Identifying Factors that Cause Discrepancies between Human and System Hazard Perception in Potential Collision Situations

Christina Kaß*, Gerald Schmidt, Wilfried Kunde*****

*EE Advanced Technology, Opel Automobile GmbH, IPC S4-01,
Bahnhofsplatz 1, Rüsselsheim (Tel: 06142-7-72906; e-mail: christina.kass@opel.com)
**Faculty of Industrial Technologies, Furtwangen University, Kronenstraße 16, Tuttlingen
(e-mail: gerald.schmidt@hs-furtwangen.de)
*** Department of Psychology III, Julius-Maximilians-University Würzburg, Röntgenring 11,
Würzburg (e-mail: kunde@psychologie.uni-wuerzburg.de)

Abstract: Data of naturalistic driving studies have shown that conventional Collision Avoidance Systems (CAS) activate a high rate of unnecessary alarms. These alarms are associated with situations predefined as hazardous by the system algorithm, while not perceived as hazardous by the human user. This driving simulator study aimed to identify factors that cause discrepancies between human hazard perception and the risk assessment of CAS. All participants encountered situations with a braking lead vehicle that would have usually activated alarms in conventional CAS. However, drivers' hazard perception and the intensity of their braking responses varied dependent on the outcome of the conflict that either remained or dissolved. Additionally, the predictability of the outcome influenced drivers' hazard perception, while it had no impact on their driving behaviour.

Keywords: Unnecessary alarms; human hazard perception; system risk assessment; collision avoidance systems; driving behaviour; driving simulator study.

1. INTRODUCTION

Prior research has shown that collision avoidance systems (CAS) improve driver performance in imminent collision situations by increasing drivers' awareness for potential hazards (Kusano & Gabler, 2012; Lee, McGehee, Brown, & Reyes, 2002; Maltz & Shinar, 2004). So far, CAS have applied fairly simple logical correlations to determine the risk of the current traffic situation and to activate collision alarms (Heide & Henning, 2006). Data of naturalistic driving studies have shown that between 32 and 47% of all activated collision alarms resulted in no or only minimal driver responses (Flannagan et al., 2016; General Motors Corporation, 2005). In these situations, an alarm was still activated by a present other vehicle in the same lane. Therefore, the alarm activation was correct according to the implemented algorithm, while the absence of driver responses did not cause a collision. Alarms that are issued in situations predefined as hazardous by the system algorithm but not by the driver are referred to as unnecessary alarms (Lees & Lee, 2007). The present driving simulator study seeks to identify factors that cause discrepancies between human hazard perception and the system's risk assessment that may finally influence drivers' responses to collision alarms. It was hypothesized that human drivers consider dynamic situational changes and predictions of the outcome of potential conflicts for their subjective hazard perception (in contrast to the CAS).

1.1 Risk assessment of collision avoidance systems

The CAS uses its sensors to continuously monitor the environment around the vehicle, such as the distance to other road users and their velocity. Concurrently, in-vehicle sensors measure the vehicle's dynamic state (e.g. velocity and yaw rate) and input control information (e.g. steering wheel angle and pedal position). In the next step, parameters measured by different sensors are integrated to decision criteria to represent a projection of a future status within the next few seconds. To assess the risk of the current situation, the system compares currently measured values to threshold values that system designers have predefined as critical. As soon as current values fall below predefined thresholds, the system issues a collision alarm. More specifically, alarm decisions are based on the time to collision (TTC) criterion between host vehicle and conflict partner. The TTC represents the time required for two road users to collide if they remain on the same path at constant speed. It is calculated by the distance between two road users divided by their relative velocity (Janssen & Nilsson, 1991). In a situation with a decelerating lead vehicle, the so-called *Enhanced* TTC calculation additionally considers the relative deceleration (ETTC; Winner, Hakuli, Lotz, & Singer, 2015).

Environmental events with identical TTC values result in the same level of risk assessment every time they fall below a predefined threshold.

1.2 Human hazard perception

Wickens, Hollands, Banbury, and Parasuraman (2013) described human information processing while driving as follows. While the system perceives environmental objects and their behaviour with sensors, human drivers use their senses, in particular the visual system, to perceive relevant elements in the environment (sensory processing). To extract meaningful events and objects (perception), selective attention is required. The further processing of attended information can require different levels of cognitive processing. In some situations, drivers can use well-learned reaction patterns performed automatically without conscious control. More complex situations require deeper cognitive processing. In this phase, drivers use prior knowledge stored in long-term memory to comprehend the meaning of the perceived elements with regard to their current goals. Based on their comprehension of these elements, drivers are usually able to predict their own subsequent actions and sometimes those of other road users. Drivers then select and execute an action, such as steering or braking. Changes in the environment caused by drivers' actions, in turn, create new patterns to be sensed (feedback loop between action execution and sensory processing). A construct that aims to describe and integrate the described cognitive processes is referred to as situation awareness (Endsley, 1995b). Situation awareness is based on the three levels perception, comprehension, and projection. According to Endsley (1995b), situation awareness constitutes the basis for decision making and the performance of actions. With regard to human subjective hazard perception, we differentiate between drivers' situational risk assessment as part of the comprehension and projection levels within an encountered situation (Gauss, 2008) and the hazard perception concerning the overall traffic situation in retrospect. For example, the situational risk assessment of a visually distracted driver may be inadequately low due to perception errors. However, the subjective hazard perception in retrospect is expected to be higher as soon as the driver has noticed that he or she missed important information that might have almost caused a collision. In our research, we are consistently referring to drivers' retrospective subjective hazard perception of a traffic situation. Finally, drivers' subjective hazard perception determines their perceived need for assistance with regard to the encountered traffic situation (Kaß, Schmidt, & Kunde, 2018).

