Interaction design for automation initiated steering manoeuvres for collision avoidance

Interaktionsdesign für ein automatisches Ausweichmanöver zur Kollisionsvermeidung

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This paper provides a summary of three experimental studies conducted at DLR research facilities (two simulator studies and a test track study) testing different interaction designs for an automation initiated steering manoeuvre in emergency situations. The results of all three studies are discussed in the light of current technical developments allowing for automated steering interventions on the one hand and human factors issues such as controllability of false activations and overridability of interventions by the driver on the other hand. The results show both the safety potential and the still existing controllability issues of partially decoupling the driver.

Keywords—emergency; active steering; steer-by-wire

I. Introduction

Technological progress has enabled an ever increasing number of advanced driver assistance systems and will lead to higher modes of automation where significant parts of the driving task can be delegated to the vehicle [1], [2]. Of specific interest is the automation in emergency situations where the driver often lacks the necessary quickness and experience to successfully resolve the situation. The basic options in the most typical emergency situation, a daunting rear-end collision, are braking, steering or a combination thereof. While supported or automatic braking for collision avoidance or mitigation is already available in several vehicles on the market, automatic steering is still under investigation and only few results exist [3],[4],[5].

Within the EU project interactIVe, support in emergency situations is addressed and integrated into the assistance and automation systems for "normal" driving. Therein, the design of the appropriate human-machine interaction plays a pivotal role and is approached in an iterative, user-centered process [6]. In order to gain further insight in systems with automatic steering interventions in emergency situations, a series of three studies in simulators and a test vehicle (Figures 1, 2) was performed at DLR within interactIVe. The studies investigated automation-initiated steering activities in different emergency situations; a summary of the results is presented in this paper.

All three studies were based on the observation gained from other studies in the interactIVe project that drivers tend to oversteer the automatic steering intervention, [7]. Therefore, the research task centered on finding an interaction design that minimizes the drivers' tendency to steer against the intervention while allowing the driver to control the automatic intervention in case of a false activation (controllability test).

The first study explored a design using torque overlay with a conventional steering configuration, while the second and third study investigated the options available by steer-by-wire systems.

Figure 1. Test vehicle FASCar

Figure 2. Dynamic Driving Simulator

II. Study 1: Effect of Warnings Before Automatic Steering Intervention

The first study was run in the DLR driving simulator, see Figure 2. The goal was to test three different interaction designs for an automatic steering intervention in critical traffic situations against a baseline. The main research question was to find an interaction design that helps to make the automation intervention more effective by avoiding the tendency of the driver to counter steer. Moreover, this design should support the driver to control the situation in case of false automatic intervention.

Method

Participants and experimental design: 40 participants took part in a driving simulator study and were distributed to one of four groups. Each group experienced a critical rear-end collision situation. The 30 drivers of the three automation groups were supported in this situation by an automatic steering intervention, each group experiencing a different interaction design: a) *pure automatic intervention*, b) *automatic intervention and directional haptic pre warning*, c) *automatic intervention and non-directional acoustic pre warning*. Ten participants experienced the emergency situation without any intervention (baseline). Additionally, the three automation groups experienced an automatic steering intervention in a false alarm situation to test for controllability.

Scenarios: Two scenarios were tested, one with a critical collision situation and one with a false alarm. Both scenarios used a two-lane rural road with one lane per direction with curvy and straight road sections. The drivers were instructed to drive as precisely as possible at 100 km/h and in the center of the lane. They were asked to count backward loudly from time to time during the drive. Drivers were not informed about the actual goal of the study but were told that the study explores driving under distraction.

In the first drive, a critical event occurred on a straight road section and the driver was not involved in any distraction task. In the critical event a vehicle suddenly popped up in front of the ego-car at a Time To Collision (TTC) of 2.1 seconds (**Fehler! Verweisquelle konnte nicht gefunden werden.**3). To standardize the event as much as possible for all drivers, the event was triggered as soon as the ego-vehicle crossed a specific road section and drove 100km/h +/- 2.5 km/h and was centered in the lane. To test the steering intervention in a standardized way, the scenario was designed such that a collision could no longer be avoided by braking but only by steering.

