博士(工学)論文概要

Design and Evaluation of Semi-automated Steering Interventions for Avoiding Collisions during Lane Change

(車線変更中の衝突回避のための半自動化操舵介入の設計と評価)

システム情報工学研究科　リスク工学 専攻

ALZAMILI HUSAM MUSLIM HANTOOSH

２０20年　３月

1. Introduction

As indicated by 50 million injuries and more than 1.2 million fatalities annually due to road accidents, traffic safety has become a social problem throughout the world that requires countermeasures [1]. Road-accident information that suggests human error is a major cause of car crashes has pushed researchers to design and develop systems for human error suppression [2]. Various driver support systems have been accordingly deployed to make the driving task safer, easier, and more comfortable, and to aid drivers when necessary by providing technology for forward collision avoidance, lane change aiding, lane keeping assistance, adaptive cruise control, and auto-parking support [3, 4, 5]. The preliminary results of these studies have emphasized the significant benefits of these systems [6].

However, it has been noted that the usability and performance of driver support systems, particularly in the long view of human–machine interaction, depend on not only the sophistication of the system and its robustness, but also on human–machine cooperation and performance [7]. In other words, neither human nor machine alone can always perform a driving task perfectly under all circumstances. An appropriate level of human–machine cooperation is thus required to provide safe decision making and action implementation even within highly automated systems [8]. How humans cooperate with a machine system is closely linked to their understanding and trust in such system. Although an automated system may perform perfectly, the failure of systems to handle situations because of a lack of human cooperation caused by misunderstanding and low trust has been reported [9]. Therefore, further research is needed to achieve an appropriate level of cooperation between human and automated systems.

To avoid an imminent collision, a driver must perform an evasive time-critical manoeuvre using steering, braking, or both. Such evasive steering can be required to move the vehicle away from a hazard caused by an erroneous steering manoeuvre during the lane change, merge, or overtaking processes. Supporting driver decision making in such time-critical scenarios with measures such as collision warning systems can reduce the crash rate by more than 50% [10]. However, several factors, including driver characteristics, alarm timing, system reliability, and other environmental factors such as speed and distance between vehicles, can influence the effectiveness of warning systems [11]. These factors, which determine the total system usability and performance, can exert a negative impact on driver trust in and acceptance of a support system [6]. For example, an early alarm, while increasing system effectiveness, might be considered to be false alarm and thus adversely affect perceived system reliability, while a late alarm will not give drivers sufficient time to respond to imminent collision situations. Even with appropriate or adaptive alarm timing, cases in which drivers ignore warning system alarms and proceed with their erroneous action have been observed to be the result of variation in driver characteristics [3].

Consequently, stronger automation interventions have been considered to increase system effectiveness in highly critical situations like increasing the steering wheel torque and decoupling the driver's steering input, i.e., steer-by-wire [3, 12]. While increasing the steering wheel torque has been found to be efficient in terms of safety, driver trust, and cooperation, disadvantages have also been observed, such as an increase in the required steering effort and damping of the driver's reaction, which can limit the overall system performance [13]. On the other hand, decoupling the steering input from the driver for a certain amount of time may seem promising from a system effectiveness perspective and necessary in some highly critical situations [3], but from the perspective of human factors, decoupling the driver steering might lead to problems related to safe usage practices and human surprise, which typically have a negative impact on trust and cooperation between humans and automated systems [14]. This suggests the need for a system that is able to select the most effective type of automated intervention to avoid an imminent collision situation, depending on the hazard encountered and the driver's ability to perceive and handle it, known as *adaptive automation* [15, 16].

Adaptive automation, in which the driving task is divided into subtasks that can be separately or cumulatively automated by either advance human direction or depending on the situation has been suggested as a way to improve human–machine interaction and cooperation [15]. Such dynamic control allocation of (sub) tasks could be handled explicitly by the human or implicitly by the system. The allocation of control by the human (driver) may not be efficient as the human may not always be able to act in a timely manner [9]. However, the handling of the dynamic control allocation by the system requires designing an automated decision module that enables the system to determine to what extent which tasks for what situation should be automated. Thus, one of the most advantageous characteristics of adaptive automation is to keep the human in charge to the greatest extent possible by providing support only when necessary. In spite of this promise, the ability of human drivers to appropriately interact with the different interventions used in adaptive automation when needed poses a significant design challenge [16]. The question now is how does the driver trust, accept, and interact with such different levels of automated interventions. Some pitfalls could be expected as the human may not be easily able to deal with dynamically changing configurations of adaptive control systems

The present study accordingly proposes a system comprised of multiple assist functions to support drivers in avoiding lane change collisions by focusing on steering interventions that guide the lateral vehicle motion to drive the vehicle away from the hazard. The system has the authority to decide which type of support should be provided to the driver depending on the driver's ability to handle the situation, measured in terms of the drivers' ability to perceive the situation and recognize the hazard. Preliminary results show that steering interventions are likely to reduce crash rates and increase steering reaction and performance [17]. Therefore, the main objective of this study was to investigate the effectiveness of different automation intervention strategies in terms of safety, overall performance, and driver trust and acceptance while keeping controllability in mind.

Using a driving simulator, the present study conducted three sequential driving experiments. The first aim was to investigate the effects of automation authority and control allocation on drivers' understanding of the adaptive system in safety-critical situations. The second aim was to design an effective and usable adaptive collision avoidance system in which the control can be flexibly and dynamically transferred between agents depending on capabilities and limitations of both agents. The third aim was to enhance human-automation interaction using training approach.

2. Study I: Human Factors Issues Associated with Safety-Critical Driving Support Systems: Effects of Human Understanding of Automation Abilities on Driver Performance and Acceptance of Lane Change Collision Avoidance Systems

This part of the present study aims to investigate how the interactions between control authority and the accuracy of drivers understanding of the system combine to affect driver performance to avoid critical conditions caused by automation limitations. It is investigated how different driver assistance systems, through the steering wheel, for avoiding collisions during different enforced lane change maneuvers influence the lane change behaviour of drivers compared to unsupported driving previously investigated [3]. By exploring parameters for reducing disruption to human-automation interactions, this research aims to contribute to the development of collision avoidance systems. The hypothesis was that the drivers trust and accept automation assistance as long as they have the final authority. It was also hypothesized that the effects of drivers' understanding of automation limitations and functionalities is related to their ability to retain the control.

2.1. Method

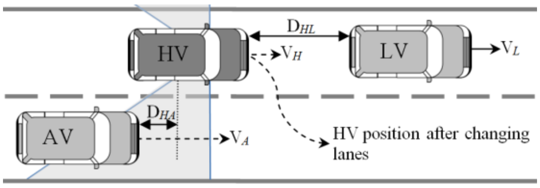
2.1.1. Participants and Apparatus

Forty eight participants (24 females; 24 males; M_{age}= 30.0; STD_{age}= 9.2) were recruited to participate in the driving experiment, which was carried out in a driving simulator made by Honda, as shown in Fig. 1. The cockpit consists of a single adjustable car seat, motorized steering wheel, an automatic transmission system, and a concave diagonal screen to create 120-degree field of view with small displays for the side and rear views.

Fig. 1. Honda driving simulator showing the driver cockpit and driving scene

2.1.2. Lane Change Collision Avoidance Systems Design

Analysis of traffic accident data shows that lane change crashes most commonly occur when there is a vehicle which, at the time of lane change initiation, is in the adjacent lane area from 1 m in front of the host vehicle's front bumper to 9 m behind the host vehicle's rear bumper [18]. The likelihood of lane change accidents can significantly increase when a vehicle is located in the adjacent lane area that cannot be directly observed by the driver through the front window or rear and side view mirrors, which is known as the blind spot (BS) [19]. In this study, a critical event arises while a driver of a host vehicle (HV) attempts to avoid a rear-end collisions with a slow lead vehicle (LV) by changing lanes and dangerously closes in on a vehicle in the adjacent lane area (AV), as shown in Fig. 2. In cases where the HV's driver fails to detect the presence of AV, overestimates the distance between vehicles or underestimates the AV speed and proceeds with lane change initiation, a collision may occur between HV and AV during the lane change execution.



