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Evaluation of three different interaction designs for an automatic steering intervention

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ABSTRACT

The study was designed to test three different interaction designs for an automatic steering intervention against a baseline. Forty participants participated in a driving simulator study with four experimental groups. Each group experienced an imminent rear-end collision situation. The thirty drivers of the three automation groups were supported by an automatic steering intervention, each group experiencing a different interaction design: (i) pure automatic intervention, (ii) directed haptic warning plus automatic intervention, (iii) undirected acoustic warning plus automatic intervention. Ten participants underwent the emergency situation without any intervention (baseline). Additionally, participants of the three automation groups experienced an automatic steering intervention in a false alarm situation to test for controllability. It was hypothesized that the directed haptic warning plus intervention would support the effectiveness and the controllability most successfully. The results show that all automatic steering interventions supported an evasion manoeuvre in the imminent collision situation but no further difference in performance was found between the three interaction designs. Subjective data revealed that not all drivers recognized the steering intervention. For the false alarm situation, some drivers could not override the false automatic intervention and could not stabilize the vehicle in the lane. Further research is needed to improve the effectiveness of automatic steering interventions in emergency situations and the controllability in false alarm situations.

1. Introduction

Technical developments in the vehicle domain allow for the introduction of enhanced assistance systems and automation functionalities reaching from driver information and support systems up to the complete automatic control of specific driving tasks such as the lateral or longitudinal control of the vehicle (for an overview see Bishop, 2005; Eskandarian, 2012; Winner, Hakuli, & Wolf, 2009). In this simulator study one example of an automatic function was tested: an automatic steering intervention that can help to reduce imminent rear-end collisions. Accident data show that rear-end collisions represent a substantial proportion of the total amount of crashes (German Federal Statistical Office, 2013; National Transportation Safety Board, 2001). Advanced driver assistance and automation systems that help to avoid the collision or reduce the severity of collisions are already available in serial production vehicles. Examples for these systems are systems that warn the driver, systems that intensify drivers braking reaction and systems that initiate automatic braking

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autonomously (for an overview see Maurer, 2012; Winner, 2009). All these systems have in common that they influence the longitudinal control of the vehicle to avoid or mitigate the crash.

Nonetheless, some specific situations exist where collisions cannot be avoided by braking but only by steering manoeuvres as explained for instance by Malaterre, Ferrnandez, Fleury, and Lechner (1988) or Allen, Rosenthal, and Aponso (2005). However, driving studies show that a number of drivers tend only to brake and often do not try to avoid the obstacles by steering in imminent rear-end collision situations even if this would be the more appropriate reaction (Adams, 1994; Malaterre et al., 1988). There are different potential reasons for this behaviour: First, it seems to be a nearly involuntary, maybe instinctive, reaction to stop one's own movement in the case of an imminent collision to reduce the impact of the collision. Second, steering manoeuvres are more complex than braking and therefore require a higher situation awareness of the driver and higher driving abilities. Therefore, in situations where the collision can only be avoided by an evasion manoeuvre drivers tend to end up in a crash. That is why automatic steering interventions are now under development that could help to avoid collisions that cannot be avoided by braking (Bender et al., 2007a; Dang et al., 2012; Eidehall, Pohl, Gustafsson, & Ekmark, 2007; Fernandez Llorca et al., 2011; Itoh, Horikome, & Inagaki, 2013; Keller et al., 2011). In the face of such critical collision situations, the system – the automatic steering intervention system – initiates a complete shift of control in the driving task from the driver who is manually driving to the system. For this, the system needs to detect and process relevant information about the situation, needs to decide on an appropriate action and implement the selected action for avoiding the obstacle by steering. Following the concept of Parasuraman, Sheridan, and Wickens (2000) the automation level for this kind of automatic intervention can be described as high for all four stages of the perception-act cycle. Compared to that, the automation level on the decision and action stages is low when the driver is driving manually and the intervention system is not active. A transition from manual driving to automatic intervention occurs whenever the system detects that a critical situation develops, decides that the best action to avoid the collision is a steering intervention and predicts that the driver will not react appropriately. Thus, this approach is different from existing research on transitions, where continuously automated driving (e.g. a combination of adaptive-cruise control and automatic steering) is switched to manual driving through hand-over requests (e.g. Schieben, Flemisch, Temme, & Köster, 2011; Gold, Damböck, Lorenz, & Bengler, 2013). In the here reported system, most driving phases consisted of manual driving with a short automation phase during critical situations, when the system performed the automatic steering intervention with a fixed linkage between steering wheel and front tires.

