Research Article

Monika Ucińska*, Ewa Odachowska, Kamila Gąsiorek, and Mikołaj Kruszewski

Age and experience in driving a vehicle and psychomotor skills in the context of automation

<https://doi.org/10.1515/eng-2021-0045>

Received Sep 14, 2020; accepted Jan 03, 2021

Abstract: Past research shows that age and driving experience has a significant impact on on-road behavior. Both reaction time, as well as visual-motor coordination and speed of decision making, play an important role with regard to safety. Consequently, research in this area has been carried out for many years. However, there are still very few studies on the impact of these variables on the speed and way of taking control of an automated vehicle.

The purpose of the study designed at the Motor Transport Institute was therefore, including but not limited to, verification of the hypothesis concerning the relevance of age and experience to psychomotor skills and its impact on adaptation to automation. The research involved tools for testing psychomotor skills (reaction time, eye-hand coordination) considered in driver psychological tests. The experimental part was carried out with a passenger car simulator, where the driver's behavior was verified under a specific on-road situation, including control takeover. As expected, the analyses proved that age and experience are important factors for both control takeover and way of reaction. Deficits and some elements related to inexperience were found in older and younger drivers, respectively, and those had a significant impact on the analyzed variables.

Keywords: transport psychology, road safety, automatization, experience

1 Introduction

1.1 Introduction to the problem

Demographic forecasts indicate that the percentage of seniors participating in road traffic will increase worldwide, also in Poland. The European policy on the older population seeks to sustain their mobility as a vital element of social inclusion. Much hope in activating and maintaining the mobility of older persons is pinned on autonomous vehicles. Field-relevant analyses are an integral part of the transport policy of each country; furthermore, they play an essential role in mental support for aging societies. As there is no fully automated vehicle available on the public market at the moment, aspects concerning the need to exercise human control takeover in the event of an emergency become increasingly apparent.

1.2 Related work

The number of senior drivers increases with the demographic aging of the population. Vehicle driving represents an influential factor contributing to the quality of life and independence in terms of social and professional life. However, driving is a complex task that requires that many cognitive, motor, and visual processes, which change with age, including in the process of healthy aging, be involved. Many studies indicate that safe driving ability may decline significantly with age [11, 13, 16, 20, 23]. Deterioration of psychomotor skills, but also sensory disorders, chronic diseases, or medications taken, make the risk of participation in a road collision increasingly higher. In such cases, automated and autonomous vehicles allow for maintaining mobility, accessing necessary services, increasing independence, and thus reducing social isolation. At the same time, it is an opportunity to enhance safety and, as a result, reduce the number of road collisions and accidents caused by seniors.

The few analyses so far show that age also has a significant impact on how the driver driving an automated vehicle behaves on the road, including reaction time and control

*Corresponding Author: **Monika Ucińska:** Motor Transport Institute, Transport Telematics Center, 80 Jagiellońska Street, 03-301 Warsaw, Poland; Email: monika.ucinska@its.waw.pl

Ewa Odachowska: Maria Grzegorzewska University, 40 Szczęśliwicka Street, 02-353 Warsaw, Poland

Kamila Gąsiorek, Mikołaj Kruszewski: Motor Transport Institute, Transport Telematics Center, 80 Jagiellońska Street, 03-301 Warsaw, Poland

takeover if necessary [11, 23]. In partially autonomous vehicles, older drivers need more time to take control of the vehicle in reaction to unexpected events on the road. Younger drivers are able to detect threats almost twice as fast as older drivers [23]. Other studies indicate that it takes ca. 8.3 seconds to fully take control even for active older persons, compared to ca. 7 seconds for younger drivers [11]. When driving at 60 km/h, this means that older drivers need an additional warning distance of ca. 35 m, that is equivalent to 10 vehicles standing one after another. The reaction time during automated vehicle control takeover is not the only factor affected by age. Older drivers also tend to have a lower quality of wheel steering, accelerator and brake use task, that increases the risk of accidents [4, 11]. Furthermore, weather conditions and traffic volume play an important role in this setting, too. Unfavorable conditions, in particular the presence of snow and fog, and increased traffic volume, lead to even longer takeover reaction times and poorer takeover quality [6, 10]. If older persons perform additional tasks while driving, it may also have a negative impact [5]. Non-driving tasks result in longer reaction times and less stable driving in the case of senior drivers compared to young drivers. Studies show that the quality of automated vehicle control takeover decreases for the individuals, in particular, if a complex additional task is performed [24, 25].