V_H: The velocity of the host vehicle
V_A: The velocity of the vehicle in the adjacent lane
V_L: The velocity of the leading vehicle
D_{HA}: The distance between HV and AV
D_{HL}: The distance between HV and LV
TTC_A: The time to collision between HV and AV in seconds ($TTC_A= D_{HA}/(V_A - V_H)$)
TTC_L: The time to collision between HV and LV in seconds ($TTC_L= D_{HL}/(V_H - V_L)$)

Fig. 2. The critical context and variables used to determine risk value and system activation conditions

Two types of driver assistance systems were given to the drivers and compared based on human information processing capabilities combined with the functionalities of the automation system and its limitations. The two systems were designed to detect unsafe lane change maneuvers when the HV's driver rotated the steering wheel angle more than 0.033 rad in the direction of AV and the distance between vehicles (D_{HA}) was equal or less than 5 m, or the time to contact between HV and AV (TTC_A) was equal or less than 2 sec, as shown in Fg. 2. In such critical situations, one of the following two assistance systems was available to support the drivers:

***1) Haptic Collision Avoidance System (HCAS)*:** this system increases the steering wheel friction torque from 1 Nm up to 9.6 Nm and sets off an audible alert to resist a driver's intention to change lanes. The torque value was determined so that the drivers may readily feel the change from the normal torque. The driver remains in control of the steering during system operation, and could either cancel the lane-change, or override the additional torque and proceed with the lane change. In both cases, the system is deactivated immediately.

***2) Automatic Collision Avoidance System (ACAS)*:** this system autonomously controls the tire angle to prevent unsafe lane-change maneuvers, by keeping the vehicle in the center of the host lane. When the system is activated, the authority of the vehicle lateral control is automatically transferred from the driver to the system in machine-initiated manner. Drivers are then unable to change direction by moving the steering wheel, as the tire directions are controlled by the system (steer-by-wire). However, the drivers stay in charge of the longitudinal control during system operation. To avoid a driver being caught unawares, and increase drivers understanding of the automation action, the driver was alerted by three audio tones during system operation. The first tone was given just before the system was activated, and the second to inform the driver that the hazard in the adjacent lane had been avoided, and that the system is about to disengage. Three seconds later, a third tone indicated that the system had been deactivated, and that the steering control authority had reverted to the driver.

2.1.3. Experimental Design

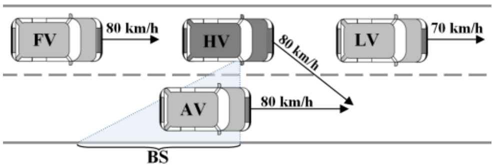
The experiment followed a 2 X 2 repeated measurements design. the two driving modes (HCAS and ACAS) were tested in two driving conditions: within system design (WSD) and outside system design (OSD).

***1) WSD*:** this condition comprised two lane change scenarios in which the hazard encountered was in line with the system design capacity. In each scenario, when the host vehicle (HV) attempted to change lanes in response to a slow leading vehicle (LV), there was a vehicle in the adjacent lane (AV) located in the blind spot of HV, as can be seen in Fig. 3-a. The HV and AV were both traveling at 80 km/h with a constant distance between them, while approaching the LV, which was traveling at 70 km/h. The systems were designed to detect AV in the blind spot. FV was a following vehicle traveling behind HV or AV at 80 km/h and could be seen by the HV's driver through the rear and side view mirrors. The aim of these scenarios was to enable drivers to better understand the system function and to experience its benefits. The experiment seeks to assess how the accuracy of drivers' understanding can affect their acceptance of, reliance on and interactions with the automation system.

***2) OSD*:** this condition comprised two lane change scenarios in which the drivers were randomly subjected to the following unexpected hazards that cannot be detected by the system. One scenario comprised a fast passing vehicle (PV) appeared in the cruising lane while the HV attempts to overtake a slow LV, as shown in Fig. 3-b. The approximate speed of the HV was 80 km/h, the LV was 70 km/h, and the PV was 100 km/h. The time gap between the HV and PV was slightly less than 3 sec. Although the PV could be seen in the HV right-side mirror, it was possible for the driver to underestimate the distance between the HV and PV. While PV was visible to the driver, the driver was unaware that the system was unable to detect it. The other scenario, shown in Fig. 3-c, comprised a chain of critical events. First, the driver had to avoid a slow LV by initiating a lane-changing maneuver. Secondly, the driver had to respond to the system intervention to avoid colliding with a motorbike in the adjacent lane. When the lane change collision was avoided by aborting the lane-changing maneuver, an immediate response was needed to avoid a rear-end collision with the LV, that was suddenly stopping. The effects of automation assistance on drivers ability to avoid other unpredictable hazards were measured, as it was almost impossible for the driver to avoid the rear-end collision by braking only. A steering maneuver was essential to avoid the hazardous condition. In this scenario, the suddenly stopped LV was visible to the driver, but not to the system.

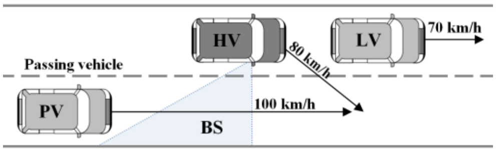
2.1.4. Tasks and Procedure

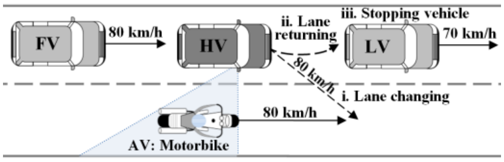
The experiment lasted three hours per participant in one day and it started with a brief to the participants of the purpose and design of the experiment. After participating in two ten-minute familiarization drives, the participants were instructed on the use of the assistance system and participated in two ten-minute training drives. During the training drives, each participant experienced two critical events under WSD condition. The data collection phase started with two drives in which the participants encountered two critical events under WSD condition followed by one drive under OSD condition (scenario-b) and lastly, one drive under OSD condition (scenario-c). Each drive lasted for approximately 10 minutes. The drivers had to experience scenarios in a randomized order to reduce the learning effect.



Scenario-a (WSD): the hazard was an adjacent vehicle in the blind spot of the host vehicle which could not be perceived by the driver through the right-side mirror

Scenario-b (OSD): the hazard, a fast passing vehicle in the cruising lane, was visible to HV's driver through the right-hand mirror





Scenario-c (OSD): the hazards were first a motorbike in the blind spot of the host vehicle and then an unexpectedly stopping leading vehicle; the dashed arrow refers to the expected path of the host vehicle, to proceeding either with lane changing or returning to the initial lane

Fig. 3. Lane change scenarios

2.2. Results and Discussions

***1) Number of Collisions*:** The lane change crashes included all crashes occurring as a result of a lane change. The drivers in each group were subjected to two types of hazardous conditions. Each condition comprised two critical events, and each event combined two risky contexts: a risk of a rear-end collision with a leading vehicle, and a risk of side collision with vehicles in the adjacent lane. In total, there were 192 critical events (48 drivers x 2 WSD scenarios x 2 OSD scenarios = 192 events) during the testing phase. During the experiment, each driver performed twenty-four lane changes, but only four were hazardous. Table I summarizes the collision data for each driving mode and condition. Forty-eight critical events are the maximum possible number of each cell in the table (24 drivers/mode x 2 events/condition = 48 events/mode).