1.3 Comparison of system risk assessment and human hazard perception

The major steps of system (CAS) and human information processing can be assumed to be comparable (Schmidt, 2012). However, prior research has shown that the risk assessment of CAS does not always match drivers' subjective hazard perception (Kaß et al., 2018). While the system's risk assessment is exclusively determined by physical measurements (TTC), results of this study have revealed that human hazard perception was additionally influenced by their current manoeuvre intention. As soon as a low TTC value was provoked by a road user that was not relevant for drivers' planned driving manoeuvre, subjective hazard perception as well as perceived need for assistance remained low. At the same time, a low TTC value would cause a high risk assessment in present-day CAS that would trigger a collision alarm. Consequently, differences in human and machine information processing caused discrepancies in human hazard perception and system risk assessment. Under these circumstances, the CAS would trigger a collision alarm that drivers would perceive as unnecessary.

In order to reduce the rate of unnecessary alarms, it might be useful to develop CAS whose risk assessment reflect drivers' subjective hazard perception of traffic events. Therefore, the system's information processing needs to take into account human cognitive principles (Heide & Henning, 2006). Technological systems that are designed according to the characteristics of human cognitive processing are referred to as cognitive systems (Hollnagel & Woods, 1983). In order to develop "cognitive driver assistance systems", Li, Wen, Zheng, and Shen (2012) suggest to identify factors that potentially influence drivers' sensing and actions. The next step is to determine how these factors influence drivers' senses and actions. Finally, this knowledge is used for perception enhancement, action suggestion, and function delegation of ADAS. The present study aims to identify factors that cause differences in human and system information processing and consequently lead to discrepancies in human hazard perception and system risk assessment with regard to the same event in the environment. Moreover, we examine the impact of these factors on drivers' actions.

1.4 Dynamic situation analysis and predictability

Previous driving simulator studies have shown that false alarms reduced compliance with alarms and trust with Advanced Driver Assistance Systems (ADAS), while unnecessary alarms enhanced compliance and trust (Lees & Lee, 2007; Naujoks, Kiesel, & Neukum, 2016). Compliance denotes the response when drivers act according to the alarm and take an evasive action (Meyer, 2004). In the reported studies, compliance was measured by brake reaction time, brake response frequency, and the magnitude of speed reduction. The activation of "classical" false alarms is caused by sensor malfunction without apparent trigger and is therefore not comprehensible for drivers (Lees & Lee, 2007). In contrast, drivers are usually able to understand the logic behind the activation of unnecessary alarms as they are triggered by apparent situational determinants. In both studies, unnecessary alarms were caused by other road users whose behaviour was neither predictable for the CAS nor for the human driver. For example, a vehicle, pedestrian, or cyclist was arriving from the side and could have possibly taken the driver's right of way. However, the conflict finally dissolved, e.g. because the conflict partner finally stopped

before causing a collision. In contrast to these results of driving simulator studies, naturalistic driving studies by Flannagan et al. (2016) and General Motors Corporation (2005) have shown that unnecessary alarms resulted in rather low compliance with collision alarms. Even though a lead vehicle was present, unnecessary alarms either did not result in braking responses or resulted in only minimal decelerations shortly after the alarm. In the study by Flannagan et al. (2016), at least 25% of these unnecessary alarms were issued in situations when the lead vehicle turned or changed lanes within four seconds after the alarm. Additionally, it was revealed that alarm rates for this kind of traffic configuration decreased over time. The authors assumed that drivers were able to predict alarms in these scenarios and therefore might have adapted their behaviour to avoid setting off unnecessary alarms. Data of the other study by General Motors Corporation (2005) did not allow for this differentiation.

In the referenced driving simulator studies (Lees & Lee, 2007; Naujoks et al., 2016), unnecessary alarms were caused by another road user that both the CAS and the driver have initially classified as potentially hazardous. Neither the CAS nor the driver were able to predict the behaviour of the other road user. In the course of the driving situation, the potential conflict partner turned out to be non-hazardous. This might be the reason why drivers' compliance did not decrease. In contrast, we assume that drivers in the naturalistic driving studies (Flannagan et al., 2016; General Motors Corporation, 2005) were able to predict upcoming changes in the near future that dissolve the potential conflict with the lead vehicle. For example, a braking lead vehicle that indicated its turn intention in combination with a free turning lane might have served as a cue to predict a non-hazardous outcome of the potential conflict. Thus, many drivers did not or only minimally react to collision alarms in these kind of situations.

Based on these assumptions, human information processing seems to have two advantages in comparison to the CAS. First, the CAS makes use of a static situation analysis and is not able to consider the dynamic course of an action. As soon as the current TTC falls below predefined thresholds, the system judges the situation as hazardous and therefore triggers an alarm. In contrast, drivers are expected to analyse the situation more dynamically. They identify a potential risk and aim to analyse whether the conflict with another road user will remain or dissolve. Second, drivers are often able to predict the behaviour of other road users in the near future. Based on the perception of characteristic cues in the environment and their connection with prior knowledge in order to comprehend their meaning, drivers are able to identify stereotypical traffic situations (Stahl, Donmez, & Jamieson, 2014). Conventional radar- or camera-based CAS have difficulties to analyse the meaning of these cues with regard to their impact on the behaviour of other road users. Thus, the system's prediction of the status in the near future is exclusively based on physical measurements concerning the ego vehicle and the potential conflict partner.