The differences between older and younger drivers also apply to the way of control takeover. Younger drivers are more likely to manually turn off the automation after receiving a request to take control of the vehicle, in other words, they are more likely to “take control” of the automation on their own initiative, compared to older drivers who usually wait for the system to turn off and thus “be given control.” The ophthalmic data analysis shows that young drivers also tend to scan the field of vision more widely than older persons. Furthermore, younger drivers tend to be distracted from the roadway for longer periods compared to older drivers [16].

The available analyses show that confidence in automating systems depends on age. Older adults have more confidence than other age groups in lower forms of vehicle automation [17]. There are also studies that shows that older people have less confidence in higher levels of autonomous technology [8]. The results of the study by Hulse [8] confirm the conclusions of the study by Abraham [1, 2] that many older drivers generally want to use partial automation, declaring less interest in full autonomy compared to younger drivers. Rovira *et al.* [19] draw attention to the fact that the ratings of confidence in autonomous cars may differ depending on the situation (reliability, driver disability, level of risk). Moreover, when drivers receive additional in-

formation, their perception of driving technologies changes accordingly [3, 19].

It has also been proven that young drivers are less dependent on automation and spend less time verifying information from the system. In contrast, older people have a higher cognitive load and they take more time to adjust their behavior to the system [14, 20].

Clear differences in on-road behavior and psychomotor skills between drivers of different ages and experience levels should be taken into account by automatic vehicle manufacturers at system design. Due to the age-related decline in the skills of older drivers, *i.e.*, takeover reaction times and warning signals in automated and autonomous vehicles would need to be adapted to their specifics. There is no definite expert consensus on how messages related to varying modalities are perceived and processed by drivers and how age and secondary tasks influence the said processes. Studies indicate that older drivers should utilize bimodal warnings instead of single-modal ones to respond quickly and more accurately to such messages [13]. In contrast, there are studies indicating that older drivers are more likely to overlook information if more than two parallel non-redundant signals are presented to different sensory channels [18].

1.3 Study objective and aims

The Polish market has seen a deficit of exploration and analysis of age and its impact on on-road behavior, reaction time, and automated vehicle control takeover. For this reason, a research experiment was designed at the Motor Transport Institute with the aim of analyzing the relevance of age and experience and psychomotor skills for the process of control takeover in automated conditions.

Based on the theoretical implications, the following research hypotheses were made:

1. the subjects' reaction time increases with age,
2. temperament affects the way of taking control of an automated vehicle,
3. the reaction time is longer when it is necessary to take over control of an automated vehicle under the conditions with distractors vs. in their absence,
4. the reaction time and the way of taking control of an automated vehicle is linked to the driver's experience.

In order to verify them, an experimental scheme study was designed.

2 Methodology

A high-class AS1200-6 driving simulator was used to carry out analyses of the control takeover process in conditions of limited situational awareness of drivers with different driving experience and of different age groups, including older drivers. Furthermore, a number of tools that are generally applied in driver psychological examinations were used. This facilitated the measurement of both driving parameters and selected psychological factors relevant to the process of control takeover (reaction time, eye-hand coordination, temperament).

The AutoSim AS 1200-6 simulator data were input to analyze the way of driving, the moment of control takeover, and on-road behavior. The reaction time and psychomotor parameters, including eye-hand coordination, were measured with the Reaction Time Meter (MCR), the Vienna Test System (WST), and visual-motor tester (AK). The Temperament Questionnaire PTS (Pavlovian Temperament Survey) [22] by Strelau and Zawadzki (1998) was used for temperament diagnosis.

The experimental scheme study involved 96 drivers, of whom 47 women and 48 men aged 19 to 69 years; the average age was ($M = 35.05$). The participation was conditional upon having valid passenger car driving license and active road traffic participation for at least six months. Admission was outsourced, and participants were paid for their participation in the study.

The study was individual. Before proceeding with the test drives, each subject drove two simulator adaptation test drives. For adaptation purposes, a personal car simulator highway drive scenario was designed. In the first adaptation part, the subjects learned how to drive with the automatic control system. In the second adaptation part, the subjects drove in a convoy behind another vehicle. Their task was to keep an appropriate distance of ca. 35m from the preceding vehicle, performing acceleration and deceleration maneuvers, without overtaking.

The adaptation drives were followed by the appropriate research part consisting of two stages. The first one analyzed the psychological parameters (reaction time with choice – RT/S3 WST; simple and complex reaction time – MCR, eye-hand coordination – AK; temperament – PTS), while the second one included an experiment with a driving simulator.

The experimental drive scenario was divided into three research scenarios (3 drives for each subject).