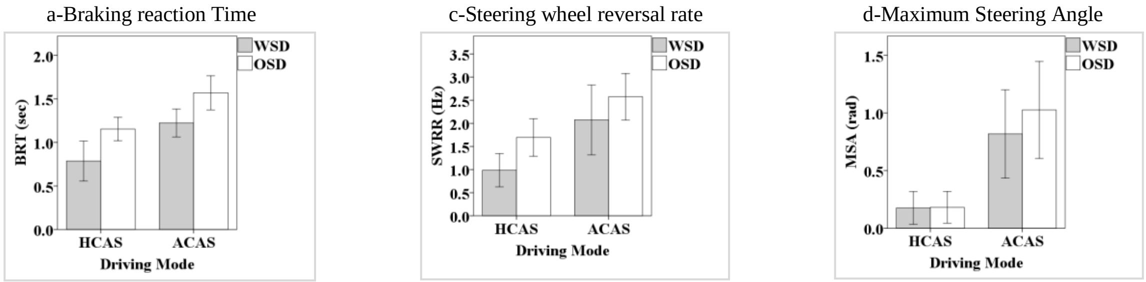
TABLE I. NUMBER OF COLLISIONS BASED ON SYSTEM DESIGN CAPACITY

Driving condition	**HV to AV and PV crashes**		**HV to LV crashes**	
	HCAS	ACAS	HCAS	ACAS
WSD	6/48	0/48	1/48	3/48
OSD	23/48	20/48	9/48	20/48

According to the chi-square test, the number of collisions was significantly different between hazardous conditions for both systems ($\chi^2(2) = 20.41$, p<0.01). This highlights the significant effect of system functional limitations on road traffic safety. The result supported the design guidelines for human-automation interactions suggested by [20, 21] regarding the necessity of providing the human operator with continuous feedback about the automation capabilities and functionality. There was a significant difference between the systems in the number of rear-end collisions, but only when the hazards encountered were beyond the systems' capabilities. This demonstrates the importance of a driver's ability to regain control when automation limitations are reached, typically when an immediate steering input is required by the driver to avoid an unexpected hazard ahead.

2) Braking Reaction Time (BRT)**:** All drivers were instructed to maintain a speed of 80 km/h, as they had to initiate overtaking maneuvers to avoid a slow LV (70 km/h) without braking. However, when the system was activated to prevent hazardous lane-changing, the drivers had to slow down to avoid a rear-end collision with the LV if the lateral maneuver was canceled. The BRT was measured as the time from the first audio tone, indicating a critical event, until the driver first pressed the brake pedal. Fig. 4-a shows the mean and standard deviations of BRT against forward roadway threats. A two-way repeated measures ANOVA showed that there was a significant interaction between driving modes and conditions (F(1, 46) = 7.9, p<0.05). It also reported significant differences between driving conditions when driving with HCAS (F(3, 260) = 9.6, P<0.01), and with ACAS (F(3, 260) = 9.3, P<0.01). The Tukey's HSD post hoc test revealed significant differences between driving modes under both hazardous conditions (P<0.01). The BRTs, when assisted by HCAS, were significantly lower than when assisted by ACAS, for both hazardous conditions. The differences between driving modes can be explained by the drivers feeling the steering wheel force feedback when the haptic system was activated; however, the relationship between the steering wheel and vehicle direction remained unchanged. This would have a minimal effect on driver attentiveness to surrounding hazards. When the ACAS was activated, there was no direct relationship between the steering wheel rotation angle and the actual direction of the vehicle; therefore, the drivers could be distracted by the automatic action.

3) Steering Wheel Reversal Rate (SWRR)**:** The SWRR was used to evaluate the impact of the automation assistance on steering accuracy and smoothness. Fig. 4-b shows the mean and standard deviations of the SWRR. According to the two-way repeated measures ANOVA, there was a significant correlation between driving modes and conditions (F(1, 46) = 10.3, P<0.01), and significant differences between hazardous conditions, ((F(3, 180) = 6.2, P<0.05) with HCAS, and (F(3, 180) = 8.3, P<0.05) with ACAS)), and between driving modes ((F(1, 46) = 10.5, P<0.01) under WSD, and (F(1, 46) = 9.1, P<0.01) under OSD)). Consistently, the Tukey's HSD post hoc indicates that SWRR was significantly affected by driving modes and hazardous conditions (p<0.01). These observations emphasize the effects of haptic feedback on drivers behavior during lane change.


a-Braking reaction Time

c-Steering wheel reversal rate

d-Maximum Steering Angle

Fig. 4. Objective evaluations of driving performance

4) Maximum Steering Angle (MSA)**:** Fig. 4-c above shows the mean and standard deviations of the maximum steering angles during the automation system operation. The MSA was used to evaluate the accuracy of drivers understanding of the automation action, compared to the actual situation. A two-way repeated measures ANOVA showed a significant effect of hazardous conditions ((F(3, 280) = 12.9, P<0.01) with HCAS, and (F(1, 280) = 13.4, P<0.01) with ACAS)). The Tukey's HSD post hoc test showed that, under OSD conditions, the MSA when driving with the ACAS was notably larger than that when driving with the HCAS (P<0.01). However, this result should be interpreted with care. While reducing the steering angle was necessary to avoid lane-change crashes in scenarios #1 and #2, it was important to use the steering maneuver to avoid a rear-end collision with the suddenly stopping LV in scenario #4. Such unexpected conflicts should be taken into consideration when designing a human-automation interaction. This suggested that, although it is essential for the automation to intervene in high-risk conditions, the human must remain in control to improve human-automation interactions. Further investigations are necessary to create design concepts for addressing such issues with human-automation interactions in emergency situations.

5) Subjective Evaluation**:** Fig. 5 depicts the drivers' rating on their willingness to use the system, feeling of control, risk perception, and ability to detect interferences with system activity. The Wilcoxon rank sum test showed a significant difference between hazardous events for each driving mode (Z = -5.5 with HCAS. and Z = -8.1 with ACAS, p<0.01). While both systems were suitably accepted when the hazards encountered were within system design capability, acceptance was significantly reduced when hazards outside system design capabilities were encountered. However, HCAS was less affected than ACAS. Between driving modes, ACAS was accepted more by drivers under WSD condition (Z = −4.7, p<0.01), but HCAS was accepted more under OSD condition (Z = −5.3, p<0.01). The reason for this could be that the drivers remained in control of the steering in all situations when driving with HCAS.

For drivers' feeling of control, there were significant differences between driving modes for all scenarios ($Z = -6.6$ under WSD, and $Z = -3.8$ under OSD, $p<0.01$). Automation authority could be considered a significant cause of the difference between the driving modes. When driving with HCAS, the test showed no significant differences between driving conditions. This could be attributed to the fact that drivers were able to control the steering during system activation. However, the statistically significant difference between driving conditions was only with ACAS ($Z = -4.7$, $p<0.01$). The results for ACAS were surprising, as drivers experienced some hazardous events outside system design capabilities, where the system was not activated; therefore, drivers felt more in control of the steering control, than during hazards within system design capabilities.

With regard to the effects of automation assistance on drivers' perception of risk, the responses could also be used to indicate how drivers relied on the automation assistance. A slight difference was observed between driving modes when the hazards encountered were outside system design capabilities ($Z = -3.1$, $p<0.05$). This could be interpreted as a driver's perception of risk being context-dependent, and not only affected by the driving mode. These indications lead to questions about drivers reliance on types of automation assistance, and suggest the need for further investigations to cover more types of automation assistance in critical and noncritical conditions. It was assumed that, if the driver was not able to detect interference, comparing his/her analysis to the one in the system, he/she could be caught unawares by the automation action. The rank-sum test showed a significant effect of the types of hazardous situations on both driving modes ($Z = -2.3$ with HCAS, and $Z = -2.8$ with ACAS, $p<0.01$), but there was no statistically significant difference between driving modes ($Z = -0.9$ with HCAS, and $Z = -0.6$ with ACAS, $p>0.05$).

