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Driver behavior following an automatic steering intervention

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ABSTRACT

The study investigated driver behavior toward an automatic steering intervention of a collision mitigation system. Forty participants were tested in a driving simulator and confronted with an inevitable collision. They performed a naïve drive and afterwards a repeated exposure in which they were told to hold the steering wheel loosely. In a third drive they experienced a false alarm situation. Data on driving behavior, i.e. steering and braking behavior as well as subjective data was assessed in the scenarios. Results showed that most participants held on to the steering wheel strongly or counter-steered during the system intervention during the first encounter. Moreover, subjective data collected after the first drive showed that the majority of drivers was not aware of the system intervention. Data from the repeated drive in which participants were instructed to hold the steering wheel loosely, led to significantly more participants holding the steering wheel loosely and thus complying with the instruction. This study seems to imply that without knowledge and information of the system about an upcoming intervention, the most prevalent driving behavior is a strong reaction with the steering wheel similar to an automatic steering reflex which decreases the system's effectiveness. Results of the second drive show some potential for countermeasures, such as informing drivers shortly before a system intervention in order to prevent inhibiting reactions.

1. Introduction

Technical advancements allow for a wide range of advanced driver assistance systems (ADAS) in vehicles. While some are more comfort oriented, such as adaptive cruise control and lane-keeping assistance, others focus specifically on support in critical driving situations. Such systems provide warnings, informational messages or even active interventions, such as automatic braking and steering interventions. Emergency brake assistants are already available in the market, whereas automatic steering assistance is still under development (Keller et al., 2011). The reasons for this are the greater complexity of such interventions, higher technological requirements and liability issues (Dang et al., 2012). One specific dilemma with the development of such systems is the necessity for a driver of being able to control the vehicle at all times as specified in the Vienna Convention (United Nations, 1968). This can be especially problematic if a driver behaves contrary to the system's intervention which could significantly lesson the system's effectiveness. This aspect was investigated in this research paper and is further described in detail in the following paragraphs.

Some commercial systems, such as the Conti "emergency steer assist" (Eckert et al., 2011) help the driver in an imminent collision situation by supporting the driver through a steering movement. These systems include specific implementations which avoid some of the development problems of such systems. First of all, the driver can override the system and should be able to control the system at any time. This approach is based on the "RESPONSE code of practice" which was developed by many European car manufacturers as a collection of criteria for developing new driver assistance functions. It has introduced the concept of controllability (Schwarz, 2006) as an evaluation criteria to be met for ADAS, especially in false alarm and system limitation situations. Controllability therefore needs to be investigated additionally in evaluation studies of steering intervention systems.

Secondly, the available systems are designed "driver initiated", i.e. the driver needs to start steering first in order for the system becoming active. This might be a problematic system implementation in case the driver does not react timely with the appropriate response. In order for these systems to be effective in avoiding or mitigating collisions, the driver needs to start steering before the system will intervene by itself. Whether this is a likely case and generally how drivers behave in emergency situations is thus important knowledge for the design and development of collision avoidance and mitigation systems.

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First hints on how drivers react in imminent collision situations is provided by Adams (1994) who concludes that drivers are more likely to brake in a collision situation than to steer. Malaterre et al. (1988) also found that most drivers in intersection collision situations braked and hardly ever reacted with sideways swerving. Moreover, they found that if the driver performs a swerving reaction, it is mostly in the same direction as the moving object. Other studies found braking but also steering as the most common reactions (Fausten, 2010; Mazzae et al., 2003; McGehee et al., 2000). One factor which could influence whether braking or steering is more prevalent is, amongst others, the available time for the reaction. This hypothesis is supported by a study in which the most frequent driver response in collision situations was dependent on the time-to-collision (TTC) (Hankey et al., 1996). In the condition with the shortest TTC (2.85 s) in which the appropriate reaction was to steer, sixteen out of 31 participants performed the correct response to steer before accelerator release and braking. In the medium (3.6 s) and long TTC (4.35 s) situations in which braking and slowing down were the appropriate reactions, only six and three participants respectively steered as the initial reaction. Similar results were found in a test-track study by Eckert et al. (2011). Based on the cited literature, the initial reaction to a collision seems to be affected by the perceived available time to react: if there is more time until the collision, braking seems to be the preferred action compared to swerving when less time is available. Additionally, studies found that drivers reacted with a swerving reaction in intersection collision situations more often when the collision obstacle was approaching from the right (e.g. Hankey et al., 1996). In the Hankey et al.'s (1996) study, participants could avoid the collision by a swerving reaction and the authors hypothesized that when the collision vehicle is approaching from the left, the gap is bigger in order to allow a swerving reaction.