In the second drive the steering intervention was activated without any reason. To standardize this false alarm intervention for all drivers as much as possible it was triggered as soon as the ego-vehicle crossed a specific road section and drove 100km/h +/- 2.5 km/h and was centered in the lane. The false alarm of the steering intervention was triggered on a straight road section and there was on-coming traffic on the left lane to make the false steering intervention more critical.

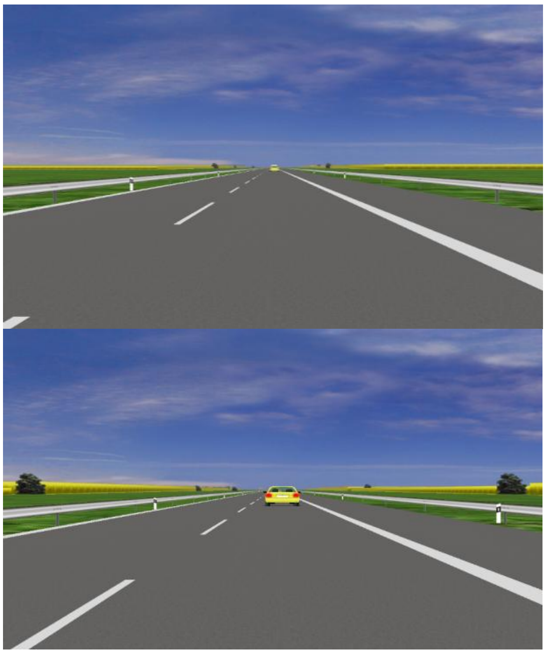

Figure 3. Driving scenario of the first test drive during uncritical driving situation (top) and in the critical situation (bottom)

support the transition of control towards the automation most successfully because the warning would give the driver a directed hint in which direction he has to steer. In addition, the controllability in a false alarm situation should be improved by the directional warning by letting the driver know about the direction of the steering intervention so that he could prepare to countersteer.

Interaction design: The intervention was an automatic steering intervention that was designed in a way that it avoided the potential rear-end collision completely by steering to the left hand lane by means of a torque overlay at the steering wheel. Other studies of the project InteractIVe showed that driver interventions such as countersteering or holding the steering wheel strongly could reduce the effectiveness of the automatic intervention. Therefore, here a higher level of torque with a maximum of 9.9 Nm was applied to the steering wheel.

Two kinds of advance warning signals were tested. One was a so-called double tic, a haptic interaction element that consisted of two tics to the left. The gap between the two tics was set to 0.1 seconds. The duration of each tic was 0.2 seconds with a linear increasing force of maximum 2.5 Nm. The other was a beep sound presented for 0.3 seconds. Both warnings started at a TTC of 2.1 seconds. This was exactly at the same time that an obstacle popped up in front of the ego vehicle. The automatic steering intervention was triggered shortly afterwards at a TTC of 1.4 seconds to the vehicle in front.

Results

The results for the drive with the critical intervention show that 3 up to 5 collisions could be avoided by the automatic steering intervention, see Table 1. Compared to that, all 10 participants collided in the baseline condition. Fisher's exact tests showed a significant difference between baseline and automatic intervention with haptic warning ($p < .05^*$) and the conditions *baseline* and *automatic intervention with acoustic warning* ($p < .05^*$). However, the results show that the intervention was not successful for all drivers. Some drivers countersteered or held the steering wheel strongly such that the automatic intervention was not successful. This driver behavior is also reflected in the lateral deviation measured at the position of the obstacle. A minimum lateral offset of 1.85 meters would have been needed to avoid the obstacle successfully. In the baseline condition that drivers only steered very little but also in the intervention conditions the average lateral deviation was smaller than the needed 1.85 meters. A Kruskal-Wallis test showed significant effects of condition ($H_{(3)} = 21.46$, $p = .01^{**}$). Bonferroni Post-hoc tests revealed that there was a significant difference between the baseline condition and all other conditions but not between the three intervention conditions.