In summary, if drivers predict a safe outcome of a potential conflict in the near future by taking external cues into account, they are assumed to perceive the situation as non-hazardous and would not or only minimally reduce their speed. At the same time, present-day CAS would not consider these external cues and would extrapolate from a low TTC value to a high crash risk. Additionally, as soon as the critical static activation threshold has been exceeded, the CAS is not able anymore to dynamically adjust its risk assessment to changing conditions. In contrast, drivers would dynamically adjust their subjective hazard perception and behaviour to the dynamic development of a potential conflict. Hence, the system would issue an alarm that drivers would presumably perceive as unnecessary.

1.5 Research goals and hypotheses

The first goal of the study was to identify factors that cause discrepancies between human hazard perception and the risk assessment of CAS. Second, we investigated the impact of these factors on drivers' natural driving behaviour. Based on the time to collision criterion, a CAS with static situation analysis would judge all investigated situations as equally critical and would set off an alarm. However, these traffic situations differed with regard to the outcome of the conflict between ego and lead vehicle. Additionally, the driver was either able to predict the other road user's actions in the near future or not. While all situations would result in a constant level of system risk assessment, we hypothesized that the outcome of the conflict and its predictability cause different levels of human subjective hazard perception and differences in drivers' braking responses. More specifically, the following hypotheses were derived:

1. Drivers perceive a potential conflict with a hard braking lead vehicle as less hazardous if the conflict dissolves in the course of time than if the conflict remains.

2. Drivers perceive a potential conflict with a hard braking lead vehicle as less hazardous if they were able to predict the outcome of the conflict in advance than if not.

3. If a potential conflict with a hard braking lead vehicle dissolves in the course of time, it is perceived as less hazardous if drivers were able to predict the outcome of the conflict in advance than if not.

4. Drivers reduce their speed less if the potential conflict with a hard braking lead vehicle dissolves in the course of time than if it remains.

5. If a potential conflict with a hard braking lead vehicle dissolves in the course of time, drivers reduce their speed significantly less if they were able to predict the outcome of the conflict in advance than if not.

2. METHOD

2.1 Participants

Twenty-one drivers (8 female) were recruited from the Würzburg Institute for Traffic Sciences GmbH (WIVW) driver test panel. We excluded two participants who drove too slowly in many scenarios. Consequently, data of 19 participants (6 female) were considered for data analyses (mean age = 43.05 years, *SD* = 11.16). As previous studies have revealed that experienced drivers outperform novice drivers in hazard detection, prediction, and in adequately responding to hazards (Crundall, 2016; Lee et al., 2008; Smith, Horswill, Chambers, & Wetton, 2009; Wallis & Horswill, 2007), we recruited only experienced drivers who held their drivers' licence for 10 years or more (*M* = 24.37, *SD* = 9.99) and covered more than 8000 km per year (*M* = 24,473.68, *SD* = 18,111.90).

2.2 Apparatus

We conducted the study in the fixed-base driving simulator (mock-up: Opel Insignia) at WIVW GmbH. The simulator provided a 300° horizontal and 47° vertical field of view. This was realized by five image channels with a resolution of 1400x1050 pixels each that seamlessly projected the simulation onto a flat screen. The rear-view was furnished by two LCD displays installed as the rear view mirror and the left side mirror. A 5.1 Dolby Surround System provided the auditory input. Nine computers were used for simulation. We used the driving simulation software SILAB 6. For intermediate questionnaires that were programmed with Qualtrics Software (Qualtrics, 2017), we used an 8'' tablet (model Samsung Galaxy 3, Android).

2.3 Experimental Design

The experiment used a 2x2 repeated measures design with the factors outcome of the conflict and predictability. The initial situation was the same for each test event. Just before an intersection, the lead vehicle activated its turn indicator for 400 ms before it suddenly braked to a standstill. Due to this event, TTC values between ego and lead vehicle always fell below two seconds. All participants drove without CAS as we aimed to measure their natural driving behaviour and their subjective hazard perception when not being supported by collision alarms. In order to manipulate the outcome of the conflict, the lead vehicle either remained stopped for 4 seconds or only for 150 milliseconds before it started again and turned at the intersection. In the latter case, participants could have driven on at a constant speed of 50 km/h without causing a collision. As a consequence, the conflict between ego and lead vehicle either (1) remained or (2) dissolved. Thus, only half of the situations could effectively lead to a collision. With regard to the second factor predictability, drivers could either (1) predict or (2) not predict the outcome of the conflict. Environmental cues that are indicative for the course of distinct traffic situations were either visible to the drivers or concealed by sight protections (see Section 2.4).

To reduce learning effects, participants experienced all factor combinations with three different traffic scenarios. Additionally, we implemented 4 filler scenarios of each of the three scenario types (4x3 = 12 filler scenarios). In these scenarios, environments were similar to those in the test events, however, the lead vehicle turned without prior deceleration at the intersection. Thus, all participants encountered 12 test events and 12 filler scenarios throughout the experiment. To control for transition effects, we permutated the sequence of the 12 test events to four different sequences. The filler scenarios were randomly allocated between the test events. Subjects were quasi randomly distributed to the four sequences.

As dependent variables, we assessed drivers' subjective hazard perception of the events and the magnitude of speed reduction in response to the braking lead vehicle. Subjective hazard perception was measured with the situation criticality scale (Neukum, Krüger, Mayser, & Steinle, 2008). This scale consists of verbal categories that are further subdivided into numerical scale points (Figure 1). The scale was introduced by the statement "Evaluate the situation, please. The situation was…". The magnitude of speed reduction was calculated as a result of the speed participants drove when the lead vehicle started braking minus their lowest speed before they re-accelerated (in km/h).