In scenario 1 and scenario 2, the driver drove in a three-vehicle platoon [*i.e.* three-vehicle platoon task (3VPT)], as the middle vehicle on a highway section with three lanes per

direction. The subject was to maintain a distance of ca. 35 meters (115 feet) from the preceding vehicle by performing acceleration and deceleration maneuvers appropriate to the vehicle in front. After ca. 60 seconds of stabilized driving, the preceding vehicle suddenly braked, forcing the driver to react (to brake).

After resuming driving, the driver performed the scenario-assigned task assigned (delayed digit recall task (n-back) in scenario 1, SURT in scenario 2), during which the preceding vehicle suddenly braked.

The delayed digit recall task (n-back) was developed on the basis of the study by Mehler, Reimer and Dusek [15]. It was designed to induce a cognitive load by engaging the driver's working (short-term) memory. It consisted of listening to sequences of numbers and recalling the number heard $n(0-2)$ digits before. This task had three levels of difficulty (0-back, 1-back, and 2-back). In the 0-back task, the subject had to recall the last number heard. In the 1-back task, the subject had to recall the penultimate number of the 10 numbers they heard. In the last, 2-back task, the lector read a list of 10 digits, and the subject was supposed to loudly repeat the digit that was spoken as the third one from the end. For example, if the lector reads numbers 3, then 2, and then 6, the subject should only say the number 3. The order of the task was as follows: 0-back – 1-back, 2-back, 0-back. Sudden braking took place during the execution of the 2-back task (after ca. 50 seconds from the beginning of the task) and the second 0-back task.

The Surrogate Reference Task (SuRT) (scenario 2) is a standardized visual-manual task [9]. It consisted in searching for the appropriate circle (the largest one) out of a dozen of circles appearing on the screen. In both tasks, their less complicated versions were performed first, and then the level of difficulty was increased.

Scenario 3 differed from the earlier two scenarios in that the drivers were randomly divided into 3 groups, each of which performed a ride in different (3) test conditions (no distractors, with limited visibility – fog, while performing a SURT task on a tablet during an autonomous ride SURT task). The ride took place in the middle lane on a highway section with three lanes, at a speed of ca. 100 km/h; after receiving a voice announcement imitated from the simulator, the driver turned on the autonomous mode allowing the vehicle to take control.

The driver's task was to react to the (audio and visual) message, which appeared at the arrival at the traffic incident site, about the need to take control of the vehicle. Control takeover took place in three ways: (a) change of lane by the driver; (b) pressing one of the pedals (braking, accelerating); (c) in case of no reaction from the subject (or as a result of too slow or delayed reaction), the vehicle per-

formed the braking maneuver itself. After passing the obstacle (danger), a message asking to activate the automatic mode again was displayed. The situation was repeated 3 times.

In the experiment, the weather and lighting ambient conditions were subject to control.

3 Results analysis

The analysis includes variables from psychological research and an experiment conducted on a driving simulator. The RT/S3 Test – Reaction time Test, which is part of the Vienna Testing System, was used to test the following: average reaction time, average motor time, reaction dispersion time rate, motor dispersion time rate, correct reactions, missed reactions, incomplete reactions, and wrong reactions. The reaction parameters meter (MCR Test) was used to assess simple and complex reactions. For each of these, correct, wrong, and missed reactions were differentiated. The average reaction time and the span (deviation) of reaction times were also evaluated. In the context of the visual-motor tester (AK), the following were measured: average reaction time, correct reactions, wrong reactions, missed reactions.

The Temperament Questionnaire PTS was used to determine the following parameters: Strength of Excitation (SPP), Strength of Inhibition (SPH), balance between the said processes (RWN), and Mobility of Nervous Processes (RPP); moreover, the balance of nervous impulses, as the SPP:SPH ratio, was verified.

When analyzing data from the driving simulator, it was important to determine: how different experimental conditions affected the time of pressing the brake; in what conditions collisions happened most frequently; what were the characteristics of persons who caused a collision, and; how individual variables were linked to driving parameters. Furthermore, under the convoy drive element, it was registered whether the vehicle drove in one lane or shifted to an adjacent lane, and whether the vehicle driver adjusted the vehicle movement with the steering wheel against driving conditions (with and without distractors).

In total, the experiment registered the following indicators of direct driver behavior and traffic parameters:

In scenario 1:

- time to press the brake pedal,
- number of collisions during the convoy ride,
- speed changes (average speed, speed deviation),
- trajectory of movement (change of driving trajectory),
- position on the lane (lane cross-section position, standard position deviation),

- minor adjustments to steering wheel rotation.