Table 1: Study 1 - Frequency of collision and lateral deviation in the collision situation

Variant	no collision	collision	lat. dev. in m mean (SD)
No intervention (Baseline)	0	10	0.19 (0.15)
Pure automatic intervention	3	7	1.52 (0.85)
Automatic intervention + directional haptic warning	5	5	1.83 (1.21)
Automatic intervention + non-directional acoustic warning	4	6	1.52 (0.58)

Table 2 shows the results for controllability measured by the number of drives with a lane departure after the false alarm. Lane departure was defined as a lateral deviation of more than 0.85 meters to the left. Only results for the three intervention conditions are reported as this situation was not tested for the baseline condition. In total, 20 participants departed from the lane to the left. Six of ten drivers recovered in the haptic warning condition whereas three resp. one recovered in the pure intervention or acoustic warning condition. Fisher exact tests showed a significant interaction between the conditions *Automatic intervention + directional haptic warning* and *Automatic intervention + non-directional acoustic warning* ($p <.05^*$). No further differences were found. The maximum lateral deviation was smallest for the directional haptic warning. A Kruskal-Wallis test showed a tendency of significance at the significance level of 0.1 ($H_{(3)} = 5.076$, $p =.08$). Bonferroni Post-hoc tests revealed that the difference was between the haptic and acoustic warning condition. Both results indicate that haptic warnings had a more positive effect on the controllability than the acoustic warning.

Table 2: Study 1 - Frequency of controlled false alarms and lateral deviation in the controllability situation (LD=lateral deviation)

Variant	Recovered LD<0.85m	Not recov. LD>0.85m	Max. LD mean (SD)
Pure automatic intervention	3	7	1.20 (0.53)
Automatic intervention + directional haptic warning	6	4	0.84 (0.49)
Automatic intervention +non-directional acoustic warning	1	9	1.36 (0.51)

Conclusion

The automatic steering interventions decreased the number of collisions significantly compared to no intervention. Three up to five collisions out of ten were avoided. However, drivers had a tendency to countersteer or to hold the steering wheel strongly so that the intervention was not as successful as it could have been. This is why the next studies reported in Sections III, IV were set up to test an interaction design that uses a steer-by-wire system to improve the effectiveness of the intervention. For the false alarm situation, haptic warnings seem to be most promising compared to acoustic warnings and are further elaborated.

III. Study 2: steer-by-wire designs for automatic steering intervention in test vehicle

The second study was run on a test track in the research vehicle FASCar II, a vehicle which is equipped with a steer-by-wire system. This study examined if temporarily decoupling the driver from steering leads to a more effective collision avoidance while still enabling controllability in an unjustified activation of the manoeuvre.

The main motivation for this study was to create an effective way to avoid rear-end collisions by an automated steering intervention. Related to the first simulator study, we suspect that driver could unwillingly become a disturbing variable within an evade maneuver. Literature shows that the driver influences the effectiveness of haptic collision avoidance systems by counteracting the system intervention [7], **Fehler! Verweisquelle konnte nicht gefunden werden.**. A new approach, the driver decoupling, was tested. The decoupling strategy ignores the steering inputs of the driver for a certain period of time and ensures that the driver could not unwillingly influence the system intervention.

Method

Participants and experimental design: A total of 47 participants attended the present experiment. Due to technical problems two participants were excluded. The remaining 45 participants (27 male and 18 female) had an average age of 30.4 years (*SD* = 9.9). Each condition had a balanced group-design (9 male, 6 female) and consisted of 15 participants. Three different system interventions were examined in a between-subject design. The Participants were instructed to drive through a marked circuit at the "Heinrich der Löwe" casern in Brunswick, Germany. The test track consists of different driving task as a slalom course, driving with speed control or a turning area. These elements were primary chosen to distract the driver from the real intention of the study. The test track was identically for all experimental groups. Due to a cover story, participants were made believe that they should test a drive-by-wire steering system instead of a collision avoidance system.

The present study used the FASCar II, a special experimental car form the German Aerospace center (DLR) to realize the different system interventions. The FASCar II is based on a VW Passat and is instrumented with a wide variety of sensors. Furthermore the FASCar II is equipped with a steer-by-wire system which was necessary for the condition Driver Decoupled. The dynamic evade maneuver was realized by a virtual obstacle on a predefined digital map. The FASCar II computed collision avoidance trajectories based on the vehicle state and the environment representation. Since both were standardized by the experimental setting and the usage of a digital map the same avoidance trajectory resulted for every participant.