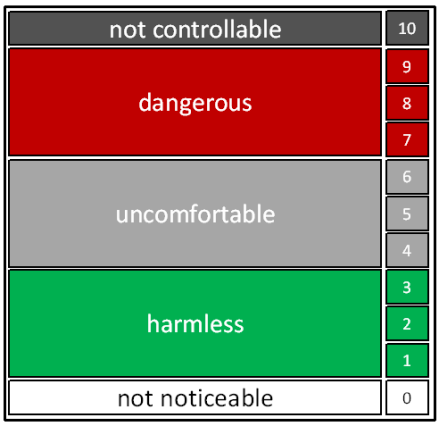

Fig. 1: Situation Criticality Scale.

Translated from "ACC-Stop&Go: Fahrerverhalten an funktionalen Systemgrenzen [ACC Stop&Go: Driver Behavior at Functional System Boundaries]" by Neukum, A., Krüger, H. P., Mayser, C., & Steinle, J., 2008, in M. Maurer & C. Stiller (Eds.), *5. Workshop Fahrerassistenzsysteme - FAS 2008*, p. 144. Copyright 2008 by fmrt. Reprinted with permission.

2.4 Driving environment and driving scenarios

The entire simulation drive took part in an urban environment with a speed limit of 50 km/h. To attain equal velocity conditions between different participants and traffic scenarios, we implemented a speed limiter with a maximum velocity of 50 km/h. To improve the salience and predictive

power of the environmental cues used to manipulate predictability in three test scenario types, we conducted a pre-test with 27 participants. Therefore, we used the situation awareness global assessment technique (SAGAT) method by Endsley (1995a). Participants watched videos of the scenarios. The screen was blanked at the moment the lead vehicle started to brake. We asked participants to explain the scenario, what is going to happen next and how they would react in this situation. The three scenario types and the realization of the four factor combinations of outcome of the conflict and predictability are described in the following.

In the first scenario, a pedestrian on a crosswalk in the right turning street served as the cue to predict a remaining conflict (see upper part of Figure 2). The lead vehicle had to wait as long as the pedestrian crossed the street until it could turn into the street. A free crosswalk indicated a dissolving conflict as the lead vehicle could immediately start again and turn at the intersection. In the non-predictable condition, the view on the crosswalk was obscured by a wall (see lower part of Figure 2). The second scenario was almost similar to the first one. However, the crosswalk was located in the *left* turning street. Thus, the lead vehicle indicated its turn intention to the left. In the third scenario, there was a bus station at the beginning of the right turning street with a stopped bus with activated hazard lights that blocked the street. In the remaining conflict condition, the bus remained stopped with continuously activated hazard light. When the conflict dissolved, the bus deactivated its hazard lights and started driving. In the non-predictable condition, the view on the bus was obscured by a wall.

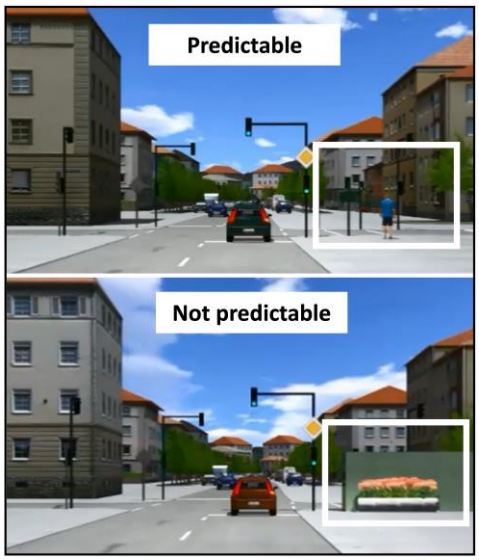

Fig. 2: Realization of the predictable and non-predictable remaining conflict in Scenario 1.

2.5 Procedure

The Ethics Committee of the Institute for Psychology of the Julius-Maximilians-University Würzburg has declared the study to be ethically unobjectionable. Upon arrival, participants received written instructions containing information about the purpose of the study, the simulation environment, the speed limit, driving with a speed limiter, and an explanation of every single verbal category of the situation criticality scale. Additionally, they signed a consent form that informed them about their right to decline to participate and to withdraw from the study at any point and the method of data anonymization.

Participants started with a five-minute practice drive. Throughout the experimental drive, each test event was followed by a programmed announcement “Please stop here” after participants have passed the intersection. This method aimed to avoid that drivers would stop during every event with a hard braking lead vehicle which would have influenced driving measures. After having stopped, drivers entered their subjective hazard perception rating concerning the encountered event into a tablet. During the experiment, the study leader was in a separate control room from where she monitored the driver. At the end of the experiment, participants were thoroughly debriefed.

2.6 Data analysis

All analyses were carried out using IBM SPSS statistics software (Version 22). We conducted repeated-measures analyses of variance (ANOVAs). Pairwise comparisons were calculated with paired sample *t*-tests. The significance level was set at $\alpha = .05$. Dependent measures that were analysed in the ANOVAs reflect averaged ratings of the three different test scenarios (see Section 2.4).

3. RESULTS

To analyse the impact of the outcome of the conflict and its predictability on subjective hazard perception, we conducted a 2x2 repeated-measures ANOVA with hazard perception as dependent variable. Means and standard error bars for within-subject designs (O'Brien & Cousineau, 2014) are displayed in Figure 3. There was a significant main effect for outcome of the conflict, $F(1, 18) = 23.43$, $p < .001$, $\eta_p^2 = .57$. In accordance with the first hypothesis, drivers perceived the remaining conflict with the lead vehicle as significantly more hazardous than the dissolving conflict. Additionally, there was a marginally significant main effect for the factor predictability, $F(1, 18) = 4.05$, $p = .059$, $\eta_p^2 = .18$. When drivers were not able to predict the outcome of the conflict, it was perceived as more hazardous than a conflict with predictable outcome on a marginally significant level. This result moderately supported the second hypothesis. There was no significant interaction effect between the outcome of the conflict and its predictability, $F(1, 18) = 0.03$, $p > .05$, $\eta_p^2 = .001$. However, a paired sample *t*-test revealed a significant difference of subjective hazard perception between predictable and non-predicable dissolving conflicts, $t(18) = 2.69$, $p < .05$. Consistent with the third hypothesis, dissolving conflicts were perceived as significantly less hazardous if drivers were able to predict the outcome of the conflict than if not.

