lines for the median and the 0.1 and 0.9 quantiles of the braking response time according to the distance from the lead vehicle.

The driver response times obtained for this scenario were compared with the braking response times from the author's earlier tests conducted with a driving simulator [8].

The analysis reveals that the braking response time is similar to that from the previous test only when the distance between the vehicles is very short, e.g. 10 m. For other distances, the driver response times for braking are 0.2–0.5 s longer. Previous investigations by the author show that the test participants 'driving on a motorway' did not respond to a real road situation, but to the braking instruction 'brake' displayed on the screen. The response was similar in nature to a simple response because the driver responded to a simple light incentive. It is important to note that the

Table 1 – Statistical parameters of the braking response time t_B

Distance between vehicles	Braking response time t_B [s]				
	0.1 Quantile	0.25 Quantile	Median	0.75 Quantile	0.9 Quantile
10 m	0.65	0.71	0.85	0.93	1.15
20 m	0.76	0.85	1.15	1.30	1.47
30 m	0.85	0.91	1.10	1.30	1.62
40 m	0.80	0.85	1.10	1.50	1.76
50 m	1.00	1.22	1.45	1.90	2.10

Table 2 – Statistical parameters of the steering response time, t_S

Distance between vehicles	Braking response time t_S, [s]				
	0.1 Quantile	0.25 Quantile	Median	0.75 Quantile	0.9 Quantile
10 m	0.55	0.63	0.70	0.85	0.90
20 m	0.62	0.78	1.03	1.20	1.60
30 m	0.85	0.91	1.20	1.43	1.80
40 m	0.85	1.00	1.40	2.10	2.45
50 m	1.23	1.83	2.52	3.00	3.40

driver could perform only one predetermined emergency manoeuvre - braking. The fact that the response times in comparable situations were different indicates that the type of the analysed situation has a significant effect on the findings concerning the response time. *Table 2* presents the statistical data of the steering response time.

Figure 6 shows steering response times t_S.

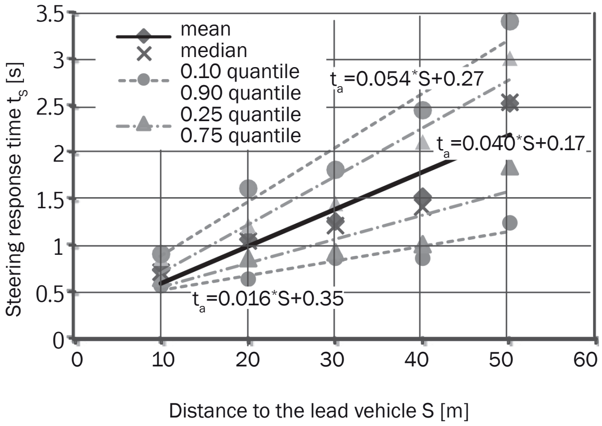

Figure 6 – Values of the steering response time t_S

As can be seen, they vary more than the accelerator pedal response times and the braking response times. It is worth mentioning that in this case, the largest scatter of results is observed for a distance of 50 m, where the values of 0.9 and 0.1 quantiles differ by up to 2.1 s.

3.2 Version 2 of the scenario

Version 2 of the scenario differed from version 1 in that during the rapid braking of the lead vehicle there were other vehicles present in the left adjacent lane. As a result, it was very difficult to steer around the lead vehicle. The steering manoeuvre usually ended with a collision. *Figure 7* shows values of the accelerator pedal response time.

As can be seen, the times obtained in this version of the scenario are much shorter. The values of the response time increase with the distance from the lead vehicle, but it is important to note that the increase is not so large as in version 1 of the scenario. The values of the quantiles suggest that the response times are more comparable.

The values of the braking response time were assessed in the same manner. The statistical parameters of the braking response time are provided in *Table 3*. The driver response times obtained for this scenario were shorter than the braking response times from version 1 of the scenario.