Scenarios: The three different system interventions were tested in a collision avoidance scenario. In this scenario the decoupling strategy was compared to the *Driver always Coupled* and the *Manual Driving* condition. The evade scenario consists of an approximately 500 meter straight lane marked by traffic cones. The lane had a roadway with of 3.20 meters and was part of the round course. The activation of the speed control marks the start of the evade scenario. The speed control accelerated the vehicle to a constant speed of 50 km/h. The speed control was used to create a generalized and comparable situation. Thereby each subject had the same criticality and time left for reaction. A light barrier triggered the obstacle which appeared within 0.8 seconds and covers half of the lane. The collision scenario has the characteristic that collision avoidance by braking only was not possible for the driver. The evasive manoeuvre was the only option to successfully avoid a collision. At a TTC of 1.6 seconds the system intervention started.

The second scenario represented an unjustified system intervention (false alarm) and was tested in condition *Driver always Coupled* and *Driver Decoupled*. Comparable to the collision avoidance scenario, the velocity of the vehicle was held constant by a cruise control. In the false alarm scenario the cruise control was set to 30 km/h. The speed had to be limited due to safety reasons. Even if there was no obstacle visible in the vehicle's lane, the system reacted with an automatic steering intervention. The test situation consisted of a narrow lane marked by traffic cones. The lane was 3.20 meters wide. After 70 meters there was a 30 meter gap in the row of traffic cones on the left side of the lane. At this point the automation showed the faulty behavior in form of an intense steering manoeuvre to the left side as though there had been an obstacle on the lane in front of the vehicle.

Interaction design: The condition *Manual Driving* included no steering intervention or other support in the collision situation and functioned as a control group. The system intervention in condition *Driver always Coupled* was characterized by a directed torque on the steering wheel. At a TTC of 1.6 seconds the automation tried to start a dynamic evade maneuver to avoid the daunting collision. The driver remained in full control of the vehicle and was able to follow the planed evade maneuver or override (counter steering / hold steering wheel strongly) and stop it. The condition *Driver decoupled* consisted of a similar system intervention except for one important feature: The driver was decoupled from steering (due to steer-by-wire) for 0.5 seconds. During this time the driver had no influence of the vehicle guidance and even counter steering was disregarded by the system. After these 0.5 seconds the driver had the chance to recouple himself to steering through counter steering for 0.3 seconds. Even if the driver did not counteract, he was fully coupled and back in control of the vehicle after a total of 0.8 seconds after the start of the intervention, Figure 4.

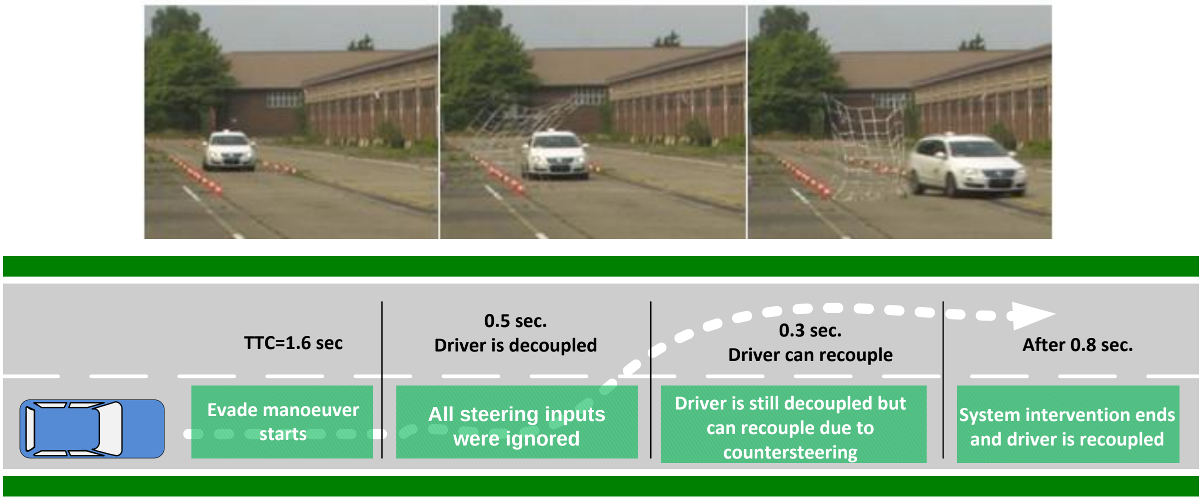

Figure 4. Collision avoidance scenario and interaction design for condition *Driver Decoupled*

