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Car Gestures – Advisory warning using additional steering wheel angles

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ABSTRACT

Advisory warning systems (AWS) notify the driver about upcoming hazards. This is in contrast to the majority of currently deployed advanced driver assistance systems (ADAS) that manage emergency situations. The target of this study is to investigate the effectiveness, acceptance, and controllability of a specific kind of AWS that uses the haptic information channel for warning the driver. This could be beneficial, as alternatives for using the visual modality can help to reduce the risk of visual overload. The driving simulator study ($N = 24$) compared an AWS based on additional steering wheel angle control (Car Gestures) with a visual warning presented in a simulated head-up display (HUD). Both types of warning were activated 3.5 s before the hazard object was reached. An additional condition of unassisted driving completed the experimental design. The subjects encountered potential hazards in a variety of urban situations (e.g. a pedestrian standing on the curbs). For the investigated situations, subjective ratings show that a majority of drivers prefer visual warnings over haptic information via gestures. An analysis of driving behavior indicates that both warning approaches guide the vehicle away from the potential hazard. Whereas gestures lead to a faster lateral driving reaction (compared to HUD warnings), the visual warnings result in a greater safety benefit (measured by the minimum distance to the hazard object). A controllability study with gestures in the wrong direction (i.e. leading toward the hazard object) shows that drivers are able to cope with wrong haptic warnings and safety is not reduced compared to unassisted driving as well as compared to (correct) haptic gestures and visual warnings.

1. Introduction

Traffic psychology has revealed some evidence that drivers profit from AWS that rise drivers' attention and direct it toward the potentially risky objects in the scene. Especially novice drivers, when driving in complex urban environments, could profit from such assistance. This helps drivers to identify potential hazards or critical situations in the near future and react accordingly (Underwood, 2007). In this context, an AWS could be seen as a technical co-pilot that accompanies the driver and gives additional and early information if an object is likely to become a risk for traffic safety.

As an example, Naujoks et al. (in press) studied the effect of an AWS on drivers' behavior in different situations. The driving situations varied in (1) the visibility when approaching the conflict point (the conflicting road user is visible vs. not visible) and (2) the possibility to anticipate the conflict (depending on the right-of-way condition). The AWS was realized by a simulated HUD and a notifying tone indicating the type of conflict as well as the direction of the hazard 2 s before the latest possible warning moment (see below for a detailed explanation). The results of the study conducted in a driving simulator show that driving safety profits especially in conflict situations that appear suddenly and are not foreseeable (e.g. because the conflicting partner ignores the driver's right-of-way).

Due to the substantial safety potential of AWS, Naujoks (2015) discussed concepts of collision mitigation and imminent warnings (e.g. forward collision warning systems) and suggests that such systems should be supplemented by advisory warnings.

This leads to the following categorization of ADAS based on the point in time when the warning is presented to the driver (Neukum, 2011; Naujoks and Neukum, 2014):

- *Collison mitigation*: The latest point in time for warning the driver can be estimated using the drivers' reaction time and maximum deceleration of the vehicle (ISO 15623:2013(E)). Later warnings

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are too late for collision avoidance but could help to reduce the impact of a collision by triggering appropriate actions (e.g. emergency brake assist).

- *Imminent warning*: Established concepts of imminent warnings become active prior to the latest possible warning moment. The main objective of imminent warnings is to trigger an immediate driver action, such as braking or steering in order to avoid a collision (Lenné and Triggs, 2009).
- *Advisory warning*: By applying AWS, the time frame prior to the imminent crash warning (>1500 ms) is used to inform the driver about potentially dangerous driving situations. The AWS should alert the driver and direct his attention to a potential conflict in order to increase his preparation time before response (Neukum, 2011).

1.1. Human machine interface (HMI) for an AWS

AWS pose high demands for the design of the information/warning toward the driver (Naujoks et al., in press). Especially the fact that the prediction of a situation can be wrong and thus might lead to unreliable warnings (e.g. false alarms or missing warnings), makes it challenging to develop an HMI which is accepted by the drivers (Bliss and Acton, 2003; Sorkin, 1988).

Regarding timing, advisory warnings should be presented as late as possible, in order to ensure maximum reliability – but as early as necessary for triggering an appropriate driver reaction. Naujoks et al. (2012) showed that visual-auditory information presented 1–2 s before the latest possible warning moment leads to a significant reduction of traffic conflicts (compared to non-assisted driving). Using a fixed-base driving simulator Naujoks and Neukum (2014) investigated the effect of early warnings presented via HUD on driver behavior and acceptance. The timing of the warning was varied in five steps (between the latest possible warning moment and up to four seconds prior to the latest possible warning moment in steps of 1 s). The results show that upcoming conflicts should be indicated 1–2 s prior to the latest possible warning moment in order to trigger appropriate driver reactions and reduce situation criticality. Although earlier warnings did not contribute to a further reduction of the risk for a collision, drivers preferred to receive the warning even 2–3 s prior to the latest possible warning moment.