Within the research community there are two approaches about the role of the human operator during the automatic steering intervention. These roles depend on the decision how to distribute the authority to shift control and to control the overall human-machine system in (time-) critical situations and are controversially discussed (Billings, 1991; Billings & Woods, 1994; Christoffersen & Woods, 2002; Endsley, 1996; Flemisch et al., 2012; Inagaki, 2003; Inagaki & Sheridan, 2012; Itoh & Inagaki, 2013; Moray, Inagaki, & Itoh, 2000; Scerbo, 1996; Young, Stanton, & Harris, 2007). One approach is to give the system the full authority to initiate a shift of control within the human-machine system and to perform the automatic intervention with no possibility for the driver to gain back control, i.e. to override the automatic intervention. This would of course require high technical reliability of the system and technical implementation of hardware components, such as a steer-by-wire system, that allows a complete separation of the driver's and the automation's input on the vehicle control. Another approach is to give the system the authority to initiate the shift in control and to start an automatic intervention while the driver is still able and allowed to gain back control and to override the automatic intervention.

The chosen approach depends strongly on the decisions and philosophy of the system designers and existing legal restrictions. For example, in aviation the two largest aircraft manufacturers, Airbus and Boeing, differ in their approaches. While Airbus' design philosophy is to give the automation full authority in critical situations, Boeing allows the pilots to override automatic interventions if necessary (Hughes & Dornheim, 1995). For the automobile domain the second approach, allowing the driver to override the automatic intervention, is currently used for all available collision avoidance systems on the market. One reason for this is the Vienna Convention on Road Traffic (Convention on Road Traffic, 1968) which is the basis for several national legislative regulations requiring the driver to stay in control of his vehicle. This is the reason why we focused on investigating interaction designs that ensure a high effectiveness of the automatic intervention while still giving the driver the authority to override the automatic intervention.

To implement such an authority distribution for an automatic steering intervention successfully two contradictory prerequisites need to be fulfilled by the design. On the one hand, the driver must be able to override the automatic steering intervention, for example in case of false activation. Given that the automatic intervention actively influences vehicle movements, the controllability by the driver is especially important when the system activates itself in a false alarm situation where no critical event is present. The ability of the driver to control the automatic interventions is a crucial criterion in the Code of Practice (PreVENT, 2006; Schwarz, 2006) for the design and evaluation of Advanced Driver Assistance Systems (ADAS). According to the Code of Practice controllability is defined as the "likelihood that the driver can cope with driving situations including ADAS-assisted driving, system limits and system failures" (PreVENT, 2006, p. 5).

On the other hand, the driver, whose initial reaction to a rear-end collision is braking not steering, shall not override the steering intervention if it is triggered by a real imminent collision. Unfortunately, studies revealed that drivers often prevent automatic steering interventions. As long as no steer-by-wire system is used strong automatic steering interventions in such emergency situations are accompanied by an immediate movement of the steering wheel. The driver can override the intervention by holding the steering wheel or by steering in the opposite direction of the intervention. Studies on automatic steering interventions found that drivers tend to show this overriding reaction mitigating the potential benefits and decreasing the overall effectiveness of such interventions (Bishel, Coleman, Lorenz, & Mehring, 1998; Brockman et al., 2013; Ziegler,

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