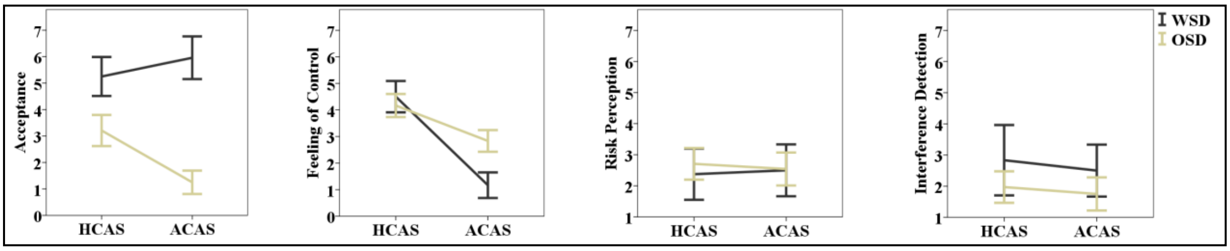


Fig. 5. Subjective rating by drivers on their ability of interference detection

3. Study II: Improving Driver Interaction with Collision Avoidance Systems using Adaptive Automation: Effects of Multiple Steering Interventions on Driver Performance and Trust

Study I does not consider the influence of drivers' ability to handle the situation. Automation systems may show different safety values under different degrees of risk, particularly when a visual limitation precludes an effective driver response. Focusing on the effectiveness of collision avoidance systems, the Study I's experiment did not thoroughly consider the influence of a driver's ability to perceive and handle a situation. However, collision avoidance systems may exhibit diverse safety values under different degrees of risk, particularly when a visual limitation precludes an effective driver response. Study II attempts to make some progress on the adaptive collision avoidance topic by assessing adaptive automation's effectiveness under various critical conditions and considering both agents' abilities and limitations. The study possesses two primary aims: (1) to investigate how drivers interact with different levels of automation interventions used in situation-adaptive automation to support those drivers while making hazardous maneuvers; and (2) to determine the extent to which drivers' trust and acceptance are affected by automation authority as well as the context encountered for designing usable and effective collision avoidance systems.

3.1. Method

3.1.1. Participants and Apparatus

Forty International healthy drivers (12 females; 28 males; M_{age}= 38.1, STD_{age}= 10.8) with valid Japanese driving licenses participated in this study, which was carried out using Honda driving simulator (Fig. 1 above).

3.1.2. Investigated Lane-Change Scenarios

In this study, the critical adjacent lane area was divided into four potentially dangerous parts depending upon how the driver may have perceived objects in the adjacent lane as follows:

Scenario #1. The front proximity zone (FPZ) includes the area beside the vehicle that can be observed by looking through the front window's right/leftmost area. In this scenario, the AV is traveling at 80 km/h in the critical adjacent lane area when the HV approaches a slower vehicle ahead, traveling at 70 km/h. The front part of the AV is located in the FPZ, while the rear part is located in the blind spot (BS) such that the host driver is able to see the AV's front in the rightmost corner of the front screen.

Scenario #2. The rear proximity zone (RPZ) includes the area behind the vehicle that can be observed by looking through the side-view mirrors. In this scenario, while the HV is about to pass the LV by maneuvering toward the cruising lane, the AV is traveling at 80 km/h in the HV's proximity zone such that the front part of the AV is located in the HV's BS and the rear part is located in the RPZ. The host driver is able to see the AV's rear in the right-hand mirror.

Scenario #3. The blind spot (BS) includes the area beside the HV that cannot be directly observed while the driver is looking through the front window or side- and rear-view mirrors. In real-world driving, drivers can view the BS by looking out either side window; however, due to the available field of view in this experiment, the drivers were unable to see their BS in the adjacent lane. This parameter was meant to encourage drivers to build a mental model of the assistance system and experience the adaptive collision avoidance system’s benefits during critical maneuvers. In this scenario, the AV is traveling at 80 km/h and is located completely inside the HV’s BS such that the host driver is unable to see the AV while looking through the front-, side-, and rear-view screens.

Scenario #4. The fast approach zone (FAZ) is located in the adjacent lane area between 9–49 meters behind the HV’s rear end. Although drivers can perceive the FAZ by looking through the side- and rear-view mirrors, they may nevertheless underestimate the speed of fast-approaching vehicles. Drivers’ misunderstanding of such situations increases the likelihood of accident occurrence, particularly when the time gap between vehicles is less than 1.6 s. In this scenario, while the HV approaches the LV, a fast-moving AV is approaching from behind, in the passing lane, at 100 km/h. Although the AV is located outside the proximity zone and can be seen by the host drivers in the rear- and side-view mirrors, the AV is located in the FAZ, and the time headway between vehicles would be between 0.9–1.2 s at the time of a lane change initiation. The host drivers might underestimate the AV’s speed and feel that the distance between the AV and HV is safe for changing lanes.

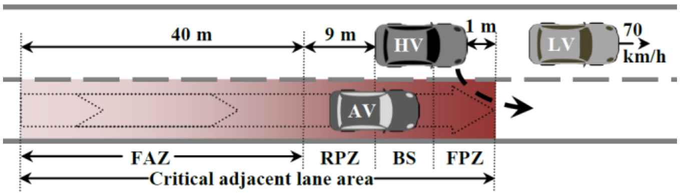


Fig. 6. Hazardous lane-change scenarios.

3.1.3. Lane-Change Collision Avoidance Systems Design

1) Haptic Steering Control System (HSCS): See “2.1.2. Lane Change Collision Avoidance Systems Design” above. The steering wheel torque value is calculated based on the AV’s position in the adjacent lane area: Non-hazardous= 1.5 N/M; FPZ= 5 N/m; RPZ= 7 N/m; BS= 9.6 N/m; and FAZ= 9.6 N/m).

2) Automatic Steering Control System (ASCS): See “2.1.2. Lane Change Collision Avoidance Systems Design” above.

3) Adaptive Control System (ACS): the ACS’s design integrates characteristics of the haptic and automatic steering control functions. This system has the ability to perceive a situation and decide the driver’s most appropriate assist function. In this study, the different lane-change scenarios provide different driver abilities and limitations to perceive, evaluate, and avoid a critical situation. Accordingly, the system provides adaptive control assistance based on each situation (see Table II).

TABLE II. AUTOMATED FUNCTIONS OF THE ADAPTIVE CONTROL SYSTEM

Scenario	Automated function
Non-hazardous	No automated intervention
FPZ	The system sets off a warning and increases the steering wheel torque from 1.5 N/m to 5 N/m.
RPZ	The system sets off a warning and increases the steering wheel torque from 1.5 N/m to 7 N/m.
BS	The system decouples the driver’s steering input and automatically drives the vehicle away from the hazard.
FAZ	The system sets off a warning and gradually increases the steering wheel torque from 1.5 N/m to 9.6 N/m.

3.1.4. Experimental Design and Procedure

To evaluate driver–system intervention, system effectiveness, and the combined effects of an automated function and a hazardous scenario on driver performance, the experiment followed a 4 x 4, mixed factorial design. The participants were divided into four balanced groups with ten drivers each according to their self-reported questionnaires. Each group had to encounter the four critical lane-change scenarios (FPZ, RPZ, BS, and FAZ) under one of four driving conditions: no automation assistance (NA), haptic steering control system (HSCS), automatic steering control system (ASCS), and adaptive control system (ACS).

