Haptic Shared Guidance and Automatic Cooperative Control Assistance System: Performance Evaluation for Collision Avoidance during Hazardous Lane Changes

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Abstract: Automation systems that regard humans as the final authority have been found to be efficient and are therefore widely accepted. However, it has been argued that automation needs to be allowed to act autonomously in some time-critical situations, such as road traffic accidents. Possible interactions might occur between humans, especially those not well trained as car drivers, and authorised autonomous systems. A study using a driving simulator was designed to examine human-machine interactions when driving with two types of assistance systems: sharing of steering control that provides haptic control guidance through the steering wheel to resist hazardous lane changes, and an automatic cooperative system that acts autonomously to avoid hazardous lane changes. Whilst the drivers were in charge of steering in all circumstances when sharing the steering control, they were unable to steer their vehicles during the autonomous control. Results showed that increasing automation authority does not necessarily lead to improved safety. Other factors like human-machine cooperation need to be considered when the assistance system experiences functional limitations. Although lane change crashes were significantly reduced when the drivers were supported by the autonomous system, drivers reacted earlier and more convenient when supported by the haptic system.

Key Words: automation authority, control, human-machine cooperation, safety, lane changing.

1. Introduction

Driving a car is a highly complex task that requires continuous information processing by the drivers, in highly dynamic and potentially high workload environments with other drivers and numerous objects [1],[2]. In such an environment, human error, which can result in a road traffic accident, is likely to occur. According to road traffic accident statistics, human errors were a cause in more than 90% of traffic accidents [3],[4]. Automating the driving task is one of the expected approaches to improve road traffic safety by either reducing or preventing human error. A wide range of driver assistance systems have been developed to facilitate vehicle control, reduce workload, and avoid collisions [5]. However, still the most frequently asked question is: to what extent should the automation be given the authority to act in risky situations? This study attempts to partially address this question in terms of automation authority and human-machine interaction.

1.1 Human Factors Associated with Automated Driving

Human-centred automation, which maintains the human as the final authority, is a widely accepted concept for an automated system design [6]. According to this concept, systems such as visual, aural, tactile and haptic warning systems [7]–[9] may extend drivers’ perception abilities, support drivers’ situational awareness, or even encourage them to select the most appropriate action in the situation. However, action selection and implementation remain the drivers’ responsibility. Whilst the effectiveness and driver acceptance of these systems have been demonstrated conclusively [10], the overall safety may depend on other issues like limitations and reliability of the human driver and the automation system, and traffic conditions like risk value and time criticality [11],[12].

Supporting drivers’ action implementation requires giving more authority to the assistance system to act as an active agent. This means that a vehicle control can be partially or entirely passed from the driver to the system either to relieve drivers from some driving tasks or to avoid hazards. Adaptive cruise control (ACC), lane departure prevention (LDP), lane change collision avoidance and Automatic Emergency Braking Systems (AEBS) are examples of automation systems that support drivers’ action selection and implementation [13]–[15]. Unfortunately, several issues have been reported while using these systems, such as loss of situation awareness and skills, overreliance, over-trust, and distrust caused by automation surprises [16],[17]. It has been suggested that these human factors issues can be addressed by establishing an effective collaboration among the human drivers and the automation systems. Shared and cooperative controls were introduced as methods to keep interacting agents, human and automation, always in the direct control loop [18],[19].

1.2 Automotive Shared and Cooperative Control Systems in Safety-critical Situations

In automotives, car driving tasks can be generally divided into two functions: (1) lateral control (LAC), which can be controlled with the steering wheel, and (2) longitudinal con-
control (LOC), which can be controlled with gas and brake pedals. The automated system may share a single function with the human driver (shared control), or perform one of the functions entirely while the human driver performs the remaining function (cooperative control) [20]–[22]. Haptic lane keeping assistance systems can be an example of shared control where the system and the driver contribute simultaneously to the steering wheel input to control the vehicle approximately in the centre of the host lane [23]. Adaptive cruise control is an example of semi-autonomous cooperative driving system that is capable of speed maintenance, while the driver controls the steering function.