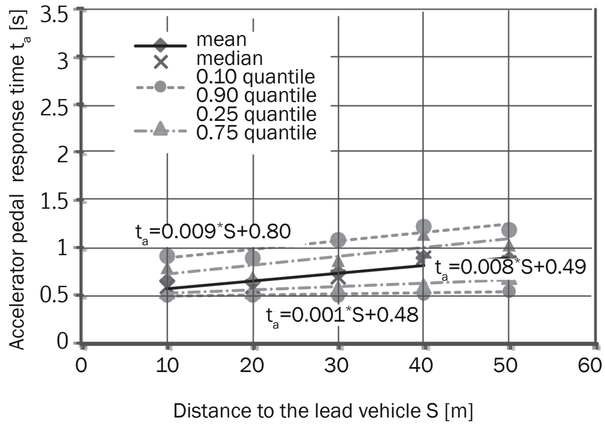

Figure 7 – Values of the accelerator pedal response time t_a in version 2 of the scenario

When the distance between the vehicles was small, the values of the median were comparable. For longer distances, e.g. 50 m, they differed by about 0.3 s. An increase in the distance between the vehicles causes an increase in the median value of the response time and a greater scatter of results, though it is not as large as that in version 1 of the scenario.

Comparing the values of the braking response time registered by the simulator with those obtained on a test track, when braking was also the only possible emergency manoeuvre, we can see that there are significant differences in the results. The response time recorded for a situation when there was a lorry entering a conflicting path and it was impossible to steer away from it ranged from 0.3 to 0.8 s.

The literature on the subject, e.g. [18, 19], shows that even a small modification of a scenario may result in considerably different values of the driver response time. Green [39] suggests that the way the tests are conducted largely affects the response time. He

Table 3 – Statistical parameters of the braking response time t_B in version 2 of the scenario

Distance between vehicles	Braking response time t_B [s]				
	0.1 Quantile	0.25 Quantile	Median	0.75 Quantile	0.9 Quantile
10 m	0.65	0.75	0.81	0.92	1.125
20 m	0.71	0.79	0.85	1.03	1.225
30 m	0.75	0.8175	0.975	1.225	1.345
40 m	0.71	0.83	1.22	1.41	1.65
50 m	0.78	0.92	1.15	1.25	1.70

indicates, for instance, that the driver's awareness of the possible risk of an emergency may have a substantial influence on their behaviour, and accordingly, their response time.

Figure 8 shows the values of the braking response time. The median values of the braking response time in version 2 of the scenario ranged 0.8 –1.2 s; they were about 0.05–0.30 s shorter than those recorded in version 1 of the scenario (when the driver could perform both braking and steering away).

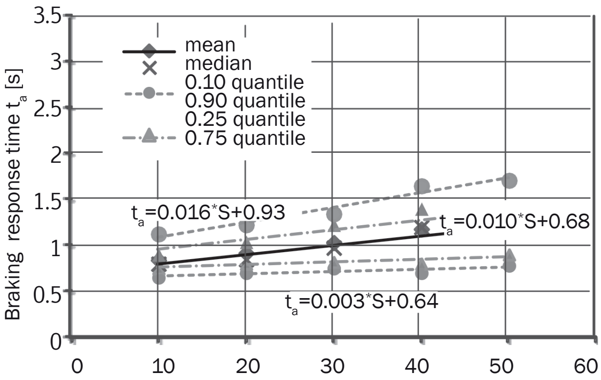

Figure 8 – Values of the braking pedal response time t_B in version 2 of the scenario

The driver response in version 2 of the scenario was, in most cases, limited to the braking manoeuvre, because the vehicles in the left lane made the steering away manoeuvre difficult to perform. As braking was the major emergency manoeuvre, the braking response time was shorter.

Table 4 presents statistical parameters of the steering response time. The median values of the steering response time for different distances between the vehicles increase with increasing distance from the lead vehicle.

Figure 9 presents values of the steering response time for the median, the mean and the 0.1 - 0.9 and 0.25 - 0.75 quantile ranges.

The steering response differs from other responses in this version of the scenario; the differences in the steering response time are the greatest. It should be noted that the scatter of results increases with increasing distance from the lead vehicle. The greatest scatter of results was reported for the distance of 50 m and it was approximately 2.2 s.