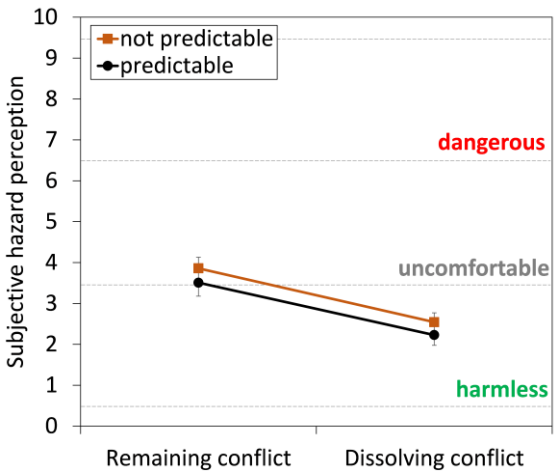

Fig. 3: Subjective hazard perception grouped by outcome of the conflict and its predictability (error bars represent SE for within-subject designs).

To examine the effect of the outcome of the conflict and its predictability on driving behaviour, a 2x2 repeated-measures ANOVA with magnitude of speed reduction as dependent variable was calculated. Figure 4 illustrates the corresponding means and standard error bars for within-subject designs (O'Brien & Cousineau, 2014). The ANOVA revealed a significant main effect for outcome of the conflict, F (1, 18) = 181.87, $p < .001$, $\eta_p^2 = .91$. In accordance with Hypothesis 4, drivers' magnitude of speed reduction was significantly higher when the conflict remained than when it dissolved. However, there were no significant effects for the factor predictability, F (1, 18) = 1.43, $p > .05$, $\eta_p^2 = .07$, and for the interaction between outcome of the conflict and predictability, F (1, 18) = 1.09, $p > .05$, $\eta_p^2 = .06$. Consequently, the predictability of a dissolving conflict had no impact on the magnitude of speed reduction. Hypothesis 5 was therefore not supported by the results.

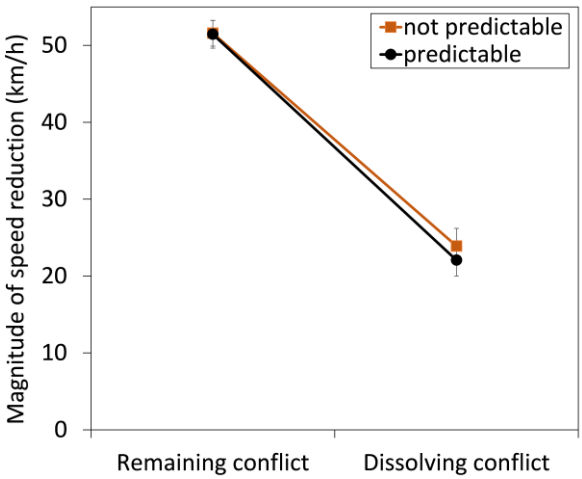

Fig. 4: Magnitude of speed reduction grouped by outcome of the conflict and its predictability (error bars represent SE for within-subject designs).

4. DISCUSSION

The aim of this driving simulator study was to gain insights into factors that cause discrepancies between human hazard perception and the risk assessment of CAS. Additionally, we examined the impact of these factors on drivers' braking responses. Therefore, 19 participants encountered situations with a hard braking lead vehicle. All situations would have resulted in consistently high risk assessments of present-day CAS and, thus, would have triggered collision alarms. However, these situations varied with regard to the outcome of the conflict with the braking lead vehicle. The conflict either remained or dissolved with the dynamic course of time. Furthermore, drivers could either predict or not predict the outcome of the conflict in advance. We hypothesized that the outcome of the conflict and its predictability would cause different levels of human subjective hazard perception and differences in drivers' natural driving behaviour in terms of the magnitude of speed reduction.

In line with the first hypothesis, the results indicated that drivers perceived the remaining outcome of the conflict with the lead vehicle as more hazardous than the conflict that dissolved with the course of time. In contrast to the risk assessment of CAS that is based on a static situation analysis, human drivers seem to consider the dynamic course of traffic situations for their subjective hazard perception. Situations that have initially involved a potential conflict with another road user resulted in varying levels of subjective hazard perception depending on the ultimate outcome of the conflict. Consequently, this finding revealed that dynamic situational changes may lead to discrepancies between human hazard perception and system risk assessment.

With regard to the second hypothesis, the results have shown that drivers' subjective hazard perception was higher when they were not able to predict the outcome of the conflict than if they were able to predict the outcome in advance. This finding corroborates the assumption that drivers' information processing has the advantage over systems' information processing to be able to perceive and comprehend cues in the environment in order to identify and predict stereotypical traffic situations (Endsley, 1995b; Stahl et al., 2014). Conventional CAS do not consider these additional information to predict the other road user's status in the near future in relation to the ego vehicle. Thus, drivers' ability to predict the outcome of potential conflicts can be identified as additional factor that might cause mismatches between human and machine risk analysis.

