Research Article

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Psychological factors of the transfer of control in an automated vehicle

https://doi.org/10.1515/eng-2021-0046 Received Sep 11, 2020; accepted Jan 03, 2021

Abstract: In accordance with the requirements of the NHTSA guidelines on Level 3 automation, the comfortable control transition times is about 40 seconds. The data obtained so far are consistent with the assumption that the situation is better when drivers receive a warning about critical events than when they have to take over control unexpectedly. How these variables are shaped in the presence of distractors and what influences psychological factors have on these aspects remains unknown. For this purpose, a research experiment was developed in which control was taken over when the driver was additionally forced to perform the indicated activity (e.g. by looking away from the road), or when road conditions made it impossible to focus on the road. Psychological (temperament) and psychomotor variables (reaction time, hand-eye coordination) were controlled. The study was conducted on active road traffic participant drivers (N=95). Not only the time of taking control was analyzed, but also the way that may have a significant impact on road safety. The results revealed a significant influence of distractors on the manner control is taken over. In the conditions without distractors, the subjects were more likely to take over control than to cause automatic braking.

Keywords: control transition, autonomy, transport psychology, road traffic safety

1 Introduction

The progressive development of the automotive industry towards vehicle automation sets new requirements for drivers alike. At present, it is not possible to pass the full con-

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Monika Ucińska, Mikołaj Kruszewski, Kamila Gąsiorek: Motor Transport Institute, Transport Telematics Center, 80 Jagiellońska Street, 03-301 Warsaw, Poland trol over to the vehicle as a fully automated vehicle fitted with technologies enabling the system to perform all driving functions without any human intervention is not yet allowed to operate in road traffic. In NHTSA automation level 3 – 4 vehicles, i.e. where partial automation is present, drivers are obliged to react appropriately when the system reports such a necessity, i.e. in situations that go beyond the capabilities CAV technology. The driver's ability to take over control after the period of automated driving depends on the transition request conditions. The control transition may be expected by the driver, for instance, in a situation where the automated system is deactivated before leaving the freeway. It may also be unexpected, for instance, in the case of a critical road incident at a time that would normally be the period of automated driving (i.e. other vehicle stopped on the lane, road accident, crosswalk). It is preferable when drivers expect the necessity to take over control of the vehicle compared to when they are suddenly forced to take it. The unexpected need to take over control under time pressure is a heavy burden to the driver [18].

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Critical road incidents are a major problem for drivers. In such situations, it is noted that drivers exhibit worse driving parameters (*i.e.* longer reaction times, collisions or accidents) in partial automation conditions than they do in manual driving conditions [2, 14]. Such drivers abuse the brake pedal more often, look into the rear-view mirrors less often, have problems with maintaining a constant speed and lane position [6, 7]. They also keep shorter minimum distances from the preceding vehicle. Drivers' coping mechanisms are much poorer at vehicle control transition. In unexpected critical situations, especially when the drivers have a high level of trust in the system [15].

Moreover, secondary tasks performed during driving have an impact on drivers' behavior during control transition as well. Such operations are responsible for the deterioration of the ability to supervise automation [4–6, 12, 16, 20]. According to the available studies, it may be concluded that operations requiring visual attention, thus causing distraction from the road, and operations requiring special involvement, such as the cognitive ones, are particularly harmful. Auditory tasks cause less distraction [17]. Moreover, weather conditions, the road situation, and traffic volume have an equally important influence on the driver's

behavior during the transition, and they may modify the secondary task influence [1, 8, 16, 19]. However, there are still studies in which the influence of cognitive load, *i.e.* the secondary task influence on the control transition time, has not been observed [11].

Driver experience and adaptation to the automation system also influences driver control. Drivers with little experience in driving in automation mode tend to be more cautious, i.e., they do not transit control to the system or continuously monitor the system operation and take over manual control even before the system starts to react to a critical situation [9, 10]. There is no clear consensus on how much time it takes for the driver to notice that the system is unable to cope with the situation and that they need to replace the automation and take over control of the vehicle. Studies suggest that they need about 15 seconds to resume control of the vehicle and up to 40 seconds to stabilize it [13]. In the experiment by Merat et al. [13], when the driver was attentive and the need to take over control was predictable and expected, it took on average 10 seconds to regain proper control of the vehicle. In this situation, the drivers' position in the lane was also more stable. When the drivers were less attentive, it took about 35-40 seconds to resume control. This means that the response time is almost 3-4 times longer under conditions of distraction.