In scenario 2:

- time to press the brake pedal,
- number of collisions during the convoy ride,
- speed changes (average speed, speed deviation),
- trajectory of movement (change of driving trajectory),
- position on the lane (lane cross-section position, standard position deviation),
- number of affected SURT circles,
- number of mistakes in SURT.

In scenario 3:

- averages and standard deviations for the takeover reaction time (i.e. until taking control, or changing the lane, or braking before the traffic incident) depending on the distractor'
- method of taking control,
- automatic driving modes (if the subject drove in such a mode, or took over control).

3.1 Psychomotor skills

The analyses started with checking the psychomotor efficiency of the subjects. In the Reaction Time Test (WST), older subjects had longer average reaction times, $r = .21$, $p = .038$, had longer average motor time, $r = .34$, $p = .001$, as well as longer dispersion reaction time, $r = .26$, $p = .012$. The values of individual variables recorded in the three age groups are presented in Figure 1.

Figure 1: Mean reaction times, mean motor reaction times, dispersion times measured by the Reaction Time Test (WST) in the three age groups, $N = 95$.

In the reaction time test (MCR) for both simple and complex reactions, the older subjects had fewer correct reactions, $r = -.26$, $p = .012$ (simple reactions), $r = -.29$, $p = .004$ (complex reactions). Moreover, in complex reactions, age correlated positively with almost all indicators, i.e. average reaction time, $r = .46$, $p < .001$, with maximum reaction

time, $r = .43$, $p < .001$, with minimum reaction time, $r = .30$, $p = .003$, with the number of erroneous reactions, $r = .21$, $p = .044$ and the number of omitted reactions, $r = .22$, $p = .029$. Thus, the assumed research hypothesis No. 1 was confirmed. Mean, minimum and maximum reaction times (s) recorded in the complex reactions in the test of reaction times (MCR) by age group are shown in Figure 2.

Figure 2: Mean, minimum and maximum reaction times in complex reactions as measured by the test of reaction times (MCR) in the three age groups, $N = 95$.

There were also positive relationships between the visual-motor coordination test indicators with age, for the mean reaction time, $r = .60$, $p < .001$, for correct reactions, $r = -.58$, $p < .001$, for erroneous reactions, $r = .59$, $p < .001$, and omitted reactions, $r = .49$, $p < .001$. The values of individual variables depending on the age group are presented in Figure 3.

Figure 3: Mean reaction times, correct, incorrect and omitted reactions as measured by the visual-motor coordination test (AK) in three age groups, $N = 95$.

For psychological variables, the correlation between age and temperament (PTS) was also analyzed. Age was not correlated with the PTS temperament scales. The only trend-level significant correlation noted was the one between age and SPH (Strength of Braking Processes), $r = -.19$, $p = .07$. The PTS indicators decreased with age.

Regardless of age, the correlation between temperament and on-road behavior in research conditions was analyzed. The analyses did not show a correlation between the PTS scales and the time to brake under any conditions. The only trend-level negative correlation was observed between time in the 2-back condition and SPP (Strength of Stimulation Processes), $r = -.19$, $p = .071$ and RPP (Mobility of Neural Processes), $r = -.19$, $p = .075$. Individuals with higher stimulus and greater mobility took longer until they pressed the brake.

The regression analysis showed that the trend-level strength of braking processes (SPH) was related to the effect of the 2-back condition (compared to the lack of distractors) on the braking start time, $B = 0.04$, $SE = 0.02$, $t = 1.97$, $p = .05$. Further analysis showed that the time until pressing the brake was 0.38 sec. longer in the 2-back conditions than in the baseline conditions, where $t = 2.47$, $p = .015$, but only for persons with the highest strength of braking processes. For persons with a low strength of braking processes, the difference between conditions was not significant, $p > .73$.

The strength of braking processes was also related to the difference between the baseline conditions and SURT conditions, $B = .05$, $SE = .02$, $t = 2.42$, $p = .017$. In persons with a low SPH as well as with a high SPH, the time until pressing the brake was significantly longer under the SURT conditions than under the baseline conditions, but the difference was twice as significant in persons with a low SPH, $B = -1.00$, $t = -5.88$, $p < .001$, than in persons with a high SPH, $B = -0.41$, $t = -2.45$, $p = .016$. Thus, the assumed research hypothesis No. 2 was confirmed. The braking start time in seconds in the base condition, 1 and 2-back, SURT conditions depending on the strength of braking processes is shown in Table 1.

In convoy driving, no significant correlations were observed between PTS scales and aggregated lane and steering wheel movement indicators.