Suppose that a driver manoeuvres his or her vehicle laterally between different lanes without being aware of the presence of hazards in the targeted lane, such as vehicles in the blind spot or fast approaching vehicles as can be illustrated in Fig. 1. If the driver proceeds with lane changing without collecting sufficient information about the surrounding environment, a possible collision might occur. Now, a research questions arise: What type of assistance should be given to the driver in this situation? Is providing the driver with haptic guidance through the steering wheel enough, or should an autonomous action be implemented to avoid a possible collision? If the type of support is decided upon, what are the effects of automation assistance and automation functional limitations on a driver’s response to other surrounding traffic hazards?

To address these questions, both types of assistance, haptic shared and autonomous cooperative controls, need to be examined under various traffic conditions where drivers can be exposed to different hazardous situations. The assistance function of both systems was designed based on the soft and hard protections for avoiding collisions during lane-change by Itoh and Inagaki (for relevant reviews, see [24]). The present paper has also subjectively evaluated the effects of automation assistance on drivers’ trust in acceptance of automation, system effectiveness for improving safety, and drivers’ feeling of control.

It was hypothesized that providing an autonomous collision avoidance action can be more efficient; however, drivers’ performance can be significantly improved when using the haptic guidance. It was also expected that drivers’ subjective assessment can be influenced by the type of hazards more than the type of assistance. A preliminary pilot study with volunteer drivers was conducted to test the hypotheses and feed it into the design of a larger scale experiment [25],[26]. This paper reports the results of the second experiment with 48 participants using a driving simulator.

2. Experiment

2.1 Participants

Forty eight licensed drivers (24 males and 24 females) between the ages of 20 and 55 years (m = 30.0; S.D. = 7.5) participated in the experiment. Their driving experience ranged between one to thirty years (m = 9.4; S.D. = 8.1). None of the participants had any previous experience using a driving simulator or a driver assistance system.

2.2 Apparatus

The study was designed using the motion-based driving simulator (HONDA DA-1105) shown in Fig. 2. The simulator consists of a single seat cockpit located to the right side with 120° wide screen in front and three small LCD screens to simulate sides and rear view mirrors. The motion-based function was disabled to avoid motion sickness, and the volume of the sound system was set to the minimum to make it difficult for the drivers to recognise the presence of other vehicles. The driving course was a 6 km long loop on a two-lane highway.

2.3 Experimental Design

To address the research questions, a mixed factorial design of assistance type and hazard type was used.

2.3.1 Assistance system

Two types of driver assistance systems for avoiding collisions during lane-change were used in this experiment. The reliability and accuracy of these assistance systems can be subject to driver and environment monitoring methods. It was assumed that there is an accurate and fully reliable monitoring method; the system regarded the situation as risky and was activated when the driver inputs a steering angle (\(\theta\)) equal to or more than 0.038 rad to the direction of a vehicle in the adjacent lane and the distance (d) between vehicles is 5 m or less as shown in Fig. 3.

Drivers were divided into two equal and balanced groups. Each group was assigned to drive with one of the following systems:

i) Haptic Lane Change Collision Avoidance System (H-LCAS). This system resisted unsafe lane-change by stiffening the steering wheel to warn the driver. When it was activated, the steering friction torque given by the system was increased from 1 Nms to 9.6 Nms. The torque value was determined so that there is an accurate and fully reliable monitoring method; the system regarded the situation as risky and was activated when the driver inputs a steering angle (\(\theta\)) equal to or more than 0.038 rad to the direction of a vehicle in the adjacent lane and the distance (d) between vehicles is 5 m or less as shown in Fig. 3.

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i) Haptic Lane Change Collision Avoidance System (H-LCAS). This system resisted unsafe lane-change by stiffening the steering wheel to warn the driver. When it was activated, the steering friction torque given by the system was increased from 1 Nms to 9.6 Nms. The torque value was determined so that the drivers may readily feel the change from the normal torque, while allowing them to override the additional torque. An auditory signal was given to the driver just before the steering wheel was made heavier. The system restored the original value of the steering wheel torque either immediately after de-

Fig. 1 Hazardous lane changing manoeuvre.