Each participant was required to perform four practice scenarios preceding four testing scenarios in a single day over a total duration of three hours. The four testing scenarios were equivalent to the four investigated critical lane-change scenarios (FPZ, RPZ, BS, and FAZ). Each critical scenario occurred once during the testing phase, and the sequence of testing scenarios was counterbalanced among the participants to reduce their learning effects. Scenarios were also designed to be different among drives to avoid a repetitive hazard effect. The amount of time allotted for each drive was approximately five minutes, and no feedback was given to participants when a collision occurred; rather, they were asked to continue driving until the end of each scenario in order to avoid negative reactions that may have affected their performance during the remaining drives.

3.2. Results and Discussions

1) Safety Effectiveness Indicators: In this experiment, each participant had to perform at least sixteen lane-change maneuvers during the testing phase, only four of which were potentially hazardous. Considering the four hazardous lane-change scenarios, Fig. 3 compares the number of collisions between groups for each scenario. The collision data indicate that all systems were significantly more effective in reducing lane-change collisions compared to the unsupported driving condition (Chi square = 41.1, df = 3, $p < 0.01$). As clear as it seems, the number of collisions during unsupported driving was not very high, which may be attributed to the possibility of the learning effects caused by the repetitive hazards on the same day. In real-world driving, it is rare for one to experience such a high number of critical scenarios in one day; however, such effects may also be applied to the number of collisions under the supported driving conditions. Thus, collision data, while encouraging, should be interpreted with caution.

According to a Chi-square test, significant differences were found between lane-change scenarios for each driving condition (Chi-square = 8.0 “NA”, 4.1 “HSCS”, 4.3 “ASCS”, 6.2 “ACS”, df = 3, $p < 0.01$). In Scenario #1, the number of collisions was low even for the unsupported group, the main reason for which may be attributed to the drivers’ ability to see the AV’s front end through the front side-view window; this means some drivers in the supported groups did not make use of the system when they encountered such a scenario. In Scenario #2, drivers’ ability to see the AV’s rear end through the side mirror depended on their driving skills. Thus, the number of collisions was slightly greater than those in Scenario #1, although all assistance systems were effective at avoiding collisions in Scenario #2. When the AV was located in the BS (Scenario #3) with no way to be seen, the number of collisions significantly increased exclusively for the NA and HSCS groups. In Scenario #4, although the drivers were able to see the fast-approaching car through the side mirror, they were more likely to misjudge its speed. The fast-approaching vehicle in Scenario #4 was especially surprising to the drivers because the AV’s speed was approximately 80 km/h in all lane-change scenarios during the training and testing trials. This condition emphasizes the importance of training for an effective interaction between humans and automation. Finally, the ASCS system was able to avoid all collisions in Scenario #4.

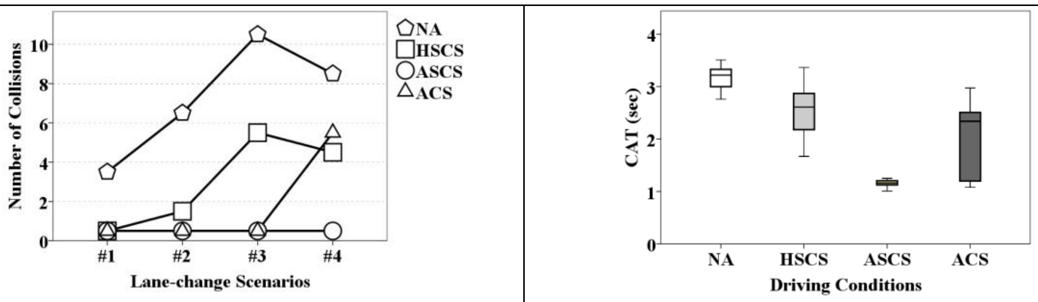
2) Collision Avoidance Time (CAT): CAT refers to the time the driver needs to avoid a side-impact collision caused during hazardous lane-change maneuvers with or without automation assistance. In this study, each hazardous lane-change maneuver comprised three sequential stages (see Fig. 5). The first stage begins when the driver inputs a steering angle to avoid a slow LV ahead by maneuvering toward the cruising lane when a vehicle is driving in the critical adjacent lane area. The second stage begins when the driver recognizes the hazard and turns the steering wheel toward the initial lane to avoid colliding with the AV with or without automation assistance. The third stage begins when the driver reaches the host lane. Thus, the avoidance maneuver begins when the driver turns the steering wheel to the opposite side of the AV and ends when the HV completely returns to the initial lane and starts driving straight and forward once again. The CAT value was calculated as the total time required by the HV’s driver to complete Stages II and III (see Fig. 5).

In this experiment, drivers received no feedback when a collision occurred, mainly to avoid any negative psychological effect that may have been caused by the accident and may or may not have affected their performance during their subsequent driving trials. The drivers were asked to continue driving until the end of each scenario. Therefore, it was possible to calculate the CAT in most hazardous lane-change maneuvers under all driving conditions. Fig. 6 illustrates the CAT’s mean and standard deviation during a lane change for each driving condition. A one-way analysis of variance (ANOVA) revealed a significant driving condition effect (F (3, 117) = 107.2, $p < 0.01$), and the minimum CAT was recorded under the ASCS (M = 1.16, SD = 0.05, 95% CI = 0.14, 0.17). All collision avoidance maneuvers under the ASCS were automatically performed by the system, although multiple comparisons revealed that the CAT means for other supported groups (HSCS: M = 2.55, SD = 0.40, 95% CI = 2.40, 2.70; ACS: M = 2.07, SD = 0.63, 95% CI = 1.85, 2.29) were also significantly different ($p < 0.01$) than the CAT mean for the unsupported group (M = 3.15, SD = 0.25, 95% CI = 3.00, 3.30). Although no significant difference was identified between the HSCS and ACS, the collision avoidance time under the adaptive system was slightly lower than that of the haptic system. To more thoroughly explain these results, one should analyze and understand drivers’ steering behavior.

3) Maximum Steering Wheel Angle (MSWA): The drivers’ maximum steering input was determined to evaluate the impact of automation assistance on their steering behavior during a hazardous lane change. Fig. 8 compares the MSWA’s mean and standard deviation between lane-change scenarios for each driving condition. A two-way repeated measures ANOVA revealed a significant difference between groups (F (3, 156) = 9.11, $p < 0.01$) and a significant effect of lane-change scenarios (F (3, 36) = 12.74, $p < 0.01$). The smallest MSWA value was observed under the haptic system. This finding broadly supports the work of other studies in this area by emphasizing the significance of using haptic feedback to guide a vehicle’s lateral maneuver during time-critical situations [3, 14, 22]. The largest MSWA value was observed under the automatic system; however, comparing this result with the collisions data (Fig. 3) indicates that drivers’ steering behavior affects safety only when they are in charge of the steering wheel.

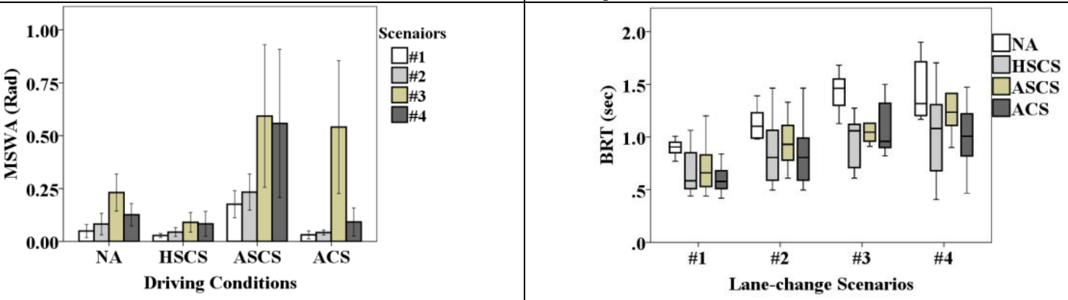
On one hand, the automatic system’s strict form may not be compatible with the human-centered design concept because the system possesses final authority over the lateral vehicle motion control; on the other hand, each driver was in charge of the longitudinal vehicle motion control. Thus, the vehicle was cooperatively controlled by both the driver and the system during the automatic system’s operation. Although the drivers were engaged in and able to observe the automatic system’s automated process, they could not fully understand why the automated function resulted in unstable steering movements. Drivers’ understanding of the automatic system’s automated steering function did not improve even when used in the adaptive system as the MSWA was significantly increased in Scenario #3. In this scenario, the drivers were unable to perceive the hazard in their BS until they needed to concur with the automatic action and reduce the vehicle’s speed.