The question of how these variables look in the situation of distractors is still valid. The deficit of this type of exploration studies makes it still impossible to answer many research questions related to this topic. Elements concerning psychological factors connected with the driver's taking control of an automated vehicle certainly needed to be clarified. For this purpose, a study was designed to check the impact of limited driver situational awareness on the control transition operation in the event of turning off the automated driving system. Also selected psychophysical factors related to the driver's responses were considered.

2 Methodology

The research purposes consisting of the analysis of psychological parameters related to vehicle control transition were achieved during an experimental study. The study was designed with the use of a high-class AS1200-6 driving simulator, which is used in psychological driver testing, enabling the measurement of driving parameters, selected psychological factors relevant to the process of control transition (reaction time, eye-hand coordination, temperament).

The manner of driving, the moment of control transition, and driver behavior were analyzed using data from

the AS1200-6 Driving Simulator. Reaction time and psychomotor parameters in the form of eye-hand coordination were evaluated using testing equipment such as the Vienna Testing System (WTS), Reaction Time Meter (MCR) and visual-motor tester (AK). Temperament was evaluated using Temperament Questionnaire PTS by Strelau and Zawadzki (1998).

The experimental scheme study involved 95 subjects (47 women and 48 men), the average age was (M = 35.05). Participation required a suitable passenger car driving license (cat. B in Poland) and active road traffic participation for at least six months. Recruiting was outsourced, and participants were paid for their participation in the study.

The study was individual. Each participant of the study before the test drives proceeded to the adaptation on the simulator. The adaptation study was conducted on a freeway section with three lanes per direction. In the first part of the adaptation, the participants learned how to drive with the automatic control system. In the second part, the subjects drove in a convoy behind another vehicle. Their task was to maintain an appropriate distance of about 35m from the preceding vehicle, performing acceleration and deceleration maneuvers, without overtaking.

Adaptation was 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 using a driving simulator.

The experimental drive scenario was designed in three variants (one variant in neutral conditions, and two variants with distractors). Subjects were randomly assigned to 3 groups, each of them driving a different type of scenario: (1) none distraction to the driver's attention; (2) a fog-type distractor, (3) a distractor as a SURT task to be performed (SURT is a task where participant need to find the largest circle out of several circles appearing on the tablet screen).

Each drive took place on a freeway section with three lanes per direction. There was little road traffic, and the person under examination was instructed to drive in the middle lane while maintaining a speed of approx. 100 km/h (about 62 mph). After several seconds, a message was displayed on the screen, telling the subject to activate the automated driving mode (using the appropriate console button). After switching it on, the subject was asked to remove their leg from the pedals and hands from the steering wheel. The subject could change the vehicle speed by pressing console buttons. After reaching the required scenario place (accident, blocking traffic), the subject received another message to take over control of the vehicle.

In variant without a distractor (1), after arriving at the incident scene, the subject was informed about the need to take over control of the vehicle (audible and visual information on control transition was displayed on the projector screen). Control transition took place in three ways: (a) change of the lane by the driver (remaining in an automated driving mode), (b) pressing one of the pedals (braking, accelerating), (c) in case of no response from the subject (or as a result of too slow or delayed response), the vehicle performed the braking maneuver itself.

After passing the obstacle (danger), a message asking to activate the automated driving mode again was displayed. The situation was repeated 3 times.

In variant (2), the driver drove in conditions of limited visibility (fog) from the beginning, and the operations were the same as in variant 1 (to take over control 3 times after reaching the obstacle).

In variant (3), the driver drove in good road conditions. While driving in automated mode, the SURT task was switched on, and it was performed on a tablet by the subject.

3 Analysis result

The analysis included 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, response dispersion time rate, motor dispersion time rate, correct responses, missed responses, incomplete responses, and wrong responses. The reaction parameters meter (MCR Test) was used to differentiate correct, wrong, missed responses. The average reaction time and the range (deviation) of reaction times were also evaluated. Under the eye-hand coordination test, the following were measured: average reaction time, correct responses, wrong responses, missed responses. The last task was to fill in the Temperament Questionnaire PTS. It was used to determine the following parameters: Force of the Stimulation Process (SPP), Force of the Inhibition Process (SPH), and Mobility of Nervous Impulses (RPP).

When analyzing data from the driving simulator, it was important to determine how different experimental conditions affected the control transition, whether the time was also affected by the test, and whether there was a visible learning effect, and how individual variables were related to the response time to the control transition call under different conditions.

The experiment registered the following indicators of direct driver behavior and traffic parameters such as:

- average and standard deviations for the take over reaction time (*i.e.* until taking control or changing the lane or braking before the road incident);
- method of taking control;
- automatic driving modes (if the subject drove in such a mode, or took over control).