Table 1: The strength of braking processes and the braking start time in base conditions, 1 and 2-back, SURT, $N = 95$.

The strength of braking processes	2-back condition	The braking start time		
		0-back condition	SURT	Without distractors
People with low SPH	2,44	2,15	3,56	2,47
People with high SPH	2,21	1,96	2,84	2,5

3.2 Age and experience and on-road behavior

The next step was to test whether age and experience were related to reaction times in emergency braking situations. The analyses showed that the time to start braking was dependent on the age of the subjects in the presence of distractors. The results were as follows: for the 2-back condition, $r = .37$, $p < .001$, for the 0-back condition, $r = .32$, $p = .002$, for the SURT condition, $r = .31$, $p = .002$. In conditions without distractors, such a relationship was not observed, $r = .18$, $p = .079$. Figure 4 shows the reaction times in emergency braking conditions depending on distractors.

Figure 4: The reaction times in emergency braking conditions depending on distractors, $N = 95$.

For better illustration of this relationship, a division was made into age groups: the youngest group included subjects aged 18-26, the medium group included subjects aged 27-39, and the oldest group included subjects aged 40 – 65 years of age. When age in such a division was taken into account as an inter-objective variable, analyses showed that although it was related to reaction times, $F(2,90) = 5.50$, $p = .006$, $\eta^2p = .11$, in such a way that seniors also had longer times to start braking, age did not moderate the differences in those times resulting from distractors, $p > .45$.

Then the rho Spearman correlation analysis was applied for variables that were expressed on the ordinal scale and braking start times in 4 conditions, while the rho Pearson correlation was used for variables expressed on the linear scale. The analyses showed that the longer the subject actively drove the car, the longer they took to use the brake in the 2-back condition, $r = .32$, $p = .004$. This is very likely to be related to age; older persons had a better chance to drive the car for a longer time (expressed in years). Simultaneously, older persons took longer to start braking than the younger ones. No correlation was found between

age and other indicators of direct driver behavior and traffic parameters for sudden braking.

In convoy driving, the analysis of steering wheel movement and lane position indicators showed that age correlated positively with the standard deviation of lane position in the 0-back and 2-back conditions – therefore, greater deviations from the average position in these conditions were recorded for older individuals; for 0-back: $r = .21$, $p = .039$, for 2-back: $r = .21$, $p = .041$. At the trend level, age also correlated positively with the standard deviation of lane position in the 1-back condition, $r = .19$, $p = .067$. No other age-related significant correlations were observed in the study. The values of the standard deviation of the lane position in the 0-back, 1 and 2-back conditions in different age groups are shown in Table 2.

Table 2: The standard deviation of lane position in the 0-back, 1-back, and 2-back conditions in particular age groups, $N = 95$.

Age group		Condition		
		0-back	1-back	2-back
Young people	M	0,10	0,11	0,10
	SD	0,05	0,06	0,04
Middle aged people	M	0,14	0,12	0,14
	SD	0,05	0,07	0,06
Elder people	M	0,12	0,13	0,14
	SD	0,05	0,09	0,11

The correlation analysis also showed that the greater the length of time spent driving, the higher the standard deviation of lane position, $r = .29$, $p = .008$. However, driving years were strongly correlated with age, $r = .90$, $p < .001$, which was also associated with standard deviation, $r = .24$, $p = .022$.

In the next step, an r-Pearson correlation analysis was carried out in order to verify if age was related to the times of reactions to a request for takeover control in subsequent tests. The results of the analyses in question showed that the reaction times were not related to age.

Then, for the effect of age, which is a continuous variable, a regression analysis was applied, in which the values of reaction times in subsequent tests were averaged to simplify the analysis (from previous analyses using the correlation analysis referred to above, it is known that age did not correlate with reaction times in any of the tests). The analyses were performed with the PROCESS macro by Hayes [7], which uses the bootstrapping method to estimate the effects, and the indicator encoding of the multi-category variable (distractor) – driving without distractors

was compared to driving in fog and to driving with SURT. The interaction between the subjects' age and driving conditions proved significant; the change was $R^2 = .10$, $F(2.84) = 5.51$, $p = .005$. Young persons ($M = 22$ years old) had longer reaction times when driving in fog than when driving without distractors, $p = .029$, but their reaction times did not differ between the control condition (without distractors) and SURT condition. The situation was similar for persons of middle age ($M = 32$). However, the conditions shaped the reactions of seniors in a completely different way ($M = 45$). The said individuals did not have significantly longer reaction times in fog, but in SURT, $p = .004$, compared to conditions without distractors. Thus, the assumed research hypothesis No. 3 was not fully confirmed. Table 3 shows the reaction times of drivers of different ages during distractor driving, driving in fog and driving with SURT.