Fig. 2 HONDA driving simulator.

Fig. 3 Activation conditions.
tecting that there was no vehicle in the blind spot, or as soon as the driver overrode the system.

ii) Automatic Lane Change Collision Avoidance System (ALCAS): This system cancelled the driver’s steering input and autonomously controlled the lateral position of the vehicle within the current host lane to prevent lane change collisions. When the system was active, the driver was no longer able to control both vehicle directions by moving the steering wheel. An auditory signal was given to the driver just before the system was activated. Depending on the context, the driver could change the speed to increase the distance from the following vehicle in the adjacent lane. When the risk was no longer within the system boundary, the driver was provided with a second but different auditory signal to inform him/her that the system was about to be disengaged. Three seconds later, another signal similar to the second one was given and the system was immediately deactivated.

2.3.2 Type of hazard

In this experiment, all lane changes performed by the drivers were in response to hazards in front of them rather than planned or voluntary manoeuvres. In all scenarios, the drivers were instructed to drive in the left side lane and to keep the vehicle speed at 80 km/h. The drivers were prompted to change lanes several times to avoid slow leading vehicles (SLV) whose speed was 70 km/h. However, the drivers were urged to return to the left lane after each manoeuvre completion. Some of these lane changes were hazardous. Figure 4 shows the non-hazardous lane-change manoeuvres that could be accomplished safely with an appropriate performance.

Three types of hazardous lane-change scenarios were considered in this study:

A) Blind Spot Hazard: In this experiment, the term ‘blind spot’ referred to the area around the vehicle that cannot be directly observed by the driver through the front, rear, or side view screens. In real world driving, drivers can check the blind spot by turning their heads and look out the side windows [27]. However, screens that simulate the side-view windows were disabled in this experiment to make the conditions same for all participants. The purpose of this type of scenario was to illustrate the human driver’s failure to detect the blind spot by themselves and measure the collision contribution factor. This may also enable drivers to learn about their model of the system and experience its benefits.

The scenarios were designed to be 100% compatible with the design capacity of the system as shown in Fig. 5. While the host vehicle (HV) was initiating a lane changing manoeuvre to overtake a slow leading vehicle (SLV), a following vehicle (BSV) was in the blind spot of the HV. The drivers experienced this type of scenario twice during the training phase and twice during the testing phase.

B) Fast Approaching Following Vehicle (FAV): The FAV referred to the vehicle in the adjacent lane, approximately 60 to 70 m behind the HV rear bumper during lane-change initiation. The headway between the HV and the FAV would be between 2 to 2.3 s. The FAV should be monitored by the drivers through the side view screen before lane change initiation. Although the drivers could observe the FAV, the system was not designed to detect such kind of hazard in this experiment. The aim was to illustrate the effect of automation assistance on drivers’ perception of risk. It also aimed to illustrate how a driver might rely on the assistance system and to distinguish between system reliability and design capacity.

As shown in Fig. 6, the critical situation occurred when the HV initiated a lane-changing manoeuvre to overtake the SLV, while the FAV was fast approaching (100 km/h) in the cruising lane. The drivers were subjected to this type of hazard once, and that was during the testing phase.

C) Combined Hazards: In this scenario, the driver faced two hazardous situations sequentially. The first was a blind spot hazard, which was recognizable to the system, but not to the driver. The second hazard was a suddenly stopping lead vehicle, which was recognizable to the driver, but not to the system. In other words, drivers had to avoid an imminent forward collision in which they needed to change lanes, whilst they were being assisted by the system to stay in the designated lane. The main purpose of this type of scenario was to investigate how the drivers’ response to unpredictable imminent hazards could be affected by the way in which the control was allocated between humans and the automation system.

