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Visual advisory warnings about hidden dangers: Effects of specific symbols and spatial referencing on necessary and unnecessary warnings

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ABSTRACT

Augmented reality has the potential to improve the effectiveness of collision warnings in vehicles because they inherently convey spatial information about the hazard and can guide the attention of the driver towards it. For future warning systems, which can detect sight obstructed dangers, related work already revealed some advantages.

In a driving simulator study with 80 participants, we investigated the effects of three corresponding design parameters which are commonly integrated at augmented reality warnings. This study analyzes the individual contribution of specific warning symbols, warning animation, and spatial referencing. Part one of the study concentrates on the effectiveness of necessary warnings and part two on the drivers' compliance despite false alarms.

Compared to the control condition with static unspecific warning symbols, static specific warning symbols depicting the type and motion direction of the hazard led to several but inconsistent advantages. The scaling animation only improved subjective evaluation. However, spatial referencing of an (unspecific) warning symbol consistently improved drivers' reactions to as well as evaluations of necessary and unnecessary warnings. The results emphasize the potential of spatial referencing, particularly for in-vehicle warnings of future collision avoidance systems.

1. Introduction

There is an extensive body of research and guidelines for the design of the human-machine interface (HMI) of collision warnings (Campbell et al., 2007; COMSIS Corporation, 1996; Green et al., 1995; Informal Group on Intelligent and Transport Systems, 2011). However, nearly all of them refer to warnings that are issued in situations where the hazard is directly visible to the driver. For warnings of hazards that are hidden at the time of the warning onset, there are changes in some fundamental circumstances, such as available information or rates of false alarms. It is still unclear how to optimally design such warnings (Naujoks et al., 2014). Conveying specific warning information to support drivers' situation awareness despite sight obstructions could be decisive to enable drivers to rapidly select and execute the optimal response to an actual hazard. At the same time, it will be crucial to ensure low annoyance and appropriate trust in order to preserve compliance despite false alarms.

In a previous study (Schwarz and Fastenmeier, 2017), we examined the effects of modality and specificity of such warnings. The study revealed various advantages of highly specific visual warnings. However, the employed human-machine-interface (HMI) was highly advanced (see Fig. 1). It contained warning symbols depicting type and motion direction of the opponent that were rendered dynamically and spatially referenced on a head-up display. Additionally, the spatial referencing inherently conveyed information about the distance of the potential collision opponent (see Fig. 2). The aim of the current study was to dissect the effects of the different design aspects of this concept and to observe their impact on warning effectiveness and the corresponding individual aspects of drivers' behavior.

Obviously, the symbolic coded information can be implemented and analyzed independently from the distance information that is coded by the spatial referencing of the warning.

Since a driver naturally approaches the warning symbol, the concept further includes a scaling animation of the warning icon. While this aspect can be implemented and analyzed independently from spatial referencing, the latter one is inseparable, and always contains a scaling animation within our context.

The further work focuses on merely visual warnings to prevent

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Fig. 1. Specific visual AR warning in a scenario with cross traffic taking right of way from the participants' point of view.

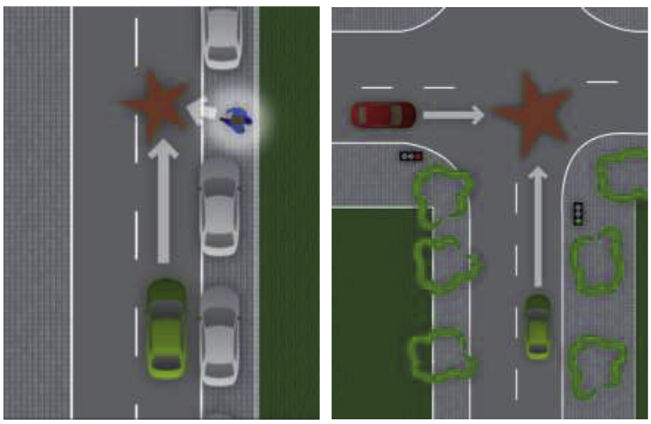

Fig. 2. Scenarios "Pedestrian running on road" (left) and "Cross traffic taking right of way" (right).

effects of different modalities from being confused. For example, an additional acoustic stimulus would probably affect driver reactions and confound the effects of the visual design aspects. The following paragraphs summarize the most relevant technical background and related work about the design aspects of the introduced warning concept.