Furthermore, the results supported the third hypothesis that the impact of predictable and unpredictable dissolving conflicts on subjective hazard perception differ. Drivers perceived dissolving conflicts as less hazardous when they were already able to predict a harmless outcome of the conflict in advance than when they were not able to predict that the conflict will finally dissolve. This result suggests that a discrepancy between human hazard perception and system risk assessment when a potential conflict finally dissolves might be less pronounced if neither the system nor the driver were able to predict this outcome of the conflict in advance.

However, a dissolving conflict that was already predictable for the human driver would cause the greatest discrepancy.

With regard to the impact of the studied factors on driving behaviour, the results were in line with our fourth hypothesis. Drivers reduced their speed to a higher extent when the conflict with the lead vehicle remained than when it dissolved. This finding indicates that drivers were able to dynamically adjust their behaviour to the course of the situation. However, when the potential conflict with the hard braking lead vehicle dissolved, drivers' magnitude of speed reduction did not differ depending on the possibility to predict the outcome of the conflict. This result was not consistent with the fifth hypothesis. It proposed that there would be a higher magnitude of speed reduction if drivers were not able to predict a dissolving outcome of the conflict than if they already knew that the conflict will dissolve. We assume that this result was mainly caused by the short period of time (150 ms) after that the lead vehicle started again and the conflict dissolved. Even if drivers were not able to predict that the conflict would finally dissolve, they were able to update their situation awareness as soon as the lead vehicle started again after having been stopped for only 150 ms (Endsley, 1995b). As a result of their updated situation awareness, drivers adjusted their behaviour dynamically and released the brake.

4.1 Limitations and future research

In all condition combinations, ratings for subjective hazard perception were relatively low, varying between harmless and uncomfortable. A possible explanation for this might be that TTC values of at least 2 seconds were not perceived as very hazardous. However, in the setting of the present study, we were not able to realize more critical TTC values. In the dissolving conflict condition, it was necessary that participants were able to drive on at constant speed of 50 km/h without causing a collision with the lead vehicle. This would not have been possible with smaller TTC values. Moreover, some participants reported that they did not perceive the encountered situations as very hazardous as they were quite similar to situations they frequently experience during everyday traffic.

In the dissolving conflict condition, drivers might have perceived the lead vehicle's driving behaviour as unnatural. In order to achieve equal conditions for the remaining and dissolving conflict, the lead vehicle braked abruptly in both conditions. However, the fast changeover between braking, standing for 150 ms, and reaccelerating might have been irritating. This might have increased drivers' hazard perception ratings. In real traffic, we assume that dissolving conflicts are more often caused by an ego driver who approaches a standing lead vehicle at an intersection that is about to turn. With prior knowledge that the potential conflict will dissolve, the driver would consciously decide to approach the lead vehicle at constant speed. The ego driver provokes a small TTC value because he or she is able to predict that the lead vehicle will be out of the way until this place is reached. Under real conditions, a predictable dissolving conflict would be mainly caused by drivers who intentionally provoke a potential conflict with another road user. However, the driver does not perceive this potential conflict as hazardous at any time. In contrast, in our experimental setting, drivers were actively forced into the dissolving conflict without having a choice. This experimental method might have caused an additional shortcoming. The time frame to actively perceive and comprehend the environmental cues that served to predict the outcome of the conflict was very short. When approaching the intersection, drivers were already able to perceive the pedestrian at the crosswalk and the bus at the bus station some seconds before the lead vehicle started braking. Nevertheless, these cues only became relevant at the moment the lead vehicle activated its turn indicator 400 ms before it finally braked. In a more realistic setting, drivers would have more time to collect relevant cues in the environment to predict the behaviour of other road users. Future research should develop more realistic traffic scenarios to examine the impact of the outcome of the conflict and its predictability on subjective hazard perception and driving behaviour. We assume that this would reveal even larger effects of the studied variables.

Prior research has shown that human hazard perception does not always match the real danger of traffic situations (Charlton, Starkey, Perrone, & Isler, 2014; Groeger & Chapman, 1990; Watts & Quimby, 1980). When CAS are considered as cognitive systems that are oriented towards human information processing, these findings need to be taken into account.

The present study identified dynamic situational changes and drivers' ability to predict the outcome of a potential conflict with another vehicle as factors that result in different levels of subjective hazard perception. Drivers' manoeuvre intention is another variable that causes this mismatch (Kaß et al., 2018). A focus group discussion by Werneke, Kassner, and Vollrath (2008) that examined requirements of ADAS suggests that drivers' current capacity, e.g. drowsiness, visual, or cognitive attention, might represent another important variable. Future research should identify and examine additional variables that might cause mismatches between human and machine hazard perception.

Moreover, future work is required to examine the transferability of the present findings to other ADAS, such as lane keep assistance systems.

4.2 Practical implications

The results of the present study help to understand how discrepancies between human hazard perception and the risk assessment of CAS concerning the same traffic situation evolve. These discrepancies may finally lead to collision alarms that drivers perceive as unnecessary (Kaß et al., 2018). Due to their low subjective hazard perception, drivers would not or only minimally respond to these alarms. CAS that base their risk assessment exclusively on physical measurements of the current driving situation will not be able

to approach higher levels of human information processing. In order to overcome mismatches between human hazard perception and system risk assessment, CAS need to take into account additional factors that were identified to influence drivers' information processing and actions. These findings provide an important element for the development of CAS that adapt alarm activation to drivers' actual need for assistance. However, this knowledge should not be applied directly to modify existing warning algorithms to suppress unnecessary alarms. First, further research must investigate the role of additional factors that might influence drivers' need for assistance. For example, the system would conceivably need information about the current cognitive workload level to decide if the driver is able to comprehend the situation and to correctly anticipate its further course. Moreover, technological improvements are important prerequisites to enable the system to predict subsequent actions of other road users. For this purpose, systems could make use of artificial intelligence. Thus, they will be able to learn from experience comparable to human drivers (Bengler et al., 2014; Goodfellow, Bengio, & Courville, 2017). These systems have the potential to observe a large number of objects in the environment to identify stereotypical traffic situations, and thereby to make accurate predictions about the behaviour of the driver and of other road users. Although these systems are currently mainly applied in the field of automated driving, the findings of this study suggest that ADAS might also profit from applying artificial intelligence to improve the system's information processing and situation awareness in complex driving situations.