4) Braking Reaction Time (BRT): In this experiment, slower LVs were placed in the drivers’ pathway to urge them to change lanes several times during each trial. When the drivers needed to avoid critical lane changes by returning to their initial lane, a braking maneuver was necessary to avoid rear-end collisions with the slower vehicles ahead. The BRT was determined as the elapsed time from the driver initiating a steering input to avoid a slow LV to the driver’s first braking input to avoid a lane-change collision. Fig. 9 shows the drivers’ BRTs during each lane-change scenario for both driving modes. A significant main effect of the driving condition was identified (F (3, 36) = 14.94, $p < 0.01$) in that the haptic (M = 0.88, SD = 0.32) and adaptive (M = 0.88, SD = 0.30) control groups had significantly lower reaction times than those of the unsupported (M = 1.22, *SD* = 0.28) and automatic control (M = 1.03, SD = 0.34) groups. The main lane-change scenario effect was also significant (F (3, 160) = 26.83, $p < 0.01$) in that the lowest reaction time among all groups was recorded during Scenario #1 and the largest reaction time among all groups was recorded during Scenario #4. However, the interaction effect was significant (F (9, 144) = 9.03, $p < 0.05$), thus indicating that the haptic control’s effect on lowering the reaction time was significantly greater for the adaptive system than that of the automatic system. Multiple comparisons with Tukey HSD and Bonferroni revealed that the BRTs were significantly more reduced for all types of assistance systems than the unsupported driving condition (M = 0.33), although there were no significant differences between systems. In addition, the comparisons revealed that the BRTs were remarkably different between lane-change scenarios under each driving condition ($p < 0.01$), except between Scenarios #3 and #4. The most striking observation to emerge from the data comparison was the notable difference between driving conditions in Scenario #3, which may support the idea of using haptic control to address some pitfalls associated with the use of autonomous control, such as a driver's feeling of his/her loss of control.



a-Number of collisions for each driving condition and lane-change scenario

b-Mean and standard deviation of the time required to avoid side-impact collisions for each condition



c-Mean and standard deviation of the MSWA for each driving condition and lane-change scenario

d-Drivers' BRTs for each driving condition and lane-change scenario

Fig. 7. Objective evaluations

5) Subjective Evaluation: Drivers' feelings of trust in and acceptance of the simulation's automation system, the level of the system's control over the steering wheel, and the level of safety experienced during system activation were subjectively evaluated. Fig. 8 presents the subjective rating results for each driving group specific to each item included in the questionnaire. The Wilcoxon Rank Sum Test revealed significant differences between driving modes for all questionnaire items (trust: $Z = -4.6$, $p < 0.05$; acceptance: $Z = -3.7$, $p < 0.05$; control: $Z = -6.9$, $p < 0.01$; safety: $Z = -5.1$, $p < 0.01$). The lane-change scenario type combined with the driving condition type influenced drivers' responses to all questionnaire items. it is apparent that drivers' ratings are more balanced among questionnaire items under the adaptive control function compared to the clearly fluctuating trend in their ratings under the haptic and automatic driving conditions. Drivers' ratings of trust and acceptance under the adaptive system are higher compared to the other driving conditions. Therefore, it seems that the drivers generally compared their understanding of the encountered situation with the automated function type to independently rate their feelings.

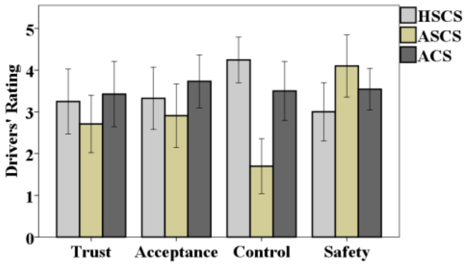


Fig. 8. Subjective comparison between systems in terms of trust in and acceptance of automation and control as well as feelings of safety.

4. Study III: Long-term Drivers Interaction with Adaptive Automation: Behavioral Adaptation to Automated Steering for Avoiding Collisions during Lane Change

While the focus of study II was to enhance system capabilities and design an effective and usable adaptive collision avoidance system (i.e., ACS) with a dynamic functional allocation, the aim of study III was to improve the way the drivers interact with and adapt to the adaptive system using training-interaction approach. The present study attempts to address the research question by supporting the drivers' mental model formation and human-automation interaction using driver education with owner's manual and simulator training. One goal for the present study was to test the claim, consistent with previous findings [14, 22, 23], that because of the drivers' understanding of the adaptive automated functions, the system's effectiveness would be less when the drivers encountered critical events while supported by the system with poor understanding of system functionalities than when those events occurred while the drivers are trained to interact appropriately with the system. It was also anticipated that driver education's effects associated with driver performance improvement would be most noticeable in how drivers assess, trust, and accept the system. A second goal for the present study was to compare the effects of long-term interaction with adaptive automation on driver adaptation to the multiple automated functions during critical situations.

4.1. Method

4.1.1. Participants and Apparatus

Forty two participants (12 females and 30 males) have been recruited to take place in the driving experiment (Mean age 33.2 ± 13.9 years) that was conducted using Honda Driving Simulator (see Fig. 1 above).

4.1.2. Experiment Protocol

In total, every participant had to perform twenty eight training and testing drives that were distributed in randomized order over four days of the experiment. The sequence of experiencing scenarios was balanced among the participants with Latin square method to reduce learning and carryon effects. For each participant, the experiment was conducted once a week for one month as follows:

Day-1) the experiment lasted two hours during which the participants received oral and written explanations about the experiment design, their ethical rights, tasks, and instructions. The actual driving started with three familiarization drives on how to use the driving simulator using nonhazardous highway scenarios such that the participants could earn an adequate skill to drive and control the simulator smoothly. During data collection phase, there were four highway drives comprised nonhazardous and hazardous overtaking manoeuvres. The participants encountered the hazardous scenarios without automation support (baseline).

Day-2) the participants were asked to read written information (two pages of printed A4 paper consists of approximately 500 words count) comprised generic manual of the system operation and properties. In order to avoid automation surprises, the information covered the critical events for which the adaptive collision avoidance system is triggered with graphics. After reading the generic manual, the participants were given opportunities for practice driving with the system and then they had to perform four testing drives. This experimental day lasted one hour in average for each participant.

Day-3) the experiment, lasted one hour, started with owner's manual based driver education prior to testing drives. The owner's manual was designed as PowerPoint slides with less textual and more graphical and auditory elements to provide drivers with necessary knowledge and skills about the operating components. The driver education lasted 30 min per participant focusing on improving drivers' understanding of the system functionalities and limitations. After the education phase,, the participants had to perform four testing drives.

Day-4) the experiment (1 h/participant) started with practical training based driver education prior to testing drives. The training lasted for 30 min and included comprehensive familiarization drives with additional descriptions by the experimenters. The objective was to improve drivers' understanding of and interaction with the system focussing on steering wheel behaviour during the activation and deactivation of the system and overall performance. After the training, the participants had to perform four testing drives.