The next step was to analyze the relationship between the driving experience and reaction times to the demand for control. The variable analyzed was the number of years of active driving (correlated with the subject's age) as it was expressed on a continuous scale. The analysis was performed

Table 3: Reaction times of drivers of different ages during driving without distractors, driving in fog, and driving with SURT, $N = 95$.

Age group	Distractor	M	SD
Young people	no distractor	3,56	1,28
	fog	4,20	1,22
	SURT	3,58	1,14
Middle aged people	no distractor	3,60	1,01
	fog	5,50	2,12
	SURT	4,24	1,05
Elder people	no distractor	3,64	1,50
	fog	3,82	1,56
	SURT	4,74	0,98

by means of regression with the bootstrapping method [7]. The results showed that the interaction between the distractors and the number of years of driving was significant, the change was $R^2 = .15$, $F(2.73) = 7.56$, $p = .001$. Individuals driving with a relatively short history of driving (3 years on average) had longer reaction times in fog than without distractors, $B = 1.53$, $p = .007$, similarly to persons with a moderately long history of driving ($M = 10$ years), $B = 1.27$, $p = .002$, whereas persons with a long history of driving ($M = 25$ years) had longer reaction times in the SURT conditions than in conditions without distractors, $B = 2.05$, $p < .001$. Thus, the assumed research hypothesis No. 4 was confirmed. The driver response times during driving without distractors, driving in fog and driving with SURT depending on the number of years of active driving are shown in Table 4.

Since the length of active driving history was very strongly related to the subject's age ($r = .90$, $p < .001$), and age interacted with the distractors predicting the reaction time, this variable was introduced as a covariant to the regression analysis described above. However, the results revealed that, if age is controlled, the interaction between driving experience and the distractors remains significant, $F(2.71) = 7.77$, $p < .001$, and its interpretation does not change.

The study also controlled the road traffic driving assessment indicators. This applied both to behaviors observed in other drivers and to the subject's own behavior. The subjects declared that the vast majority of dangerous behaviors, such as talking on the phone while driving without a hands-free car kit, or driving after drinking alcohol, are very rare. However, speeding, as it happens to more than 40% of persons every day or at least once a week, or commenting on the driving of other drivers (more than 30% of the subjects), are exceptions to this. On average, dangerous behaviors in which the subjects participated were, according to their

Table 4: Driver response times during driving without distractors, driving in fog and driving with SURT versus years of active driving, $N = 95$.

Active vehicle driving	Distractor	M	SD
Persons driving briefly ($M = 3$ years)	no distractor	3,59	1,26
	fog	5,08	2,10
	SURT	3,65	1,13
Moderately long drivers ($M = 10$ years)	no distractor	3,66	0,60
	fog	4,99	1,14
	SURT	4,23	1,01
Long-term drivers ($M = 25$ years)	no distractor	3,56	1,58
	fog	3,99	1,46
	SURT	4,81	1,23

self-declarations, very rare, $M = 3.98$, $SD = .51$. This result depended on the age of the subjects, $r = .33$, $p = .001$. What is important, however, is that the older the subjects were, the lower was the average frequency of declared dangerous behaviors.

Analyses showed that the subject considered dangerous behavior as aggressive was also related to age (negative), $r = -.25$, $p = .015$. They considered road cutting-off, horn abuse, tail riding, and driving under the influence as the most aggressive. The least aggressive were the non-fastening of seat belts, talking on the phone, and driving through a yellow light. The older the subjects were, the more aggressive the said behaviors were in their assessment.

4 Results – discussion

In the presented studies, according to the assumptions of the research hypotheses, age has been proven to have a significant impact on the way of behaving on the road when driving an automated vehicle, including the reaction time and the way of taking control if necessary.

The analyses showed that older persons took longer to start braking than younger persons. This result is very important in the context of the analyses carried out by other researchers [4, 11], who have shown that older drivers also tend to have poorer handling of the steering wheel, accelerator, and brake, which increases the risk of accidents. Such conditions may lead to accidents that are not necessarily due to speed, but to capabilities that deteriorate with age. Awareness of this issue should be an indispensable element of drivers' psychoeducation.

Furthermore, in the conditions of introducing distractors, the time to start braking also depended on the age of the subjects; older drivers would start braking later when taking control of the vehicle when under distraction. Non-driving tasks caused an increase in the reaction time compared to young drivers. These results are also consistent with previous studies in this regard [11, 23]. The fact that unfavorable weather conditions may lead to a poorer quality of control takeover was thus confirmed [6, 10].