Additionally, the knowledge gained by this study has implications for automated driving. To offer a natural driving experience, the information processing of an automated driving system needs to approach that of a human driver. Therefore, the system needs to take into account the same factors as the human driver. Instead of carrying out a hard braking manoeuvre in potentially critical situations (TTC < threshold) with dissolving outcomes, the system must additionally consider subsequent actions of other road users.

5. CONCLUSIONS

The present driving simulator study identified dynamic changes in the outcome of potential conflicts with another vehicle and drivers' ability to predict these outcomes as factors that result in different levels of human subjective hazard perception. In contrast, algorithms of present-day CAS that exclusively consider kinematic measurements for alarm activation would have judged all tested events as equally hazardous and thus would have triggered collision alarms. Moreover, drivers adjusted their braking responses to dynamic changes in the outcome of potential conflicts. However, the predictability of the outcome of the conflict had no impact on drivers' magnitude of speed reduction. As a conclusion, the study extends knowledge about human factors that cause discrepancies between drivers' subjective hazard perception and system risk assessment that may finally influence drivers' responses to collision alarms. These findings provide an important element to design CAS according to human information processing in order to build a bridge between human hazard perception and system risk assessment. In combination with additional research, such a design approach might offer the potential to reduce the rate of alarms that drivers perceive as unnecessary.

ACKNOWLEDGEMENTS AND NOTES

We would like to thank Norbert Schneider, Felicitas Muth, and Christoph Klöffel of the WIVW GmbH for their support during study preparation and execution. Furthermore, we thank Clara Beck for her help in preparing and conducting the pre-test and Jakob Kammerer for his support with regard to driving data preparation.

Gerald Schmidt was employed at Opel Automobile GmbH during study conduction.

REFERENCES

Bengler, K., Dietmayer, K., Farber, B., Maurer, M., Stiller, C., & Winner, H. (2014). Three Decades of Driver Assistance Systems: Review and Future Perspectives. *IEEE Intelligent Transportation Systems Magazine*, *6*(4), 6–22. https://doi.org/10.1109/MITS.2014.2336271

Charlton, S. G., Starkey, N. J., Perrone, J. A., & Isler, R. B. (2014). What's the risk? A comparison of actual and perceived driving risk. *Transportation Research Part F: Traffic Psychology and Behaviour*, *25*, 50–64. https://doi.org/10.1016/j.trf.2014.05.003

Crundall, D. (2016). Hazard prediction discriminates between novice and experienced drivers. *Accident Analysis & Prevention*, *86*, 47–58. https://doi.org/10.1016/j.aap.2015.10.006

Endsley, M. R. (1995a). Measurement of Situation Awareness in Dynamic Systems. *Human Factors*, *37*(1), 65–84. https://doi.org/10.1518/001872095779049499

Endsley, M. R. (1995b). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors: the Journal of the Human Factors and Ergonomics Society*, *37*(1), 32–64. https://doi.org/10.1518/001872095779049543

Flannagan, C., LeBlanc, D., Bogard, S., Nobukawa, K., Narayanaswamy, P., Leslie, A., . . . K. (2016). *Large-scale field test of forward collision alert and lane departure warning systems*. (No. DOT HS 812 247). Washington, DC: National Highway Traffic Safety Administration. Retrieved from https://www.nhtsa.gov/sites/nhtsa.dot.gov/files/812247b-lanedepartureswarningsystems.pdf

Gauss, B. (2008). Evaluation von Situational Risk Assessment Systemen [Evaluation of Situational Risk Assessments Systems] (Doctoral Dissertation). Technische Universität Berlin, Berlin.

General Motors Corporation. (2005). *Automotive Collision Avoidance System Field Operational Test (ACAS FOT) Final Program Report*. DOT HS 809 886. Washington, DC: National Highway Traffic Safety Administration.

Goodfellow, I., Bengio, Y., & Courville, A. (2017). *Deep learning. Adaptive computation and machine learning series*. Cambridge, MA: MIT Press.

Groeger, J. A., & Chapman, P. R. (1990). Errors and bias in assessments of danger and frequency of traffic situations. *Ergonomics*, *33*(10-11), 1349–1363. https://doi.org/10.1080/00140139008925337

Heide, A., & Henning, K. (2006). The "cognitive car": A roadmap for research issues in the automotive sector. *Annual Reviews in Control*, *30*(2), 197–203. https://doi.org/10.1016/j.arcontrol.2006.09.005

Hollnagel, E., & Woods, D. D. (1983). Cognitive Systems Engineering: New wine in new bottles. *International Journal of Man-Machine Studies*, *18*(6), 583–600. https://doi.org/10.1016/S0020-7373(83)80034-0

Janssen, W. H., & Nilsson, L. (1991). An experimental evaluation of in-vehicle collision avoidance systems. In *Proceedings of the 24th ISATA International Symposium on Automotive Technology and Automation* (pp. 209–214).