Results

Table 3 shows the frequency of collisions and lateral deviation in the collision situation. All participants of the condition *Driver always coupled* and *Manual Drive* crashed into the obstacle. Drivers in these variants tried to avoid the collision due to braking and show no steering action. Fisher's exact test shows that the condition *Driver Decoupled* leads to a significantly improved collision avoidance (p< .001). More than 93 percent of all collisions could be avoided due to the decoupling strategy. The main reason for the efficiency was that the negative influence of the participants (like counter steering or holding the steering wheel) was ignored. The lateral deviation differs significantly between the groups ($F_{(2,41)}$=275.98, p< .001). A Bonferroni Post-hoc test illustrates that the differences are between the condition *Driver decoupled* and *Manual Drive* and between *Driver decoupled* and *Driver always coupled*. The lateral deviation of 1.31m in condition *Driver Coupled* (nearly 3 times as much as *Driver always Coupled*) shows the effectiveness of the driver decoupling strategy.

Table 3: Study 2 - Frequency of collision and lateral deviation in the collision situation

Variant	no collision	collision	lat. dev. in m mean (SD)
Manual drive	0	15	0.36 (0.1)
Driver always coupled	0	15	0.45 (0.08)
Driver decoupled	14	1	1.31 (0.16)

Even though the parameterization of the driver decoupling led to a good performance in the collision avoidance scenario it also resulted in a poor controllability performance in the false alarm scenario. While all participants of condition *Driver always coupled* could control the unjustified system intervention in the false alarm scenario, participants in condition *Driver decoupled* were not able to control the false alarm. All 15 participants of condition *Driver decoupled* reached a higher lateral deviation than 0.85 m. In fact the lateral deviation in condition *Driver decoupled* was 1.82 m which means that they would leave their own lane. A t-test shows that the differences between the conditions are significant (t= -10.16, p< .001).

Table 4: Study 2- Frequency of controlled false alarms and lateral deviation in the controllability situation

Variant	Recovered LD<0.85m	Not recov. LD>0.85m	Max. LD mean (SD)
Driver always coupled	15	0	0.17 (0.04)
Driver decoupled	0	15	1.82 (0.58)

Conclusion

The decoupling of the driver leads to very successful collision avoidance. Due to the decoupling over 93 percent of all collisions could be avoided. The decoupling ignores the negative effects of the driver (counter steering, holding the steering wheel) and supports in time critical collision situations. Nevertheless the decoupling of the driver leads to serious problems. The system intervention seams not controllable for the driver. A false alarm leads to very high lateral deviation which may result in high risks for the driver. Although the driver decoupling strategy seems not to be perfect, we conclude that it still might bear some potential for improving collision avoidance while being controllable at the same time. The third study investigated alternative recoupling strategies to improve the controllability of driver decoupled maneuvers.

IV. Study 3: Alternative recoupling steer-by-wire design for automatic steering intervention

The third study was again a simulator study exploring alternative interaction designs regarding the controllability of the automatic steering interventions in case of false alarms. A decoupling strategy of the driver was developed using an improved algorithm to bring the driver back in control. Furthermore, different advance haptic warnings were tested that were assumed to help the driver in the false alarm situation to regain control more quickly.

Method

Participants and experimental design: 57 participants took part in this study. All participants were assigned to one of four groups. Three variants of an automatic intervention were tested in a between-subject design. These were a) a *pure intervention*, b) an *automatic intervention and directed haptic warning*, c) an *automatic intervention and undirected haptic warning* (each group has 14 participants). The interventions were compared to a condition with no intervention (baseline, 15 participants). Additionally, the three automation groups experienced an automatic steering intervention in a false alarm situation to test for controllability.

Scenarios: The tested scenarios are comparable to what was tested in study 1 (please see Section II for further details). There was one scenario focusing on a correct intervention in a critical rear-end collision situation and one scenario addressing a false intervention in a situation with no critical event.