In the first stage of the analysis, the differences in the Take Over reaction time were determined depending on the type of distractor and test. For this purpose, the analysis of variance with repeated measurements in the 3 (test 1, 2, 3) \times 3 (a type of distractor: none, fog, SURT) scheme was carried out. The results of the analysis demonstrated that the testing effect was significant: F(2.81) = 50.07, p < .001, eta2p = .38 – this means that the subjects had different response times from one test to another. Post-hoc tests (of the least significant differences) revealed that each of the tests was different from the others, p < .001, which means that the subjects achieved the shortest times of taking over control in the last, third test, while the longest reaction times were those in test 1.

Table 1: Average test-dependent Take Over reaction time (incl. confidence intervals), N = 95.

Test	М	SD	95% CI	
			LL	UL
1	5,723	,320	5,086	6,361
2	3,836	,207	3,424	4,248
3	2,777	,128	2,523	3,031

Furthermore, the analysis of variance revealed a significant effect of the task variant on the trend level, F(2.81) = 2.89, p = .061, stage 2 = .067. Post-hoc analyses (without correction for multiple comparisons) demonstrated that, in the no-distractor drive variant and the fog drive variant, take over reaction time was significantly different, p = .019. Longer response times were recorded in the fog drive variant. Average variant-dependent reaction times are pre-

Table 2: Average drive variant-dependent response times, N = 95.

Distractor	M	SD	95% CI	
			LL	UL
none	3.636	.265	3.109	4.163
fog	4.541	.270	4.005	5.078
SURT	4.159	.275	3.613	4.705

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sented in Table 2. In other conditions, take over reaction times did not vary.

The effect of interaction between the driving conditions and the test proved to be insignificant, F(4.81) = 0.53, p = .67, eta2p = .013. The achieved main test effect was not modified by the type of distractor. The subjects did better (they responded faster) in the last test than in the second and first tests, regardless of whether they drove without a distractor, in fog, or had to perform a SURT task. Average times for the tests depending on the variant of distractor are shown in the diagram below (Figure 1).

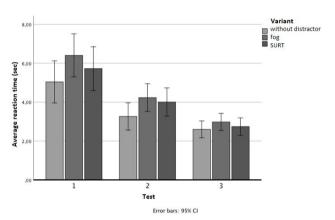


Figure 1: Average distractor variant-dependent test times, N = 95.

The tests also analyzed how drivers took control. In the beginning, the analyses were carried out to answer the question whether, in the course of the tests, the drives with different distractors differed in the manner they took control. The analyses were carried out using the multiple non-parametric H Kruskal-Wallis tests. In the course of the analyses, pairs of manners of executing control transition were compared to determine which of the two manners was more frequent. The results showed a significant influence of distractors on the manner control was taken over in test 3 when automatic braking and lane change were compared (H = 9.105, p = .011), in test 1 when automatic braking and frequency of control transition were compared (H = 9.34, p = .009 and in test 3 when lane change and control transition were compared (H = 7.63, p = .022). The distractor effect was significant at the statistical trend level in test 2, when automatic braking and control acquisition were compared (p = .09).

The post-hoc tests carried out using the Man-Whitney U test showed that conditions without distractors and with fog differed significantly in test 1 in terms of the share of automatic braking and control acquisition (U = 299, Z = -2.87, p = .004). While in conditions without distractors,

the frequency of vehicle control transition was much more frequent (in 28 cases) than braking (2 cases), in conditions with fog. the frequency of automatic braking increased (11) vs. 18). The interpretation of the results for test 2 using posthoc tests showed that conditions without distractors and with fog differentiated the test subjects' responses in terms of the frequency of automatic braking and vehicle control (U = 319, Z = -2.18, p = .029). In conditions without distractors, the test subjects were more likely to take over control (26 times) than to achieve automatic braking (3). However, in conditions where they drove in fog, braking was more frequent (10), and thus the proportion of braking events and control (19) was more even. In the case of test 3, the post-hoc tests showed a difference in the proportion of the chosen response depending on the conditions (U = 161, Z = -2.69, p = .007). During the fog condition, the subjects did not change lanes but took control of the vehicle (0 vs. 19), while under good weather conditions, the lane change response was not so rare (8 vs. 17). Furthermore, the automatic braking to lane change rate ratio differed in test 3 and was distractor dependent (U = 25.00, Z = -3.00, p = .003); when without a distractor, this proportion was relatively balanced (5 – automatic braking vs. 8 – lane change); in fog conditions, all events ended in automatic braking (N = 10). The proportion of such events also differed between fog conditions and SURT (U = 35, Z = -2.06, p = .039), where automatic braking and lane change were similarly frequent in the latter ones (7 vs. 4 respectively).