Kaß, C., Schmidt, G. J., & Kunde, W. (2018). Towards an assistance strategy that reduces unnecessary collision alarms: An examination of the driver's perceived need for assistance. *Journal of Experimental Psychology: Applied*. https://doi.org/10.1037/xap0000184

Kusano, K. D., & Gabler, H. C. (2012). Safety Benefits of Forward Collision Warning, Brake Assist, and Autonomous Braking Systems in Rear-End Collisions. *IEEE Transactions on Intelligent Transportation Systems*, *13*(4), 1546–1555. https://doi.org/10.1109/TITS.2012.2191542

Lee, J. D., McGehee, D. V., Brown, T. L., & Reyes, M. L. (2002). Collision warning timing, driver distraction, and driver response to imminent rear-end collisions in a high-fidelity driving simulator. *Human Factors*, *44*(2), 314–334. https://doi.org/10.1518/0018720024497844

Lee, S., Klauer, S. G., Olsen, E. C. B., Simons-Morton, B. G., Dingus, T. A., Ramsey, D. J., & Ouimet, M. C. (2008). Detection of Road Hazards by Novice Teen and Experienced Adult Drivers. *Transportation Research Record*, *2078*, 26–32. https://doi.org/10.3141/2078-04

Lees, M. N., & Lee, J. D. (2007). The influence of distraction and driving context on driver response to imperfect collision warning systems. *Ergonomics*, *50*(8), 1264–1286. https://doi.org/10.1080/00140130701318749

Li, L., Wen, D., Zheng, N.-N., & Shen, L.-C. (2012). Cognitive Cars: A New Frontier for ADAS Research. *IEEE Transactions on Intelligent Transportation Systems*, *13*(1), 395–407. https://doi.org/10.1109/TITS.2011.2159493

Maltz, M., & Shinar, D. (2004). Imperfect In-Vehicle Collision Avoidance Warning Systems Can Aid Drivers. *Human Factors*, *46*(2), 357–366. https://doi.org/10.1518/hfes.46.2.357.37348

Meyer, J. (2004). Conceptual Issues in the Study of Dynamic Hazard Warnings. *Human Factors*, *46*(2), 196–204. https://doi.org/10.1518/hfes.46.2.196.37335

Naujoks, F., Kiesel, A., & Neukum, A. (2016). Cooperative warning systems: The impact of false and unnecessary alarms on drivers' compliance. *Accident Analysis & Prevention*, *97*, 162–175. https://doi.org/10.1016/j.aap.2016.09.009

Neukum, A., Krüger, H. P., Mayser, C., & Steinle, J. (2008). ACC-Stop&Go: Fahrerverhalten an funktionalen Systemgrenzen [ACC Stop&Go: Driver Behavior at Functional System Boundaries]. In M. Maurer & C. Stiller (Eds.), *5. Workshop Fahrerassistenzsysteme - FAS 2008* (pp. 141–150). Karlsruhe: fmrt.

Qualtrics. (2017). Qualtrics. Provo, Utha, USA: Qualtrics. Retrieved from http://www.qualtrics.com

Schmidt, G. (2012). The influence of anticipation and warnings on collision avoidance behavior of attentive drivers (Doctoral Dissertation). Julius-Maximilians-Universität, Würzburg. Retrieved from https://opus.bibliothek.uni-wuerzburg.de/files/6282/Dissertation_GSchmidt2012.pdf

Smith, S. S., Horswill, M. S., Chambers, B., & Wetton, M. (2009). Hazard perception in novice and experienced drivers: the effects of sleepiness. *Accident Analysis & Prevention*, *41*(4), 729–733. https://doi.org/10.1016/j.aap.2009.03.016

Stahl, P., Donmez, B., & Jamieson, G. A. (2014). Anticipation in Driving: The Role of Experience in the Efficacy of Pre-event Conflict Cues. *IEEE Transactions on Human-Machine Systems*, *44*(5), 603–613. https://doi.org/10.1109/THMS.2014.2325558

Wallis, T. S. A., & Horswill, M. S. (2007). Using fuzzy signal detection theory to determine why experienced and trained drivers respond faster than novices in a hazard perception test. *Accident Analysis & Prevention*, *39*(6), 1177–1185. https://doi.org/10.1016/j.aap.2007.03.003

Watts, G. R., & Quimby, A. R. (1980). *Aspects of road layout that affect drivers' perception and risk taking*. Crowthorne, Berkshire, England: Transport and Road Research Laboratory. *TRRL Report 920*.

Werneke, J., Kassner, A., & Vollrath, M. (2008). An analysis of the requirements of driver assistance systems - when and why does the driver like to have assistance and how can this assistance be designed? In *Proceedings of European conference on Human Centred Design for Intelligent Transport Systems* (pp. 193–203).

Wickens, C. D., Hollands, J. G., Banbury, S., & Parasuraman, R. (2013). *Engineering psychology and human performance* (4. Auflage). Boston: Pearson.

Winner, H., Hakuli, S., Lotz, F., & Singer, C. (Eds.). (2015). *Handbuch Fahrerassistenzsysteme: Grundlagen, Komponenten und Systeme für aktive Sicherheit und Komfort [Manual Driver Assistance Systems]*. (3rd ed.). Wiesbaden: Springer Vieweg.

Identifying Factors that Cause Discrepancies between Human and System Hazard Perception in Potential Collision Situations

Kaß, Christina; Schmidt, Gerald; Kunde, Wilfried

In: Kognitive Systeme / 2018 - 1

DOI: https://doi.org/10.17185/duepublico/48593

URN: urn:nbn:de:hbz:464-20190417-110341-7

Link: https://duepublico.uni-duisburg-essen.de:443/servlets/DocumentServlet?id=48593