Interaction design: The intervention was an automatic steering intervention that was designed in a way that it avoided the potential rear-end collision completely by steering to the left hand lane. For the intervention a torque of about 4 Nm was applied to the steering wheel at a TTC of 1.6 seconds. During the intervention the driver was decoupled from steering. That means that the driver inputs like holding the steering wheel or slight steering against the intervention had no effect. However, the driver was able to recouple himself by countersteering. If the driver steered more than 22° against the system intervention he regained control of the steering and recoupled himself. The recoupling criteria was chosen according to results of previous study (study 2, Section III) and designed based on expert rating: In study 2 counter steering against justified interventions stayed below 22°, while counter steering against false alarms exceeded 22° steering wheel angle. In study 2, this condition was usually met while the driver was still completely decoupled, therefore this new strategy was expected to perform superior to a purely time-based recoupling strategy. No braking intervention was applied. In case of successful collision avoidance, the steering intervention stopped as soon as the rear end of the ego vehicle passed the front end of the lead vehicle. Otherwise it stopped at the time of collision.

Two kind of advance haptic warning signals were tested in addition: An undirected haptic signal in form of a short vibration of 0.3 seconds and a tic towards the direction of the steering intervention. This tic had a duration of 0.3 seconds with a linearly increasing force of maximum 3 NM. Both warnings started 0.1 seconds after the sudden stop of the lead vehicle at a TTC of 2 seconds.

It was hypothesized that the further developed algorithm to regain control would help the driver to control false alarm situations better. Furthermore, it was assumed that advance warnings would help the driver in a false alarm scenario to regain control quicker compared to the pure intervention as he has more time to react. The directed haptic warning should improve controllability the most due to the additional information in which the steering intervention will occur.

Results

The results show that 12 to 13 collisions could be avoided by the system intervention. Compared to that, all 15 participants of the baseline collided. The Fisher's exact tests showed a significant difference between baseline and the pure automatic ($p < .001$) and the conditions *baseline* and *automatic intervention with directional haptic warning* ($p < .001$) and between *baseline* and *automatic intervention with non-directional haptic warning* ($p < .001$). Compared with each other the system intervention show no significant differences between them (*automatic intervention with directional warning* vs. *non-directional haptic warning*, p=1; *automatic intervention with directional warning* vs. *pure intervention*, p=1; *automatic intervention with non-directional warning* vs. *pure intervention*, p=1). 80-86 percent of all crashes could be avoided in conditions with an automatic intervention and a directional or non-directional advance warning. However, in the pure intervention without any advance warning also 80 percent of all collisions could be avoided. The advance warnings seemed to have no further benefit in the collision avoidance scenario. A Kruskal-Wallis-Test shows a significant difference in the lateral deviation between the groups ($x^2_{(3)}= 33.22$, $p< .001$). The reason for that is the large difference of the baseline and the experimental groups with automatic system intervention. An ANOVA shows that there are no significant differences between the three groups with system intervention ($F_{(2,39)}=.235$, $p= .792$).

Table 5: Study 3 - Frequency of collision and lateral deviation in the collision situation

Variant	no collision	collision	lat. dev. in m mean (SD)
No intervention (Baseline)	0	15	0.07 (0.05)
Pure automatic intervention	12	2	2.91 (0.72)
Automatic intervention + directional haptic warning	12	2	3.05 (0.7)
Automatic intervention + non-directional haptic warning	13	1	2.9 (0.61)

Even if the advance warnings have no benefits in the evade maneuver it is possible that they have a positive influence of the controllability in a false alarm scenario. Unfortunately, there was no participant who was able to control an unjustified system intervention. In the false alarm scenario all participants reached a higher lateral deviation than 0.85 m which was the criterion for a controllable system intervention. An ANOVA illustrates that there are significant differences between the groups ($F_{(2,39)}=4.94$, $p= .012$). A Bonferroni Post-hoc test revealed that the differences are between the condition with directional warning and non-directional haptic warning. The directional warning seems to be better controllable than a non-directional advance warning. Nevertheless, there are no significant differences between the directional advance warn and the pure system intervention.

Table 6: Study 3 - Frequency of controlled false alarms and lateral deviation in the controllability situation

Variant	Recovered LD<0.85m	Not recov. LD>0.85m	Max. LD mean (SD)
Pure automatic intervention	0	14	1.80 (0.23)
Automatic intervention + directional haptic warning	0	14	1.69 (0.24)
Automatic intervention +non-directional haptic warning	0	14	1.97 (0.24)

Conclusion

The results of the evade manoeuvre prove that automatic and decoupled steering manoeuvre for collision avoidance were very effective. Due to the decoupling strategies 80-86 percent of all crashes could be avoided. In contrast to that, all participants in the baseline condition collided with the obstacle. An indicator for that is the lateral deviation at obstacle. As shown in the previous studies (Study 1 & 2) drivers without any system interaction try to avoid a collision by braking not by steering. Even if participants of the decoupled conditions recoupled themselves (countersteering exceeding 22°) they were able to follow the evade trajectory and avoid the collision.