Driving stability also seems to change with age; older drivers have shown less stability in lane maintenance and steering wheel movement.

In the context of psychological variables, the analyses did not show a relationship between age and temperament. Only the correlation between age and strength of braking processes, which is important at the trend level, was noted. Temperament is a relatively constant personality trait [21],

and therefore no correlation between age and this variable was found in the analyses.

5 Conclusions

The results of this experiment allowed to verify four research hypotheses.

There was a positive correlation between the driver's reaction time and age. The Reaction Time Test (WST) shows that older subjects had longer mean reaction times, had longer mean motor time, and also had longer dispersion reaction times. The results were confirmed by a second test – the response time test (MCR). In complex reactions, age positively correlated with almost all measures, including mean reaction time, maximum reaction time, and minimum reaction time. These results confirm the first hypothesis, which states that “the reaction time of drivers decreases with age”.

Hypothesis 2, that temperament influences the way of taking control has been confirmed. A negative correlation was found between the reaction time in the 2-back condition and SPP (Strength of the stimulation process) and RPP (Mobility of neural processes). People with higher stimulation strength and greater mobility had longer times to apply the brake. In drivers characterized by high strength of braking processes (SPH) during the additional n-back task (in the 2-back conditions), the time to apply the brake was longer than in the base conditions (without distractors). In addition, for people with low strength of braking processes during the additional SURT task, the time to apply the brake was significantly longer than in the base conditions (without distractions). A correlation was also observed in people with high SPH, but it should be noted that this difference was twice as large in people with low SPH.

The third hypothesis “reaction time when it is necessary to take control of an automated vehicle under the conditions of introducing distractors is longer than in the absence of such” has not been confirmed. The obtained results are not fully conclusive. As mentioned in section 3.2, young and middle-aged people had longer reaction times when driving in fog than when driving without distractors. However, their response times did not differ between the control condition (without distractors) and the SURT condition. The elderly had significantly longer responses to SURT compared to conditions without distractors. This relationship was not observed for the reaction times in the fog. Further studies in this area are necessary.

However, the results confirmed the fourth hypothesis. The response time and the method of taking control of an

automated vehicle are related to the experience of the driver. The results showed that the interaction of distractors and the number of driving years was significant. People with little driving experience (driving an average of 3 years) had longer reaction times in fog than without a distractor. The same relationship was noticed in people with intermediate experience, driving vehicles for a moderately long time ($M = 10$ years). On the other hand, the subjects with the greatest experience, driving vehicles for a long time ($M = 25$ years), had longer reaction times in SURT conditions than in conditions without a distractor. Moreover, it was noted that the longer the driving experience, the higher the standard deviation of the position in the lane. Moreover, in the context of driving in a convoy, it was noted that the greater the driving experience, the higher the standard deviation rates of the position in the lane. In the context of sudden braking, the analyzes showed that the more experience the driver had, the longer he had to apply the brake in the 2-back task.

Summarizing, as expected, the conducted experiment proves that age and experience are important factors in terms of both the transfer of control and the manner of reacting. Deficiencies in older drivers, as well as some elements related to the lack of experience in younger drivers, can have a significant impact on the behavior of drivers when driving an automated vehicle. For this reason, knowledge about them should be an essential element of driver training and psychoeducation.