4.2. Results and Discussions

The first set of analyses examined the effectiveness of driver education for improving the system effectiveness in terms of safety. The system effectiveness was measured in terms of number of crashes and near crashes during hazardous overtaking manoeuvres. The total number of potentially hazardous overtaking manoeuvres was 168 per day for all participants (42 participants x 4 hazardous manoeuvres/day = 168). This makes the total number of accidents during the entire experiment equal to 672 possible accidents. The number of crashes and near crashes was calculated depending on the time to collision (TTC) between the host vehicle and vehicle in the adjacent lane area. Accordingly, the crash rate (CR) and near-crash rate (NCR) are calculated as in (1) and (2). The collision reduction effectiveness (CRE) and collision avoidance effectiveness (CAE) are derived from CR and NCR as in (3) and (4) respectively. CRE is measured to evaluate to what extent the system's support was effective in reducing number of collisions. CAE is measured to evaluate to what extent the system support has improved safety. The variables $CR_{supported}$ and $CR_{unsupported}$, and $NCR_{supported}$ and $NCR_{unsupported}$ in the equations are the crash rate and near crash rate for supported and unsupported driving modes, respectively.

$$CR = (TTCs < 1\text{ s}) / (\text{Total TTCs}) \quad (1) \qquad NCR = (1\text{ s} < TTCs < 2\text{ s}) / (TTCs > 1\text{ s}) \quad (2)$$

$$CRE = 1 - CR_{supported} / CR_{unsupported} \quad (3) \qquad CAE = 1 - NCR_{supported} / NCR_{unsupported} \quad (4)$$

Fig. 9 presents CR, NCR, CRE, and CAE for each day of the experiment. CR indicates that the system was significantly effective in reducing collisions compared to unsupported driving (Chi square = 133.5, df = 3, $p < 0.01$). Consistently, NCR of the supported driving was significantly less that of the unsupported driving (Chi square = 121.2, df = 3, $p < 0.01$). These results are consistent with the collision data obtained in previous studies (Itoh and Inagaki 2014, Muslim and Itoh 2018^{b}, Cramer and Zadeh 2011). The further reduction of collisions in Day-3 and Day-4 can, therefore, be attributed to the driver education effectiveness. This highlights the strong positive correlation between drivers' ability to perceive the risk and interact with the system and system effectiveness ($r = 0.41$, $p < 0.01$). What stands out is the significant difference between CR and NCR yielding a significant difference between CRE and CAE (Chi square = 109.6, df = 1, $p < 0.01$). The CRE percentage is higher than CAE for all supported days of participation. These differences indicate that reducing number of collisions is not enough to improve the overall safety. This is because CRE value is more related to the design of the system, such as reliability, robustness, and automatic action authority, while CAE is more related to human-automation cooperation. However, the differences between experimental days show that both measures are significantly affected by driver adaptation to the automation assistance. On the one hand, improving CRE from 67% to 100% reveals that the further improvement is imposed by the training interaction and not by the design of the system as the system is already assumed 100% reliable during the experiment. On the other hand, even though the training was efficient at improving the percentage of CAE from 56% to 85%, the percentage did not reach 100%, thus indicating that in adaptive automation where the human and system integrate to handle a situation, the overall safety and performance may not reach 100% due to factors related to human limitations and context demands variability.

Fig. 10 presents the mean and standard deviation of the maximum steering wheel angle for each experimental day. For Day-2, the maximum steering wheel angle was used to evaluate drivers understanding of the automation assistance, compared to the baseline (Day-1). For Day-3 and Day-4, the steering angle was used to assess the effectiveness of driver education in reducing the conflict between drivers' intention and automation intervention compared to Day-2. A one-way ANOVA showed a significant effect of the experimental days (F(3, 164) = 7.79, P < 0.01). The maximum steering angle recorded during Day-2 was notably larger than that of Days-1, Day-3, and Day-4. A possible explanation for this would be that the drivers could not form an appropriate mental model of the system when they first experienced the system in day #2. Therefore, the steering wheel control of the drivers was not smooth during the activation and deactivation of the system. The driver education in Day-3 and Day-4 was effective in reducing the steering wheel angle, which indicates an improvement in drivers' understanding of the system. However, these results should be interpreted with care. In this experiment, the participants were unable to see or feel accidents when occurred. Thus, the participants proceeded with the driving trials even when they were involved in accidents. This was mainly to avoid negative influence of the accidents on participants' behaviour during the subsequent drives. For this reason, the maximum steering wheel angle of Day-1 in which CR was high, was less than that of Day-2.

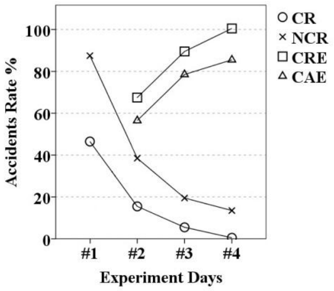


Fig. 9. Accidents rate for each day of the experiment

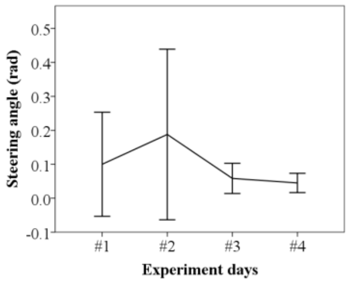


Fig. 10. Mean maximum steering wheel angle

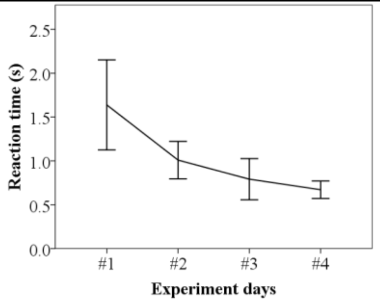


Fig. 11. Mean braking reaction time

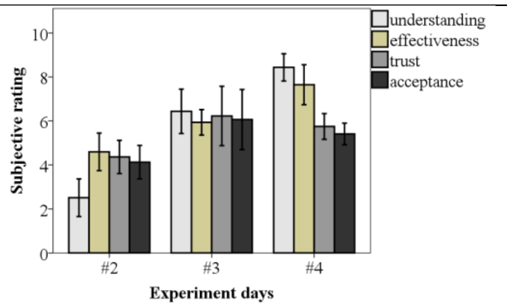


Fig. 12. Subjective ratings by the drivers

In this experiment, all overtaking manoeuvres were in response to a slower vehicle ahead. For the hazardous overtaking manoeuvre, If the manoeuvre is aborted, by the host driver and/or the system, to avoid colliding with a vehicle in the adjacent lane, the host driver had to reduce the vehicle speed by applying brake to avoid rear-end collisions with the slower vehicles ahead after returning to the initial lane. Fig. 11 compares means and standard deviations of the braking reaction time among the four days of the experiment. A one-way ANOVA revealed a significant difference between experimental days (F(3, 167) = 83.22, p < 0.01). This indicates a significant improvement in driver performance along with progress in driver experience of the system. A strong negative correlation was found between the braking reaction time and driver experience of the system (r = −0.51, p < 0.01).