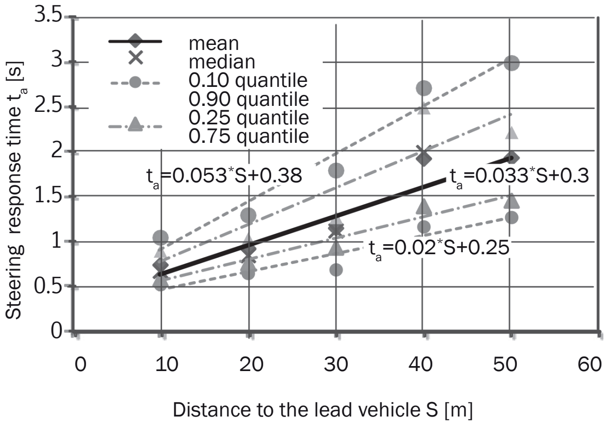

Figure 9 – Values of the steering response time t_S in version 2 of the scenario

4. DISCUSSION

The aim of the study was to determine the way young drivers responded to rapid braking of the vehicle in front when on a motorway. Young drivers with little driving experience do not know or do not strictly follow the motorway driving rules. Driving at high speeds on motorways differs considerably from driving on 'regular' roads. Many countries have a special rule concerning the safe distance between two vehicles. For example, in France the minimum distance from the vehicle in front corresponds to the distance covered in 2 s. In Germany, drivers are required to leave a gap (in meters) of 50% of the actual speed (in km/h). In Slovakia, a proper following distance (given in metres) is dependent on the limit speed. Failure to follow the rules pertaining to keeping a safe distance between vehicles may result in high fines.

In Poland there are no precise rules. The decision on the safe distance is taken by the driver subjectively. In periods of higher traffic flow, especially during holidays, the distance between vehicles may decrease and may result in a rear-end collision. Despite the fact that simulator-based tests are not able to fully

Table 4 – Statistical parameters of the steering response time, t_S

Distance between vehicles	Braking response time t_B [s]				
	0.1 Quantile	0.25 Quantile	Median	0.75 Quantile	0.9 Quantile
10 m	0.53	0.58	0.68	0.90	1.05
20 m	0.65	0.76	0.85	1.04	1.30
30 m	0.70	0.94	1.12	1.30	1.80
40 m	1.15	1.40	1.90	2.00	2.72
50 m	1.27	1.46	1.80	2.25	3.00

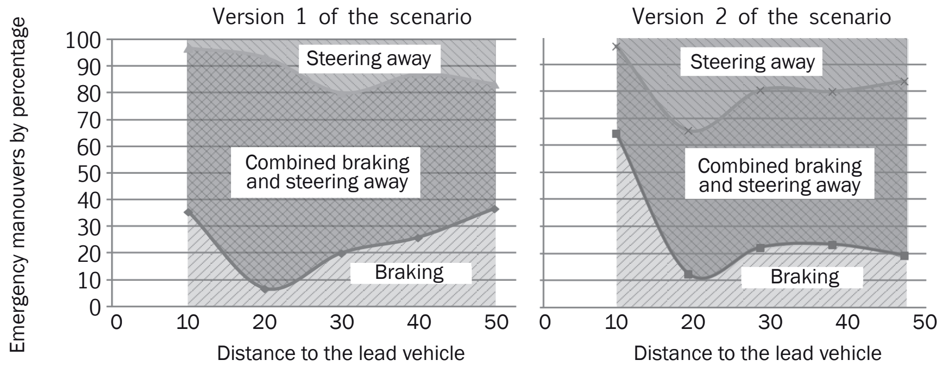

Figure 10 – Percentages of the emergency manoeuvres performed in both versions of the scenario

reproduce motorway driving, they provide information on some characteristic responses.

The decision which emergency manoeuvre should be undertaken depends e.g. on the driver response time. As shown above, the presence of other road users around the subject vehicle makes some emergency manoeuvres impossible or difficult to perform; it definitely shortens the driver response time.

The tests involved registering responses of different drivers in two specific road situations (two versions of the scenario). The data was analysed to determine whether in a particular road situation the drivers responded by braking, by steering away or by combining the two manoeuvres – see *Figure 10*. In version 1 of the scenario, the percentage of the braking manoeuvre (with no steering away) is relatively small. For a distance of 10 m between the vehicles, about 35% of the drivers used braking only while responding to version 1 of the scenario. In version 2 of the scenario, the number was higher, i.e. nearly 65%. This may suggest that the road situation in version 2 of the scenario had a stronger impact on the drivers.

Approximately 60-80% of the drivers chose to combine the emergency manoeuvres; they used braking and steering away simultaneously. When the distance from the lead vehicle increased (version 1 of the scenario), the percentage of the drivers who responded in this way first rose from 60% to nearly 80%, but then, when the distance was larger than 30 m, it declined to 40%. For distances ranging 20–50 m, the percentage of the drivers choosing combined manoeuvres levelled off at 55–60%. Analysing the diagram in *Figure 10*, we can wonder why, despite the difficulty to perform the steering away manoeuvre in version 2 of the scenario, the percentage of this manoeuvre is slightly higher. The responses may seem surprising. In this version of the scenario, some drivers decided to use the emergency lane and steer around the lead vehicle on the right. Despite the fact that such a manoeuvre is prohibited, in many situations it was the only solution to avoid an accident. The percentage of the manoeuvre of steering around the preceding vehicle on the right was quite high and it ranged 14–47% depending on the distance to the preceding vehicle.