In conclusion, under fog conditions, the test subjects were more likely to allow automatic braking or take over control of the vehicle, while under good weather conditions automatic braking was much less frequent. This pattern repeated itself during all three tests.

In the case of psychological variables, the analyses included the correlation between temperament (PTS) and psychomotor parameters in terms of response times, too. The analyses did not show the correlation between temperament and response times in tests 1 and 2, while the response time decreased with the increase in MRI (mobility of nervous processes) in test 3. However, as for the averaged response time rate, the correlations with temperament turned out to be irrelevant. Regression analyses using the Hayes PROCESSES macro did not show significant interactions between the type of distractor and PTS scales, so the temperament did not modulate the response time to a call for control transition under different conditions.

In the Reaction Time Test (WST), the average response time was positively correlated with the average response time to a call for control transition, r = .23, p = .029; the longer the average response time in the Reaction Time Test (WST), the longer the response time to a call for control

transition. The remaining test indicators were not correlated with the response times to a call for control transition. Furthermore, models for each of the indicators of the continuous Reaction Time Test (WTS) were tested as a moderator of the effect of a condition on the response time to a call for control transition. Regression analysis by bootstrapping method showed no significant interactions between the distractor variant with the Reaction Time Test (WST) indicators.

Pearson's r correlation analysis showed no correlation between the MCR test indicators in simple responses and the reaction time to a call for control transition in any test. For complex responses, a positive correlation was observed between the reaction time in test 1 and the maximum reaction time, r = .22, p = .037, and the minimum response time, r = .21, p = .040. The higher the minimum and maximum reaction time in complex responses, the longer the reaction times to the call for control transition in test 1.

It should be noted, however, that, in the case of wrong or missed responses, the indicators for the vast majority of subjects were zero, so further analyses were not conducted for such variables. For the remaining variables (continuous variables), moderation analyses were then performed using regression with the PROCESS macro, testing whether the response times and the number of correct responses in the MCR test modify the average response time to a call for control transition under different test conditions. The results showed that none of the MCR test indicators modified the response time to a control call under the three conditions.

4 Results - discussion

Summarizing, the results of statistical analyzes showed that in conditions without distractors, the subjects took control more often, *e.g.* by changing lanes, than by automatic braking. However, in conditions with a fog distractor, automatic braking was more frequent. In such situations, drivers did not change lanes, while in good weather conditions, the lane change response was frequent. There are analyses showing that a difficult road situation, caused by *e.g.* weather conditions, may lead to a mental strain and the development of the so-called emotional swing, during which thoughtless behavior may occur [3]. In this case, the thoughtlessness resulting from a stressful situation could lead to making decisions that are not fully adequate.

Other analyses [13] have shown that the control transition time is almost 3-4 times longer under conditions of distraction. This has not been proven in this case. It turned out that the subjects differed in terms of response times be-

tween tests, but the shortest response times were achieved in the last test (with a distractor), while the longest response times were achieved in the first test (without a distractor). This is consistent with the analyses proving the lack of influence of cognitive load, *i.e.* the influence of the additional operation on the control transition time [11]. However, such results may be associated with the learning effect, which, in turn, is confirmed by the research on the shorter control transition time when the necessity of transition is predictable and expected [13]. According to earlier reports, the unforeseen need to take over control under time pressure is associated with a heavy strain on the driver [18].

The presented analyses also showed that the tendency to react in a certain manner is not related to temperament, but the influence of psychomotor abilities on the speed of responding to a call for control transition was noted. As assumed, it was found that the average driver response time is related to the speed of responding to a call for control transition. The longer the response time was observed for the driver, the more time they needed to take over control of the vehicle.

5 Conclusions

The conducted analyses lead to conclusions having a real impact on road safety. The results of this experiment confirm that the driver's experience and familiarity with automation have an impact on the control over autonomous systems. This is evidenced by the differences in the reaction times of drivers between individual trials and a noticeable learning effect. Therefore, it is extremely important to train and provide drivers with information on the systems their vehicles are equipped with. Having to take control under time pressure can put a lot of stress on the driver, especially in difficult weather conditions, in heavy traffic, or when the driver is concentrating on activities other than driving. In such situations, inadequate reactions can easily occur as a result of unreflectiveness. Drivers' knowledge of the systems in the vehicle is essential for proper monitoring, understanding, and efficient error response.

This study did not show any impact of the secondary task on takeover time. However, it was shown that in conditions without distractors, the drivers more often took control, *e.g.* by changing lanes, than they led to automatic braking. In contrast, in conditions with a fog distractor, automatic braking occurred more often. More research is needed on this issue.

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