Warnings could also notify the driver of the type (type specificity) and direction (directional specificity) of the potential conflict partner as well as its distance (location specificity) and likelihood (risk specificity; Naujoks and Neukum, 2014). Concerning the effectiveness of all these parameters, scientific evidence shows mixed results (for directional-specificity see e.g. Bliss and Acton, 2003; Cummings et al., 2007; Spence and Ho, 2008; for type specificity see e.g. Cummings et al., 2007; Thoma et al., 2009; for location specificity see e.g. Popiv et al., 2010; Totzke et al., 2012; for risk specificity see e.g. Cacciabue and Martinetto, 2006; Gupta et al., 2002; Lee et al., 2004).

In general, more specific content could lead to a higher probability for providing wrong information to the driver. Nevertheless, research shows that AWS could be efficient although the content of the information delivered to the driver is wrong. Using a driving simulator, Naujoks (2015) studied the behavior of drivers that experience early warnings that indicate the wrong direction of a conflicting road user. He showed that the wrong warnings did not reduce the effectiveness of driver warnings and drivers react equally fast and brake similarly compared to drivers receiving an unspecific warning.

Regarding the warning modality, scientific work has shown that visual displays should be preferred over voice messages or intrusive audio sounds (COMSIS Corporation, 1996; Dingus et al., 1998; Green et al., 1993; International Harmonized Research Activities working group on Intelligent Transport Systems, 2008; Rhede et al., 2011). Acoustic signals are to be avoided and should be reserved only for urgent warnings. Nevertheless, a non-intrusive sound could make the information/warning more effective, because the drivers' perception of a visual warning largely depends on the viewing direction of the driver (e.g. a driver might not recognize a warning displayed in the instrument cluster, if he focusses all his visual attention on an object in the traffic scene). In general, scientific literature supports the opinion that redundant display concepts using different modalities are more efficient than unimodal information (Kramer et al., 2007; Ho et al., 2007; Scott and Gray, 2008). Despite this advantage of multi-modal warnings, purely visual displays are preferred for AWS, because AWS could be activated frequently and with some likelihood of false alarms. Therefore, intrusive warnings should be avoided, as they could lead to reduced efficiency and acceptance (Bliss and Acton, 2003; Dingus et al., 1998). Furthermore, the differences in reaction times between visual and visual-auditory warnings are less relevant for early warnings (Naujoks, 2015).

Advisory warnings based on haptic signals are a promising approach to direct the driver's attention, because they trigger fast responses and can be specific to direction as well as location without putting additional load to the visual information channel or delivering annoying acoustic signals (Neukum, 2011). Haptic information can also be delivered to the driver without annoying or alarming other passengers. Examples for using haptic information in the vehicle include lane keep assistance, heading control, active accelerator pedals for efficient driving, and collision mitigation using tightening of the seat belt (for an overview see Fecher and Hoffmann, 2015). The major drawback of haptic warnings is the fact that this modality does not allow to deliver complex information to the driver.

1.2. Objective of the present study

The approach taken in the present study uses an additional steering motion (called Car Gesture) that results in an additional steering wheel angle and torque to inform the driver about potential hazards or conflict partners. The gesture communicates to the driver in which direction the vehicle should be steered in order to increase the safety distance to a potential hazard. The basic idea is that the gesture nudges the driver to drive a safer trajectory rather than autonomously carrying out this trajectory.

An advantage of haptic warning signals is that the haptic information channel is used to a much smaller extent compared to the visual channel. The latter is the main information channel during driving and additional stimuli could lead to distraction. Another advantage is that additional steering is directional and therefore recommends in which direction (and when) the driver should move the vehicle to reduce the risk. Another benefit of using additional steering to communicate information to the driver lies in the fast reaction on haptic stimuli (Neukum and Krüger, 2003; Neukum et al., 2008a,b; Switkes et al., 2007).

As Car Gestures directly intervene with the vehicle control, the acceptance as well as safety implications have to be analyzed before the concept can be further developed. Therefore, the objective of the following driving simulator study was to investigate the effect of the gestures on the drivers' understanding, acceptance, driving behavior (e.g. speed, deceleration, steering), and safety. Furthermore, controllability was analyzed by adding wrong alarms (additional steering angle toward a potential hazard) to the experimental conditions.

The driving simulator study compared the gestures with visual warnings presented in a HUD and a baseline condition without any assistance. The analysis was done using different urban driving situations including potential hazards.