When the distance between the vehicles was 10 m, almost 100% of collisions were reported in both versions of the scenario. It is interesting to note that for a distance of 20-50 m, fewer collisions were observed in version 2 of the scenario. We might ask why. How can we explain that the number of collisions in a more difficult road situation was lower? A thesis can be formulated that the presence of other vehicles made the drivers become more concentrated, respond faster and perform more effective emergency manoeuvres. When the distance between the vehicles was about 20 m, 15–23% collisions occurred. For larger distances, the number of collisions was approximately 10%. At large distances (50 m), young drivers (with no particular experience) responded too late, which made the number of collisions higher.

5. CONCLUSION

The values of the braking response time are of great significance when emergency situations are analysed. It is these values that can be used in simulation programmes aiming to reconstruct a road accident. The values of the response time used in simulation programmes generally come from manuals, where average values are provided. Because of large discrepancies in the response time, the distance that guarantees safety can be assessed differently. Obviously, in real road conditions, the response time is likely to be longer, as shown in some studies [23, 39]. The fact that drivers perceive the safe following distance subjectively may in practice lead to a serious traffic hazard.

Interesting conclusions can be drawn from the results obtained for version 2 of the scenario, when it was almost impossible to steer around the vehicle in front. When the adjacent lanes are occupied, driving concentration levels are higher and response times are shorter. High concentration will result in a slightly shorter response time. When faced with an emergency, most drivers will apply the brake only. They must, however, be aware of the dynamically changing situation on the road. As mentioned above, in version 1 of the scenario, the drivers were free to decide on the emergency manoeuvre. Apart from braking, they could also steer around the vehicle in front. These manoeuvres are frequently combined in emergency situations. Since today's vehicles are equipped with modern electronic systems such as ABS and ESP, it is possible to combine rapid braking and steering away with no threat that the vehicle's stability will be lost (both systems being active during the tests in the simulator). Comparing the steering response times with the braking response times, we can see that the combined responses are initiated almost simultaneously. Different studies show that the safe distance is a relative term and it changes dynamically depending on circumstances. In version 1 of the scenario, when there are no other vehicles around, a distance of an order of 30 m seems fairly safe (with the number of collisions being nearly 10%). It is interesting to note that the risk of collision occurrence is slightly smaller when the subject vehicle is 'accompanied' by other vehicles - version 2 of the scenario.

Our future investigations will focus on comparing the behaviour of older drivers according to their driving experience. Another problem to be analysed is night driving with limited low-beam visibility of the vehicle in front, which will be tested using identical scenarios.

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ZACHOWANIE MŁODYCH KIEROWCÓW W NIEBEZPIECZNEJ SYTUACJI DROGOWEJ PODCZAS JAZDY W KOLUMNIE

STRESZCZENIE

Niniejsza publikacja zawiera opis badań realizowanych w symulatorze prowadzonych z udziałem młodych kierowców, którzy są grupą podwyższonego ryzyka wypadkowego. Celem prowadzonych badań było określenie sposobu ich reagowania w symulowanych sytuacjach na autostradzie. Jednym z problemów bezpieczeństwa ruchu na takiej drodze jest niezachowanie odpowiedniej odległości od pojazdu poprzedzającego, co może doprowadzić do najechania. Symulowane sytuacje dotyczyły sytuacji podejmowanego przez pojazd poprzedzający gwałtownego hamowania. Eksperymenty przeprowadzono na prawym pasie autostrady w różnych odległościach od pojazdu poprzedzającego (10-50 metrów). Wykorzystano dwie wersje scenariusza. W pierwszej wersji nie występowały obok pojazdu badawczego inne pojazdy, natomiast w drugiej wersji scenariusza zarówno za pojazdem, jak i na lewym pasie ruchu były one obecne. W symulowanej sytuacji, kierowcy mogli dowolnie realizować następujące manewry obronne: hamowanie ze sterowaniem lub tylko hamowanie. Czasy reakcji kierowcy zarejestrowanych w dwóch wersjach scenariusza analizowano statystycznie. Dane testowe zostały wykorzystane do określenia, jakie awaryjne manewry były wykonywane przez kierowców w symulowanych sytuacjach drogowych. Badania pokazują, że otoczenie pojazdu może mieć znaczny wpływ na rodzaj manewrów awaryjnych oraz czas reakcji kierowcy.