Nevertheless, the focus of this study was to improve the controllability of decoupled automatic steering maneuvers. We hypothesized that the criteria "countersteering" leads to a better controllability in case of unjustified system activation. The results show that 100% of the participants recouple in the false alarm scenario but they recouple only after an average of

0.67 up to 0.71 seconds. This late recoupling resulted in a high lateral deviation in the false alarm situation. Participants reached lateral deviations of up to 1.97 m which means that they clearly left their lane. No Participant reached the criterion of a controlled false alarm which was a lateral deviation of less than 0.85 m. Nonetheless, if the lateral deviations of the collision situation and the false alarm situation were compared it shows that drivers reacted differently. In the collision situation they reached a lateral deviation of 2.90 m – 3.05 m in the false alarm only 1.70 m – 1.94 m. This indicates that drivers are able to abort the automatic steering intervention if they realize that the maneuver is unjustified. Instead of following the system intervention blindly they check the justification of the maneuver.

Unfortunately, the advance warnings showed no significant effect on the controllability of a false alarm and the configuration chosen in this study could not improve the controllability of an unjustified system intervention. A reason for that may be the very time critical and challenging scenarios chosen in this study. Participants drove with 100 km/h and steering interventions at this speed section are always critical. Even a very fast reaction of 0.5 seconds leads to a lateral deviation over 0.85m. Additionally, the driver needs some time to decide if a system intervention is justified or not. In a time critical collision situation like the ones tested in this study this may lead to even higher lateral deviations.

V. CONCLUSION AND OUTLOOK

Previously conducted studies within the EU project interactIVe showed that in critical rear-end collision situations, drivers tend to counteract steering interventions, such that low-level torque overlays hardly have any effect. Therefore, a number of alternative interaction designs were tested in the three studies summarized in this paper. Study 1 revealed the expected dilemma that a higher level of torque for an automatic steering intervention had a significant impact but already created controllability issues for several drivers. Therefore, it seems that an effective and controllable system design for an automatic steering intervention cannot be found by just varying the level of torque in a torque overlay at the steering wheel (at least for the tested scenarios). Advance warnings seem to have a positive effect on the controllability, however at least the tested variants are still insufficient for general controllability. (Even earlier warning might have an additional benefit in false alarm situations, but could not be tested since this would have enabled the participants to avoid the critical situation for true alarms and therefore would have disabled the focus of the study.)

A temporary decoupling of the driver was shown to have a significant benefit for successful collision avoidance by steering in rear-end situations, since counteracting driver input can be disregarded. Further, the drivers were able to handle the true positive interventions very well, also easily controlling the end of the system intervention. However, it was shown that the tested interaction designs that allowed recoupling and overriding by the driver based on time and/or intervention-opposing steering input by the driver did not enable general controllability in case of false alarms.

Concluding, we can state that automatic steering interventions for rear-end collision avoidance show a potential safety benefit, but no design has yet been found that yields a high benefit and also guarantees controllability of false alarms. At this point it remains questionable whether the driver is able to control a false alarm steering intervention at all in those emergency situations.

In any case further research is necessary to find a controllable interaction design and correctly determine and arbitrate the driver's intention. Regarding the topic of arbitration, also the influence of a driver brake reaction must be further investigated. Options range from braking as overriding criterion of the steering intervention to a decoupling and ignoring the driver's brake command to avoid any interference with an automatic collision avoidance maneuver.

For the currently available interaction designs, the necessary level of system reliability would be extremely high due to the high safety integrity level required according e.g. to ISO 26262 regarding functional safety, because of the remaining controllability issues. In addition, there might be further legal issues regarding regulatory law ("Is a system allowed to initiate an automatic steering intervention and decouple the driver?") and liability law ("Whose fault is it in case an accident happens when the system intervenes correctly or falsely?") have to be addressed before the system's benefits can be exploited.

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