As can be seen in Fig. 7, the HV was constantly approaching an SLV at the same time there was a motorbike in the blind spot of the HV. In case the HV initiated an overtaking manoeuvre, the system would have been activated to avoid a possible collision with the BSV. Consequently, while the drivers were assisted by the system to stay in the host lane, the SLV suddenly stopped in such a way that the driver of the host vehicle had to either promptly apply maximum braking or change lanes to avoid a rear-end collision. It should be noted that the drivers could override the haptic system at any point, but they were
unable to override the automatic system.

2.4 Procedures

The experiment lasted for three hours in one day for each participant. First, the participants signed an informed consent to insure their ethical rights. They were then introduced to the simulator with a brief explanation of the study and the experimental design. Each driver practiced two ten-minute familiarization drives followed by two ten-minute training drives to understand how the assistance system he or she is going to use behaved when a vehicle was in the blind spot.

In the data collection phase, each driver performed four ten-minute drives in which they had to perform 24 lane-change manoeuvres. Only four lane changes were dangerous. Two hazardous manoeuvres were under condition ‘A’ and two were under conditions ‘B’ and ‘C’ respectively. The sequence of the hazardous conditions ‘B’ and ‘C’ where the participants might experience the unexpected behaviour of the system was balanced among participants to avoid the learning effect, as can be seen in Table 1.

Participants’ responses were obtained after experiencing each hazardous condition. They had to rate their feelings from “0: Not at all” to “7: Absolutely” for each of the following items:

1) Trust: “To what extent do you think the system is trustworthy?”
2) Acceptance: “To what extent do you think you would like to use the system in the real world?”
3) Effectiveness: “To what extent do you think driving with the system improved safety?”
4) Control: “To what extent do you think you had the situation under control?”

2.5 Data Analysis

In this experiment the number of collisions, steering wheel reversal rate (SRR), and braking reaction time (BRT) were collected, analysed and compared between and within groups as dependent variables. The number of collisions was analysed using the Chi-square test. Two-way repeated measure analysis of variance (ANOVA) with types of assistance systems and hazardous conditions was used to analyse SRR, and Bonferroni pairwise comparisons were used to analyse and compare BRT between groups. The questionnaire items were analysed using a rank-sum test. The significance level was set at (0.05) for all statistical analysis.

3. Results

3.1 Number of Collisions

Accidents were divided by type into: Side collisions with the BSV and the FAV and rear-end collisions with the SLV.

Data in Table 2 presents the number of side collisions per assistance system under each hazardous condition. The Chi-square test showed that there was a significant difference ($\chi^2 = 8.48$, $p < 0.05$) between systems only under condition ‘A’, while results of conditions ‘B’ and ‘C’ were comparable. It also showed that there were significant differences between conditions ‘A’ and ‘B’, and between conditions ‘B’ and ‘C’ for both systems ($\chi^2 = 8.02$, $p < 0.05$). Surprisingly, the number of collisions was significantly higher under condition ‘B’. This may indicate that the drivers either underestimated the hazard, or overestimated the capacity of the assistance system. Overall, the result shows that both systems were effective in lane-change accident reduction under conditions ‘A’ and ‘C’. However, the automatic system was slightly more efficient, because the system was the final authority.

Table 2 Number of side collisions with the FAV and the BSV.

| Scenarios | H-LCAS | A-LCAS |
|-----------|--------|--------|
| A         | 6/24   | 0/24   |
| B         | 21/24  | 20/24  |
| C         | 2/24   | 0/24   |

Table 3 depicts the number of rear-end collisions per assistance system under each hazardous condition. Between systems, results were significantly different ($\chi^2 = 9.0, p < 0.01$) only under condition ‘C’. Between hazardous conditions, there were significant differences between conditions ‘A’ and ‘C’, and between conditions ‘B’ and ‘C’ ($\chi^2 = 9.57, p < 0.01$) for both systems. Interestingly, the number of collisions was significantly different between systems in condition ‘C’. It would be easier for the drivers to avoid the collision if the system was set to immediately disengage according to the driver’s steering feedback or the situation. Whilst the automation assistance as a final authority was a possible factor to reduce collisions in condition ‘A’ (Table 3), it became a collision contributing factor in condition ‘C’ (Table 3).