SŁOWA KLUCZOWE

symulator; młodzi kierowcy; czas reakcji; autostrada o 2 pasach ruchu; jazda w kolumnie;

REFERENCES

[1] Spalding TJW, Kiss J, Kyberd P, Turner-Smith A, Simpson AH. Driver reaction time after total knee replacement. The Journal of Bone & Join Surgery. 1994;8(76-B):754-756.

[2] Ganz SB, Levin AZ, Peterson MG, Ranawat CS. Improvement in Driving Reaction Time After Total Hip Arthroplasty. Clinical Orthopaedics & Related Research. 2003;413:192-200.

[3] Madeley P, Hulley JL, Wildgust H, Mindham RH. Parkinson's disease and driving ability. Neurol Neurosurg Psychiatry. 1990;53:580-582.

[4] Philip P, Sagaspe P, Moore N, Taillard J, Charles A, Guilleminault C, Bioulac B. Fatigue, sleep restriction and driving performance. Accident Analysis & Prevention. 2005;37(3):473-478.

[5] Baulk SD, Reyner LA, Home JA, Drive Sleepiness-Evaluation of Reaction Time Measurement as a Secondary Task. Sleep. 2001;24(6):695-698.

[6] Ogden EJD, Moskowitz H. Effects of Alcohol and Other Drugs on Driver Performance. Traffic Injury Prevention. 2004;5(3):185-198.

[7] Hindmarch I. Psychomotor function and psychoactive drugs. British Journal of Clinical Pharmacology. 2004;58(7):S720-S740.

[8] Jurecki R. Badania czasu reakcji kierowców w symulatorze w różnych warunkach pracy kierowcy, Logistyka. 2014;6:5003-5014. Polish

[9] McGehee DV, Mazzae EN, Baldwin GHS. Driver reaction time in crash avoidance research: Validation of a driving simulator study on a test track. Proceedings of the human factors and ergonomics society annual meeting. SAGE Publications. 2000;3-320-3-323.

[10] Alm H, Nilsson L. Effects of mobile telephone use on elderly drivers behaviour including comparisons to young drivers behaviours. Accident Analysis & Prevention. 1995;27(5):707-715.

[11] Consiglio W, Driscoll P, Witte M, Berg W. Effect of cellular telephone conversations and other potential interference on reaction time in a braking response.

Accident Analysis and Prevention. 2003;35:495-500.

[12] Mohebbi R, Gray R, Tan HZ. Driver Reaction Time to Tactile and Auditory Rear-End Collision Warnings While Talking on a Cell Phone. Human Factors. 2009;51(1):102-110. doi: 10.1177/0018720809333517

[13] Strayer DL, Drew FA. Profiles in driver distraction: Effects of cell phone conversations on younger and older drivers. Human Factors. 2004;46(4):640-649.

[14] Gillberg M, Kecklund G, Åkerstedt T. Sleepiness and performance of professional drivers in a truck simulator: Comparisons between day and night driving. Journal of Sleep Research. 1996;5(1):12-15.

[15] Benderius O, Markkula G, Wolff K, Wahde M. Driver behaviour in unexpected critical events and in repeated exposures-a comparison. Eur. Transp. Res. 2014;6(1):51-60. doi: 10.1007/s12544-013-0108-y

[16] Lee C, Abdel-Aty M. Testing effects of warning messages and variable speed limits on driver behavior using driving simulator. Transportation Research Record: Journal of the Transportation Research Board. 2008;2069(1):55-64.

[17] Muttart J. Influence of Age. Secondary Tasks and Other Factors on Drivers' Swerving Responses before Crash or Near-Crash Events. SAE Technical Paper 2015-01-1417; 2015. doi: 10.4271/2015-01-1417

[18] Jurecki R, Stańczyk TL, Jaśkiewicz M. Driver's reaction time in a simulated, complex road incident Transport 2017. 2017;32(1):44-54. doi: 10.3846/16484142.2014.913535

[19] Jurecki R, Stańczyk TL. Driver reaction time to lateral entering pedestrian in a simulated crash traffic situation. Transportation Research Part F: Psychology and Behaviour. 2014;27(Part A):22-36. doi: 10.1016/j.trf.2014.08.006

[20] Jurecki R, Stańczyk TL. Driver model for the analysis of pre-accident situations. Vehicle System Dynamics. 2009;47(5):589-612.