The final part of the results section reports drivers' experience of the system using a four-questionnaire items as shown in Fig. 12. Repeated-measures ANOVAs were run on mental model formation, effectiveness, trust, and acceptance scores. Bonferroni post hoc tests were used to compare questionnaire individually between days. The analysis revealed a significant main effect of experimental days (F(2, 40) = 714.10, p <0.01) and a significant interaction between questionnaires and experimental days (F(6, 36) = 103.50, p < 0.01). Between questionnaires, the differences were also significant (F(3, 39) = 27.57, p < 0.01). The mental model formation and effectiveness scores were significantly increased as drivers' experience of the system increased among experimental days (p < 0.01). Compared to collision data in Fig. 5, drivers' rating of the system effectiveness is in line with the actual system effectiveness. The subjective scores for drivers' trust in and acceptance of the system were first increased in Day-3 compared to Day-2 (p < 0.01), and then decreased in Day-4 compared to Day-3 (p < 0.01). A possible explanation for this unanticipated fluctuation can be related to drivers' understanding of the system (mental mode formation). In Day-2, the rating of drivers' understanding of the system was low and it was difficult for them to form their model of the system. Therefore, the trust and acceptance ratings were below the average. As the level of drivers' understanding of the system increased in Day-3, the drivers tend to put a higher trust in the system and their level of acceptance increased accordingly. However, the standard deviation of trust and acceptance were diverging in Day-3 compared to Day-2. When the level of drivers' understanding significantly increased in Day-4, the drivers rated their feeling of trust and acceptance lower than that of Day-3 but higher than that of Day-2. The convergence of the standard deviation in drivers' rating of trust and acceptance in Day-4 can be used to conclude that the drivers were able to develop a more appropriate level of trust and acceptance in Day-4 compared to Day-2 in which the drivers could not understand the system and Day-3 in which driver's mental model of the system was still not complete. These are rather significant results and can be used to confirm the association between humans' understanding of automation and their level of trust in automation.

5. Conclusions

This study was designed to determine the effect of adaptive automation compared to conventional automated support on driver performance in safety critical situations. The study conducted three driving experiments to investigate how drivers trust and accept different categories of automated interventions for avoiding collisions during lane change. The study has also investigated how drivers supported by collision avoidance systems perform when exposed to various critical events. The results demonstrated that the support of drivers depending on the situation was effective compared to unsupported driving. Although the maximum accident reduction was achieved when using the automatic system, the adaptive system was able to achieve a better balance between safety and the drivers' ability to perceive and avoid risky situations. The adaptive system provided automatic assistance only when it was difficult for the driver to perceive the risk. The resulting driver response times and risk avoidance times suggested that human–machine interaction was improved when using the adaptive system. The use of haptic feedback under the adaptive system improved the drivers' adaptation to the automated assistance compared to the conventional automated system. The level of driver trust and acceptance was significantly improved and was more stable under the adaptive system. It can, therefore, be concluded that the effect of automated assistance on driver performance in dynamic control tasks is dependent on the driver's ability to perceive and avoid risks without automated support.

Study I indicated that overestimating the capabilities of the support system significantly degraded drivers' performance and the overall safety. Study II showed that the adaptive collision avoidance system which dynamically adjusted the capabilities of the system was able to address some of these limitations. Results also indicate that when expectations and system capabilities are aligned, drivers trust the system more appropriately and safety is improved. Study III showed that by training drivers how to interact with the systems further improved driver performance and safety. While designing systems that take into the account human skills and abilities can go some way to improving their effectiveness, this alone is not sufficient. To maximize system safety and usability, it is also important to ensure that users understand its capabilities and limitations. For this, educating users how to operate the system is essential.

References

[1] World Health Organization. (2015). *World Report on Ageing and Health*. World Health Organization: Geneva.

[2] National Highway Traffic Safety Administration (NHTSA). (2008). National motor vehicle crash causation survey: Report to congress. *National Highway Traffic Safety Administration Technical Report DOT HS*, *811*, p. 059.

[3] Itoh, M. and Inagaki, T. (2014). Design and evaluation of steering protection for avoiding collisions during a lane change. *Ergonomics*, *57*(3), pp. 361–373.

[4] Seppelt, B.D. and Lee, J.D. (2007). Making adaptive cruise control (ACC) limits visible. *International Journal of Human–Computer Studies*, *65*(3), pp. 192–205.

[5] Wada, T., Sonoda, K., and Tada, S. (2016). Simultaneous Achievement of Supporting Human Drivers and Improving Driving Skills by Shared and Cooperative Control. *IFAC-PapersOnLine*, *49*(19), pp. 90–95.

[6] Cicchino, J.B. (2017). Effectiveness of forward collision warning and autonomous emergency braking systems in reducing front-to-rear crash rates. *Accident Analysis & Prevention*, *99*, pp. 142–152.

[7] Millot, P. and Pacaux-Lemoine, M.P. (2013). A Common Work Space for a Mutual Enrichment of Human-Machine Cooperation and Team-Situation Awareness. In *IFAC Symposium: Analysis Design and Evaluation of Human Machine Systems*, Las Vegas, pp. 387–394.

[8] Hoc, J.M. (2000). From human–machine interaction to human–machine cooperation. *Ergonomics*, *43*(7), pp. 833–843.

[9] Parasuraman, R. and Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, *39*(2), pp. 230–253.

[10] Vorad, E.A.T.O.N. (2001). The Benefit of Collision Warning Systems for Commercial Vehicles. In *Presentation at ITS America 2001 Annual Meeting*, Miami.

[11] Abe, G. and Richardson, J. (2006). Alarm timing, trust and driver expectation for forward collision warning systems. *Applied Ergonomics*, *37*(5), pp. 577–586.

[12] Hesse, T., Schieben, A., Heesen, M., Dziennus, M., Griesche, S., and Köster, F. (2013). Interaction design for automation initiated steering manoeuvres for collision avoidance. In *6. Tagung Fahrerassistenzsysteme*.

[13] Schneider, N., Purucker, C., and Neukum, A. (2015). Comparison of steering interventions in time-critical scenarios. *Procedia Manufacturing*, *3*, pp. 3107–3114.

[14] Muslim, H., & Itoh, M. (2017). Human Factor Issues Associated with Lane Change Collision Avoidance Systems: Effects of Authority, Control, and Ability on Drivers' Performance and Situation Awareness. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 61(1), 1634-1638.

[15] Inagaki, T. (2003). Adaptive automation: Sharing and trading of control. In Eric Hollnagel (ed.), *Handbook of cognitive task design*, pp. 171–194. CRC Press: Boca Raton.

[16] Kaber, D.B. and Endsley, M.R. (2004). The effects of level of automation and adaptive automation on human performance, situation awareness and workload in a dynamic control task. *Theoretical Issues in Ergonomics Science*, *5*(2), pp. 113–153.

[17] Muslim, H. and Itoh, M. (2018). Steering Behavior with Different Levels of Automation Interventions for Avoiding Collisions During Lane Change. *IEEE International Conference on Systems, Man, and Cybernetics*, Miyazaki, pp. 2707–2712. DOI: 10.1109/SMC.2018.00463.

[18] Salvucci, D. D., & Liu, A. (2002). The time course of a lane change: Driver control and eye-movement behavior. *Transportation research part F: traffic psychology and behaviour*, *5*(2), 123-132.

[19] Fitch, G. M., Lee, S. E., Klauer, S., Hankey, J., Sudweeks, J., & Dingus, T. (2009). Analysis of lane-change crashes and near-crashes. *US Department of Transportation, National Highway Traffic Safety Administration*.

[20] Sheridan, T. B., & Parasuraman, R. (2006). Human–automation interaction. Reviews of Human Factors and Ergonomics, 1, 89-129.

[21] Muslim, H., & Itoh, M. (2018). A theoretical framework for designing human-centered automotive automation systems. *Cognition, Technology & Work*, 1-13.

[22] Muslim, H., & Itoh, M. (2018). Effects of Human Understanding of Automation Abilities on Driver Performance and Acceptance of Lane Change Collision Avoidance Systems. *IEEE Transactions on Intelligent Transportation Systems*, 99, 1-11.

[23] Muslim, H., & Itoh, M. (2017). Haptic shared guidance and automatic cooperative control assistance system: Performance evaluation for collision avoidance during hazardous lane changes. *SICE Journal of Control, Measurement, and System Integration*, *10*(5), 460-467.