Table 3 Number of rear-end collisions with the SLV.

| Hazardous Conditions | H-LCAS | A-LCAS |
|----------------------|--------|--------|
| A                    | 1/24   | 3/24   |
| B                    | 0/24   | 0/24   |
| C                    | 9/24   | 20/24  |

3.2 Steering Wheel Reversal Rates (SRR)

The steering wheel reversal rate was used to indicate how steering accuracy and fluency can be affected by automation authority [28]. Figure 8 shows the mean and standard deviation of SRR under each hazardous condition and support system. The SRR was computed as $\text{SRR} = N/T$, where $N$ is number of changes of direction in steering wheel rotation during time $T$, and $T$ is the time required to avoid a lane change collision in seconds.

According to a two-way repeated measures ANOVA, there was a significant interaction and difference between assistance systems ($F(1,46) = 855.3$, $p < 0.01$) and ($F(1,46) = 42.5$, $p < 0.05$ respectively). Taking into consideration that both systems were not activated during condition ‘B’, the observed SRR in this condition can be assumed as a baseline. Comparing
conditions ‘A’ and ‘C’ with condition ‘B’, Bonferroni pairwise comparisons showed that the haptic system had a minor effect on SRR compared to the automatic system ($p < 0.01$). Between hazardous conditions ‘A’ and ‘C’, ANOVA showed significant differences for both assistance systems ($F(2, 46) = 104.9, p < 0.01$) and a significant interaction among types of assistance systems and hazardous conditions ($F(2, 46) = 19.9, p < 0.01$).

### 3.3 Braking Reaction Time (BRT)

The reaction time of the driver was used to evaluate the effects of automation assistance on the driver’s situation awareness [29]. When drivers are about to change lanes, their eye focus could shift from the forward roadway towards the adjacent targeted lane [30]. When the manoeuvre of changing lanes was cancelled for any reason, the drivers needed to perceive the new dynamically changing situation in the host lane again.

In this study, the drivers’ decision to cancel a lane-change manoeuvre necessitated them to press the brake pedal to avoid rear-end collision with the lead vehicle. The braking reaction time was determined as the elapsed time from the driver initiating a steering input intended to change lanes to the driver pressing the brake pedal. Figure 9 shows the mean and standard deviation of BRT associated with each type of automation assistance. Bonferroni pairwise comparisons showed that the driver reacted considerably earlier under the H-LCAS ($p < 0.01$). The results suggested that the driver’s situation awareness related negatively to automation authority and the driver’s ability to regain control.

### 3.4 Subjective Assessment

#### 3.4.1 Trust in automation assistance

Figure 10 depicts the subjective ratings on trust in automation. The Wilcoxon Rank Sum Test revealed a significant difference between systems only in scenario ‘C’ (Z = −6.1, $p < 0.01$). Between scenarios, there were significant differences between ‘A’ and ‘B’, ‘A’ and ‘C’, and ‘B’ and ‘C’ for both systems (Z = −5.2, −3.3, −4.9, $p < 0.01$ with H-LCAS; Z = −5.0, −7.5, −4.6, $p < 0.01$ with A-LCAS). Both systems were trustworthy in scenario ‘A’, while the trust level considerably dropped in scenario ‘B’. Of interest was the indicative difference between systems in scenario ‘C’. The rating of the haptic system higher than the automatic system by the drivers could be attributed to the driver’s ability to regain the control. The context was especially surprising for the drivers when the front vehicle stopped suddenly during the activation of A-LCAS leaving a short time for them to react appropriately without being able to change directions.

#### 3.4.2 Acceptance of the automation assistance

Figure 11 presents the drivers’ willingness to use the system in the real world. The test showed a significant difference between assistance systems only under driving condition C (Z = −7.2, $p < 0.01$). Among driving conditions, there were significant differences between A and B (Z = −7.8, $p < 0.01$), and A and C (Z = −3.5, $p < 0.01$) when driving with H-LCAS, while between A and B (Z = −6.1, $p < 0.01$), A and C (Z = −4.2, $p < 0.01$), and B and C (Z = −2.8, $p < 0.01$) when driving with A-LCAS. Results show that both systems were strongly accepted only under condition A. While drivers’ response was approximately comparable between systems under conditions A and B, results were rather different under condi-
tion C. Drivers were disappointed when they experienced some possible pitfalls of the support system.

