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Augmented reality warnings in vehicles: Effects of modality and specificity on effectiveness

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ABSTRACT

In the future, vehicles will be able to warn drivers of hidden dangers before they are visible. Specific warning information about these hazards could improve drivers' reactions and the warning effectiveness, but could also impair them, for example, by additional cognitive-processing costs.

In a driving simulator study with 88 participants, we investigated the effects of modality (auditory vs. visual) and specificity (low vs. high) on warning effectiveness. For the specific warnings, we used augmented reality as an advanced technology to display the additional auditory or visual warning information. Part one of the study concentrates on the effectiveness of necessary warnings and part two on the drivers' compliance despite false alarms.

For the first warning scenario, we found several positive main effects of specificity. However, subsequent effects of specificity were moderated by the modality of the warnings. The specific visual warnings were observed to have advantages over the three other warning designs concerning gaze and braking reaction times, passing speeds and collision rates. Besides the true alarms, braking reaction times as well as subjective evaluation after these warnings were still improved despite false alarms. The specific auditory warnings were revealed to have only a few advantages, but also several disadvantages.

The results further indicate that the exact coding of additional information, beyond its mere amount and modality, plays an important role. Moreover, the observed advantages of the specific visual warnings highlight the potential benefit of augmented reality coding to improve future collision warnings.

1. Introduction

Sight obstruction is one of the most relevant contributing factors for causing accidents in road traffic (Staubach, 2009). Current collision-avoidance systems reach their limits in corresponding scenarios. New technologies like connecting road users via wireless networks (Car-to-X) will enable future systems to detect dangers earlier and even when they are occluded by obstacles like other vehicles or buildings (Fuerstenberg et al., 2007; Pierowicz et al., 2000; Seeliger et al., 2014). Therefore, warnings of such dangers 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. The generally limited reliability of automatic accident prediction (Lees, 2010; Parasuraman et al., 1997; Zabyshny and Ragland, 2003) is likely to further decrease due to earlier output, the higher complexity of the assisted situations (Hägglund, 2008) as well as limitations of the technology like latencies of data transmission (Lu et al., 2005).

False alarms are prone to annoy drivers by unnecessarily capturing their attention. This can lower drivers' acceptance of the system (LeBlanc and Tsimhoni, 2008) in terms of a low willingness to use it (Dillon, 2001). The "cry-wolf syndrome" (Breznitz, 1984) describes the phenomenon that frequent false alarms lower operators' trust in a system (Parasuraman and Riley, 1997). Behavioral consequences of annoyance (Kiefer et al., 1999; Lerner et al., 1996), as well as distrust, 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). While annoyance is defined as a subjective response, that has been used mostly in relation to acoustic stimuli (e.g. Marshall et al., 2007), trust is defined as an attitude about the utility of an agent to reach set goals (Lee and See, 2004). Overall, the potential negative consequences of frequent false alarms like

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annoyance, loss of acceptance, and loss of trust 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. Depending on the comprehension of the cause of a false alarm, Lees and Lee (2007) proposed the distinction between unnecessary (user can understand the cause) and false warnings (user cannot understand the cause). 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. For example, a driver who receives a warning and sees a pedestrian running towards the road but stopping just in time will probably understand the cause of this warning and perhaps even learn to better assess the system. In the case where that same pedestrian has been occluded by parked vehicles, the driver probably would not understand the warning cause, might assess it as a false warning, lose trust in the system, and ignore the next warning. Thus, sight obstruction of hazards could amplify the negative effects of false alarms.

1.1. Warning design

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 like available information or rates of false alarms, and it is very unclear how to optimally design such warnings (Naujoks et al., 2014). The goal of these warnings is still to support drivers in avoiding potential collisions. Because of cognitive and behavioral preconditions for the drivers to succeed, however, it might not be optimal to just elicit or guide their attention. 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. Accordingly, some general insights about warning designs should be reconsidered in the light of the possibilities and limitations of Car-to-X warnings.

1.2. Specificity of warnings

Warnings can contain different amounts of specific information about a hazard, for example, its position and 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 needs to become more relevant to improve drivers' reactions in corresponding situations.

Based on the model of stages of warning information processing (cf. Wogalter, 2006), more specific warnings can theoretically improve the comprehension of the cause of the warning and cause 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) 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, there could be reduced deterioration of compliance after false alarms (see section above).

In contrast, additional warning information requires additional cognitive processing by the driver. This contradicts vehicle warning guidelines that 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.

Presenting natural sounds or shapes that are highly familiar to drivers is an effective way of coding information about the type of hazard. Auditory icons that imitate real-world events (Gaver, 1986) can inherently convey the cause of a warning. Using this type of information presentation, Graham (1999) reported faster but less accurate responses, and McKeown and Isherwood (2007) reported faster and even more accurate responses to respective automotive collision warnings compared to abstract tones. Nakata et al. (2002) measured higher acceptance of visual vehicle collision warnings with specific icons compared to ones with general icons.

Zarife (2014) compared early warnings containing visual information about the type or the location of hazards in various traffic scenarios. While the object cues showed only a few effects, the directional cues clearly improved gaze reactions, and braking responses as well as collision frequencies. A benefit of spatial visual information on subjective evaluation of early warnings has also been reported by Naujoks and Neukum (2014a). In another experiment, verbal information about the direction of cross traffic running a red light led to quicker braking responses, more adapted deceleration, and better subjective ratings (Zhang et al., 2015). Spatially presented warning tones led to faster gaze alignment towards lateral hazards and increased head rotations after false alarms (Zarife, 2014). Further related findings include faster hazard detections and driving reactions in various traffic scenarios (Ho and Spence, 2005; Ho et al., 2006) and shorter stimulus-response times in studies from cognitive psychology (Posner and Boies, 1971; Posner et al., 1980). Nevertheless, in a study by Yan et al. (2014), spatial warning sounds caused no benefit for early warnings and even more collisions for late warnings.

Furthermore, specific warning information could support the comprehension of the cause of a false alarm and, thus, counteract the potential loss of trust and compliance. The theoretical reasoning is basically the same that we outlined earlier with respect to sight obstructions, just vice versa. A false alarm that is incomprehensible for a driver because the initial cause is hidden could become comprehensible with all the relevant information being conveyed by the warning. Accordingly, Lee and Patterson (1993) observed higher subjective reliability for auditory cockpit alarms that contained spatial information. Entin et al. (1996) measured higher trust of operators in visual automatic target detection systems after an explanation of the target selection has been shown. Only few studies addressed specific warning information about occluded hazards. Lee et al. (2002) reported that drivers ignored warnings more often when they were not able to perceive their causes. Thoma et al. (2008) also assumed (but did not prove) that specific icons are more beneficial when the reason for the warning is not visible to the driver. Therefore, further insights are necessary to provide a scientific foundation for the design of future warnings.

1.3. Modality of warnings

The related work described above showed that auditory as well as visual specific warning information can improve the effectiveness of warnings. However, comparing the results of the studies, there are negative as well as positive results for both modalities.