There are also some studies that have gone further into investigating driver behavior following automatic system interventions of collision avoidance systems. Bender (2008) for example performed a series of studies investigating driver behavior in emergency situations with automatic braking and/or steering interventions. She found that the type of intervention of the system (braking or steering) influenced the most prevalent driver reaction as braking for the braking intervention and steering for the steering intervention. Additionally, over 50% of the drivers were thinking to be in control when the system applied an emergency steering response when in fact they could not control the steering (Bender, 2008).

If the driver has missed the last possible moment to react in order to avoid the collision and it becomes inevitable, collision mitigation functions can still try to lessen the consequences of a collision (Jansson et al., 2007) even if they cannot prevent the collision. One approach is a steering intervention by optimizing the collision angle. The effectiveness of such collision mitigation systems is lessened if the driver intervenes during the system action in opposition to the system behavior. Based on the cited literature it is not clear what type of reaction the most prevalent driving behavior is in case of a very short TTC and a "system initiated" steering intervention of a collision mitigation system. Therefore, this study aimed at investigating driver behavior toward a collision mitigation system intervention – i.e. a system intervention which cannot prevent the crash but mitigate the crash impact (without assessing the technical system effectiveness). More specifically, the following four research questions were addressed:

1. How do drivers react in an imminent collision situation with a system intervention, i.e. how many will brake, counter-steer or take their hands off during the intervention?
2. Do drivers realize that the system intervened automatically?
3. How controllable do drivers perceive a false intervention of the system (aspect of controllability; Schwarz, 2006)?
4. Are drivers able to actively influence their steering behavior if they know what will happen and when they are instructed on a specific behavior?

2. Materials and methods

2.1. Participants

Forty private vehicle drivers participated in the study (men: 23; women: 17) with a minimum driving experience of more than 12,000 km/year (average of 18,359 km/year) and all but one participant had their driving licenses for a minimum of 5 years (average: 22.6 years). Participants' average age was 41.23 years with a minimum of 20 and a maximum of 54 years. In a questionnaire participants indicated their experience with driver assistance systems (rating scale 1 = no experience; 4 = much experience) and four participants indicated to have little experience with an emergency brake assistant whereas all others had no experience with such a system.

2.2. Equipment

The research questions were investigated in a fixed-base driving simulator at the German Aerospace Center (DLR) (see Fig. 1). The simulator allows an almost 270° view on a three-wall projection. The participants were seated in a quarter-vehicle on the driver's seat, the instrument cluster was replaced by LCD displays. The steering wheel could create torques of up to 30 N m.

2.3. Experimental scenario

Three scenarios were developed to simulate and test the effect of a crash mitigation system that adjusts the collision angle to lessen the collision force. It is possible that the optimal reaction of such a system, which is the adjustment of the participant's vehicle trajectory to achieve an optimal collision angle minimizing the collision force, could be counterintuitive for the driver (i.e. steering in the same direction as an obstacle) resulting in a driving reaction that interferes with the system reaction.

These three driving scenarios were a naïve drive, a repeated drive and a false alarm drive. All scenarios had in common that they were placed in the same urban environment including moderate right and left curves and the passing of intersections.

The naïve drive included a collision situation at an intersection at the end of a 15 min drive. Four different variations of this

Fig. 1. Picture of the DLR driving simulator used in the experiment.