3.4.3 Effectiveness of the automation assistance

To better understand drivers’ expectation of the system and how they might rely on its assistance, it was necessary to investigate drivers’ subjective feelings of system effectiveness. As shown in Fig. 12, the drivers thought that both systems improved safety to a certain level. Drivers rated the automatic system slightly higher than the haptic system, which is in agreement with results in Tables 1 and 2. When the system failed to detect the fast approaching vehicle in condition B, the drivers rating was significantly dropped down to the minimum level ($Z = -6.3, p < 0.01$). The context of condition B is out of the designed capacity of the system. However, drivers blamed the system for not being able to detect a vehicle that could be easily detected by them. It is noteworthy that there was a significant difference between systems under condition C when both systems failed to cope with the situation ($Z = -5.5, p < 0.01$). However, drivers rated the haptic system higher than the automatic system. This suggests that the effectiveness of shared control system depends on not only the reliability of both agents but also the driver’s ability to regain the control and assist the system when it is necessary.

![Fig. 12 Drivers’ subjective rating on system effectiveness.](image)

3.4.4 Control authority

Figure 13 illustrates the subjective ratings on drivers’ ability to change the control. The analysis found significant differences between assistance systems under driving conditions A ($Z = -6.5, p < 0.01$) and C ($Z = -6.0, p < 0.01$), but there was no significant difference under condition B ($Z = -0.2, p > 0.05$). These differences can be simply attributed to the authority level of the support system. Drivers maintained a final authority under the haptic system, while the automatic system had the final authority on vehicle directions. As expected, there was no significant difference between systems during driving condition B because both systems were not activated at all. Driving with H-LCAS, the test showed no significant differences among driving conditions as the drivers always maintained full control on the steering wheel. The statistically notable differences among driving conditions with A-LCAS were between driving conditions A and C ($Z = -6.6, p < 0.01$) and B and C ($Z = -6.6, p < 0.01$). The driver felt in charge of the steering wheel control only when the A-LCAS was not activated.

![Fig. 13 Subjective rating on drivers’ ability to modify the automatic control.](image)

4. Discussions

The present study was designed to determine the effect of automation authority on human-machine cooperation and safety. The experiment examined and compared two types of driver assistance systems with different levels of control authority under various hazardous conditions. Drivers were trained in the use of the assistance systems during which time they were not exposed to any hazardous condition. During data collection, drivers had to experience three different hazardous conditions to determine how driver and system performance may vary depending on the context.

Results of the experiment showed that the drivers reacted earlier, the reactions were smoother and were less error-prone when they received haptic force feedback. The warning signal provided with both systems had no significant effect on driver’s reaction time and steering behaviour. Given that the amount of steering friction torque during the automatic system activation was the same as the normal one, it can be claimed that using the haptic guidance can significantly reduce driver’s reaction time and inappropriate rapid steering movement.

When the system design capacity and drivers’ expectation were aligned, the haptic system was, up to a point, efficient at maintaining safety. However the automatic system provided more powerful and appropriate protection. Results of the subjective assessment found that both systems were trustworthy, improved safety, and were accepted by the drivers. So far, these results are in line with those previously found in the literature [21],[23],[24]. While previous studies drew their findings based on fully reliable systems when the hazards encountered by the drivers were within system design capacity, the present study extends these findings by illustrating how human and automation may interact when the hazard encounter can be outside the system design capacity.

When the hazard encountered is outside the system design capacity, the drivers were likely to overestimate the automation system capabilities. Whilst the drivers were able to recognise the fast approaching vehicle in the cruising lane, it is difficult to point out the exact human factors involved in such hazardous situations and why the number of accidents was dramatically increased. Perhaps, some drivers changed the lane expecting that the system would be activated if the situation is risky, i.e. overreliance. Others might fail to estimate the approximate speed of the fast approaching vehicle, i.e. human reliability. To avoid such consequences, the driver should be aware of what kind of hazard the system is designed to handle. Consider-
ing the highly complex and rapidly dynamic driving environment, automation should be developed with clear boundaries and functionality.