1.1. Technical background and false alarms

New technologies like connecting road users via wireless networks (Car-to-X) will enable future warning systems to detect dangers sooner, even if they are occluded by obstacles such as other vehicles or buildings (Fuerstenberg et al., 2007; Pierowicz et al., 2000; Seeliger et al., 2014). Since sight obstruction is one of the most relevant contributing factors of accident causation in road traffic (Staubach, 2009), such warnings should provide a huge potential for improving safety (Naujoks et al., 2014). However, the introduction of additional warnings in vehicles may unintentionally confront drivers with a rising frequency of false alarms (Hägglund, 2008; Lees, 2010; Lu et al., 2005; Parasuraman et al., 1997; Zabyshny and Ragland, 2003).

These false alarms can lower drivers' willingness to use the system (Dillon, 2001; LeBlanc and Tsimhoni, 2008). Behavioral consequences of annoyance (Kiefer et al., 1999; Lerner et al., 1996) and distrust (Breznitz, 1984; Parasuraman and Riley, 1997), which are the two major moderating mechanisms, include slower and weaker braking responses or even a tendency to ignore or turn off warnings after several false alarms (Bliss et al., 1995; Chugh and Caird, 1999; Getty et al., 1995; Sorkin et al., 1988). These potential negative consequences of frequent false alarms should get increased attention when evaluating long-term effectiveness of future warning systems.

The combination of false alarms and occluded hazards could be even more problematic in that respect. Lees and Lee (2007) proposed the distinction between unnecessary (user can understand the cause) and false warnings (user cannot understand the cause) depending on the comprehension of the cause of a false alarm. While unnecessary warnings can even support trust (Maltz and Shinar, 2004, 2007), false warnings have mostly negative consequences (Lees and Lee, 2007). Sight obstructions can impair the detection of the cause of a warning, so that an unnecessary warning is perceived as a false warning. Imagine a driver who receives a warning and sees a pedestrian running towards the street but still just stops. She or he would probably understand the cause of this warning and perhaps even learn to better assess the system. In case this same pedestrian is hidden by parked vehicles, the driver would probably not understand the cause of the warning. She or he might assess it as a false warning, lose trust in the system, and eventually even ignore the next warning. Thus, sight obstruction of hazards could amplify the negative effects of false alarms.

1.2. Warning symbols and specificity

Warnings can contain different amounts of specific information about a hazard, such as position, motion direction, or type. Immediately after a warning of a hidden danger, the only available information for a driver is the traffic environment and the warning message itself. Obviously, specific warning information should get more relevant to improve drivers' reactions in corresponding situations.

Based on the model of stages of warning information processing (cf. Wogalter, 2006), more specific warning information can theoretically improve the comprehension of the cause of the warning This can trigger or accelerate the attention allocation towards the location of the hazard. Referring to the construct of situation awareness (Endsley, 1995), additional specific warning information can support all three of its components: (1) perception of the specified feature of the otherwise hidden opponent, (2) comprehension of the cause of the warning, as well as (3) (mental) projection of the appearance of an opponent. This in turn could materialize in faster hazard detection (as soon as it becomes visible), quicker and stronger braking reactions, and a generally more efficient collision mitigation after true alarms. In addition, it could support compliance despite false alarms (see the chapter above).

In contrast, additional warning information requires additional cognitive processing by the driver. This contradicts vehicle warning guidelines which demand that "a driver should not be required to transpose, compute, interpolate, or translate displayed crash avoidance warning information" (COMSIS Corporation, 1996) because this could delay drivers' responses. However, these costs can be influenced by warning design and we propose to minimize them by an optimized coding of information.

Icons that resemble highly familiar natural shapes are an effective way of coding information about the type of hazard. Plavsic et al. (2009) and Nakata et al. (2002) measured higher acceptance with visual vehicle warnings with specific icons compared to ones with general icons.

Zarife (2014) examined early warnings containing visual information about the type or the location of hazards in various traffic