[21] Więckowski D, Pusty T, Jędrys P. Influence of the vertical load exerted by the trailer on the coupling device on towing vehicle's steerability and stability, IOP Publishing IOP Conf. Series: Materials Science and Engineering 148,012031; 2016. doi: 10.1088/1757-899X/148/1/01203

[22] Bella F. Driving simulator for speed research on two-lane rural roads. Accident Analysis & Prevention. 2008;40(3):1078-1087.

[23] Guzek M, Jaśkiewicz M, Jurecki RS, Lozia Z, Zdanowicz P. Driver reaction time under emergency breaking a car. Research in the driving simulator. Eksploatacja i Niezawodność - Maintenance and Reliability. 2012;14(2):295-301.

[24] Sheu JB, Wu HJ. Driver perception uncertainty in perceived relative speed and reaction time in car following – A quantum optical flow perspective. Transportation Research Part B: Methodological. 2015;80:257-274.

[25] Kesting A, Treiber M. How reaction time, update time, and adaptation time influence the stability of traffic flow. Compute-Aided Civil and Infrastructure Engineering. 2008;23(2):125-137.

[26] Lefèvre S, Carvalho A, Borrelli F. Autonomous car following: A learning-based approach. In Intelligent Vehicles Symposium (IV). 2015;IEEE:920-926.

[27] Walch M, Lange K, Baumann M, Weber M. Autonomous driving: investigating the feasibility of car-driver handover assistance. AutomotiveUI '15 Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications; 2015. p. 11-18. doi: 10.1145/2799250.2799268

[28] Thomas Friedrichs T, Lüdtke A. Modeling Situation Awareness: The Impact of Ecological Interface Design on Driver ' s Response Times. The Seventh International Conference on Advanced Cognitive Technologies and Applications. 2015;c:47-51.

[29] Eryilmaz U, Tokmak HS, Cagiltay K, Isler V, Eryilmaz NO. A novel classification method for driving simulators based on existing flight simulator classification standards. Transportation research part C: Emerging Technologies. 2014;42:132-146. doi: 10.1016/j.trc.2014.02.011

[30] Petzoldt T. On the relationship between pedestrian gap acceptance and time to arrival estimates. Accident Analysis & Prevention. 2014;2:127-133. doi: dx.doi.org/10.1016/j.aap.2014.06.01

[31] Brackstone M, McDonald M. Car-following: a historical review. Transportation Research Part F: Psychology and Behaviour. 1999;2:181-196.

[32] Geistefeldt J, Giuliani S, Vortisch P, Leyn U, Trapp R, Busch F, Rascher A, Celikkaya N. Assessment of level of service on freeways by microscopic traffic simulation, TRB 2014 Annual Meeting; 2014. p. 1-17.

[33] Brackstone M, Sultan B, Mcdonald M. Motorway driver behaviour: studies on car following. Transportation Research Part F: Traffic Psychology and Behaviour. 2002;5(1):31-46. doi: 10.1016/S1369-8478(02)00004-9

[34] Kesting A, Treiber M. How Reaction Time, Update Time, and Adaptation Time Influence the Stability of Traffic Flow. Computer-Aided Civil and Infrastructure Engineering. 2008;23:125-137.

[35] Biswas S, Tatchikou R, Dion F. Vehicle-to-Vehicle Wireless Communication Protocols for Enhancing Highway Traffic Safety, IEEE Communications Magazine; Jan 2006. p. 74-82.

[36] Fritzsche HT. A model for traffic simulation. Traffic Engineering and Control. 1994;35(5):317-321.

[37] Jurecki R. Badania i modelowanie reakcji kierowców w sytuacjach zagrożenia wypadkowego, Monografie. Studia, Rozprawy, M84, Kielce; 2016. Polish

[38] The National Road Safety Program (Narodowy Program Bezpieczeństwa ruchu drogowego), KBBRD 2013. Polish. Available from: on-line http://www.krbrd.gov.pl/files/file/NP-BRD-2020_przyjety _przez_ KRBRD.pdf

[39] Vogel K. A comparison of headway and time to collision as safety indicators. Accident Analysis & Prevention. 2003;35(3):427-433.

[40] Green M. "How Long Does it Take to Stop?" Methodological Analysis of Driver Perception-Brake Times. Transportation Human Factors. 2000;2(3):195-216.