The study found that driver’s performance was significantly (negatively) affected when they encountered unpredictable hazards while assisted by automation. Furthermore, the overall driver situation awareness was critically degraded leading to greater hazard. The analysis of drivers’ subjective ratings found that such type of hazardous situations significantly influenced drivers’ response to all items of the questionnaire (Trust, Acceptance, Safety, and Control).

In this study, the human-machine cooperation was presented as a function of human-centred automation. First, the results implied that drivers’ acceptance of the automation assistance is highly related to system performance in the certain situation rather than the level of automation authority. The drivers were willing to trust and cooperate with the system as long as no human-machine interaction problems, such as accidents, could possibly occur. Second, the way in which the control is divided between the human and the automation might affect the drivers’ abilities to avoid other surrounding and unpredictable hazards.

In sum, the results illustrated how drivers’ performance, subjective assessment and overall road traffic safety were significantly affected by the automation performance and functional limitation in critical situations more than the control authority. Although drivers were able to control the longitudinal position of the vehicle, their feeling of ‘control’ was considerably reduced when the system dominated the execution of the lateral manoeuvre. It can, therefore, be assumed that the effect of trading lateral or longitudinal control between human and automation on drivers’ performance and feeling of control may depend on the type of manoeuvre required to avoid the encountered hazard. Noting that the contexts given in this experiment were more related to steering manoeuvre, further contexts need to be investigated and highlighted.

5. Conclusions and Perspectives

A significant finding that emerged from this study is that the automation authority should be tuned depending on the drivers’ abilities, risk value, and time-criticality taking into account all potentially surrounding hazards and uncertainties. Based on what has been discussed in the literature and in the current study, the following parameters should be taken into account to avoid human-automation interaction problems and to achieve a dynamic and stable balance between humans and automation systems in safety-critical situations:

1) Mutual understanding: An assistance system should be able to perceive not only the surrounding hazards, but also the driver’s intention considering the traffic conditions. At the same time, the assist function should be designed in a way that the human driver may easily perceive the goal and the design limits of the automation system. Mutual understanding is a fundamental essence of the cooperation and positive interactions between the human and automation.

2) Control authority: The human should have the final decision (final authority) over the automation as long as he or she is acting. The automation assistance may assume authority only when the human is not acting or the human action is definitely determined to be erroneous in predefined situations. The point where the authority is transmitted from the human to the automation is called ‘Authority Threshold’. Determining the authority threshold is an intriguing issue that demands further studies.

3) Risk value: To determine how risky the situation is depends on time-criticality, which may significantly determine the point of authority threshold. Making an appropriate decision in the situation requires high information collection and analysis performance abilities [31]. The system should be able to collect and analyse all surrounding information when it is about to perform an action. Risk value should include all surrounding hazards and not only the detected one. For example, when a system autonomously controls a vehicle to avoid an imminent hazard, the system should take into account not only the detected hazard, but also how to safely guide the vehicle in the new situation during and after the avoidance manoeuvre.

In this study, the activation duration of the automatic system depended on the situation, i.e. the distance to the vehicle in the blind spot. Thus, the automatic system continued the activation status until the blind spot vehicle came out of the system boundary. Accordingly the system activation duration might last for longer than expected. This can potentially lead to human-machine interaction problems. It would be more efficient and accepted more by the drivers if the system activation duration could be tuned depending on the context or could be reduced to the minimum efficient time period for all critical events. It would be useful to investigate the most effective time duration for system activation with minimum side effects.

Although the current study is based on a relatively large sample of participants, further studies are still necessary. It is necessary to investigate the long-term effects of human-automation interaction on driver’s performance and safety when driving with collision avoidance systems. In real world driving, the assistance systems described might not be activated very often, therefore automation surprises are likely to occur.

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