References

- [1] Abraham H, Lee C, Brady S, Fitzgerald C, Mehler B, Reimer B, Coughlin JF. Autonomous vehicles and alternatives to driving: trust, preferences, and effects of age. *Proceedings of The Transportation Research Board 96th Annual Meeting*, 2017, Washington, D.C.
- [2] Abraham H, Reimer B, Seppelt B, Fitzgerald C, Mehler B, Coughlin JF. Consumer interest in automation: change over one year, in *Proceedings of the Transportation Research Board 97th Annual Meeting*, 2018, Washington, DC.
- [3] Biassoni F, Ruscio D, Ciceri R. Limitations and automation. The role of information about device-specific features in ADAS acceptability. 2016, *Safety Sci.* 85, 179–186. doi: 10.1016/j.ssci.2016.01.017
- [4] Clark H, Feng J. Age Differences in the Takeover of Vehicle Control and Engagement in Non-driving-Related Activities in Simulated Driving with Conditional Automation, 2017, *Accident Analysis & Prevention* 106: 468–479.
- [5] Gold C, Körber M, Hohenberger C, Lechner D, Bengler K. Trust in automation—before and after the experience of take-over scenarios in a highly automated vehicle. *Procedia Manufacturing*, 2015, 3, 3025–3032.
- [6] Gold C, Happee R, Bengler K. Modeling take-over performance in level 3 conditionally automated vehicles. *Accident Analysis & Prevention*, 2018, 116, 3–13.
- [7] Hayes AF. *Introduction to mediation, moderation, and conditional process analysis: A regression-based approach* (2nd edition). New York: The Guilford Press. 2018
- [8] Hulse LM, Xie H, Galea ER. Perception of autonomous vehicles: relationships with road users, risk, gender and age. 2018, *Safety Sci.* 102, 1–13. doi: 10.1016/j.ssci.2017.10.001
- [9] ISO (International Organization for Standardization). *Road Vehicles—Ergonomic Aspects of Transport Information and Control Systems—Calibration Tasks for Methods which Assess Driver Demand Due to the Use of In-Vehicle Systems*; ISO: Geneva, Switzerland, 2019; ISO standard number 14198.
- [10] Körber M, Gold C, Lechner D, Bengler K. The influence of age on the take-over of vehicle control in highly automated driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, 2016, vol 39, pp 19–32.
- [11] Li S, Blythe P, Guo W, Namdeo A. Investigating the effects of age and disengagement in driving on driver's takeover control performance in highly automated vehicles, *Transportation Planning and Technology*, 2019, 42:5, 470–497.
- [12] Li S, Blythe P, Guo W, Namdeo A. Investigation of Older Driver's Takeover Performance in Highly Automated Vehicles in Adverse Weather Conditions. *IET Intelligent Transport Systems* 12 (9): 1157–1165, 2018.
- [13] Lundqvist LM, Eriksson L. Age, cognitive load, and multimodal effects on driver response to directional warning. *Applied Ergonomics*, 76 (2019), 147–154.
- [14] McBride SE, Rogers WA, Fisk AD. Do younger and older adults differentially depend on an automated system? presented at the Human Factors and Ergonomics Society 54th Annual Meeting, 2010.
- [15] Mehler B, Reimer B, Dusek JA. MIT AgeLab delayed digit recall task (n-back). MIT AgeLab white paper number 2011-3B. MIT, Cambridge, MA 2011.
- [16] Molnar LJ. Age-Related Differences in Driver Behavior Associated with Automated Vehicles and the Transfer of Control between Automated and Manual Control: A Simulator Evaluation. University of Michigan, 2017.
- [17] Pak R, Rovira E, McLaughlin AC, Baldwin N. Does the domain of technology impact user trust? Investigating trust in automation across different consumer-oriented domains in young adults, military, and older adults. *Theor. Issues Ergon.* 2016b, *Sci.* 18, 199–220. doi: 10.1080/1463922X.2016.1175523
- [18] Pitts BJ, Sarter N. What You Don't Notice Can Harm You: Age-Related Differences in Detecting Concurrent Visual, Auditory, and Tactile Cues. *Human Factors*, 60(4), 2018, 445–464.
- [19] Rovira E, McLaughlin AC, Pak R, High L. Looking for Age Differences in Self-Driving Vehicles: Examining the Effects of Automation Reliability, Driving Risk, and Physical Impairment on Trust. *Front Psychol.* 2019;10:800. Published 2019 Apr 26. doi:10.3389/fpsyg.2019.00800
- [20] Sanchez J, Rogers WA, Fisk AD, Rovira E. Understanding reliance on automation: effects of error type, error distribution, age and experience, *Theoretical Issues in Ergonomics Science*, 15(2), 2011, 1–27.
- [21] Strelau J, Zawadzki B, Piotrowska A. Temperamental models related to the theory of activation and their implications for intelligence. *Psychological studies*, 35, 165–201, 1997.
- [22] Strelau J, Zawadzki B. *Pavlovian Temperament Survey PTS*. PTP, Warsaw, 1998.

- [23] Wolfe B, Seppelt BD, Mehler B, Reimer B, Rosenholtz, R. Rapid Holistic Perception and Evasion of Road Hazards. *Journal of Experimental Psychology: General*, 2019.
- [24] Wu Y, Kihara K, Hasegawa K, Takeda Y, Sato T, Akamatsu M, Kitazaki S. Age-related differences in effects of non-driving related tasks on takeover performance in automated driving, 2020.
- [25] Wu Y, Kihara K, Takeda Y, Sato T, Akamatsu M, Kitazaki S. Effects of scheduled manual driving on drowsiness and response to take over request: A simulator study towards understanding drivers in automated driving. *Accident Analysis & Prevention*, 124, 2019, 202–209.